

# Digestibility and performance of steers fed varying inclusions of corn silage and modified distillers grains with solubles to partially replace corn in finishing diets<sup>1</sup>

D. B. Burken, B. L. Nuttelman, M. J. Jolly-Briethaupt, J. L. Gramkow, S. E. Gardine, T. J. Klopfenstein, J. C. MacDonald, and G. E. Erickson<sup>2</sup>

Department of Animal Science, University of Nebraska, Lincoln 68583

**ABSTRACT:** Two finishing and 1 digestibility experiment evaluated the partial substitution of corn with corn silage and corn modified distillers grains with solubles (MDGS). Steers were used in Exp. 1 (n = 295; 467 ± 52 kg) and Exp. 2 (n = 225; BW = 348 ± 27 kg) in a 2 × 2 + 1 factorial arrangement of treatments with factors including corn silage (15 or 45%) and MDGS (20 or 40%) plus a control diet consisting of 5% cornstalks and 40% MDGS. In Exp. 1, there were tendencies for a corn silage × MDGS interaction for ADG, final BW, and G:F ( $P \leq 0.08$ ). In the overall F-test for G:F, there were no differences between the control treatment and 15:20, 15:40, or 45:40 ( $P \geq 0.15$ ), however, steers fed the control treatment had increased G:F compared to steers fed 45:20 treatment diets ( $P = 0.03$ ). In Exp. 2, there were no corn silage × MDGS interactions ( $P \geq 0.12$ ). As corn silage increased in the diet, ADG, final BW, and G:F decreased ( $P \leq 0.01$ ). As MDGS increased from 20 to 40%, ADG and G:F tended to improve ( $P \leq 0.07$ ). In the overall F-test, the control was not different for G:F from 15:20, 45:20, or 45:40

( $P \geq 0.15$ ), but had a 4.8% poorer G:F compared to 15:40 ( $P < 0.01$ ). In Exp. 3, ruminally fistulated steers (n = 6) were used in a 5 × 6 Latin rectangle design and fed 15 or 45% corn silage with 20 or 40% MDGS as a 2 × 2 factorial. An additional diet consisting of 95% corn silage and 5% supplement was fed. There were no corn silage × MDGS interactions for nutrient intake, total tract digestibility, ruminal pH measurements, acetate:propionate ratio (A:P), or in-situ disappearance data ( $P \geq 0.31$ ) for the 2 × 2 factorial. As corn silage increased in the diet, DMI, NDF intake, ruminal pH, A:P, in-situ NDF disappearance of corn bran, and DM disappearance of corn increased ( $P \leq 0.09$ ) with decreases in DM and OM digestibility ( $P \leq 0.03$ ). As MDGS increased in the diet, there was an increase in NDF intake, total volatile fatty acid concentration, and NDF disappearance of corn bran ( $P \leq 0.03$ ) with no differences for any other tested variables ( $P \geq 0.13$ ). In general, increasing corn silage in place of corn in finishing diets containing MDGS results in a modest reduction in ADG and G:F with increases in ruminal pH.

**Key words:** corn silage, distillers grains with solubles, feedlot, roughage

© 2017 American Society of Animal Science. This is an open access article distributed under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

Transl. Anim. Sci. 2017.1:382–396  
doi:10.2527/tas2017.0046

## INTRODUCTION

The amount of U.S. corn production used for alcohol fuel has increased from 0.89 to 128 million t since 1980 (ERS, 2014). Because of the resultant increased competition for corn, alternative feedstuffs have been sought after to replace corn in cattle finishing diets. The

use of corn silage in partial substitution of corn grain in beef finishing diets has been shown to be economical in times of expensive corn (Goodrich et al., 1974; DiCostanzo et al., 1998a). Additionally, utilizing corn silage allows the cattle producer to harvest the entire corn plant at a time of maximum quality and tonnage, and secure substantial quantities of roughage/grain inventory. Past research (Goodrich et al., 1974; Gill et al., 1976; Erickson, 2001) with corn silage partially replacing corn in finishing diets has resulted in reductions in G:F as corn silage inclusion is increased; however, this research was completed prior to the expansion of the ethanol industry and the common use of distillers

<sup>1</sup>A contribution of the University of Nebraska Agriculture Research Division, supported in part by funds provided through the Hatch Act.

<sup>2</sup>Corresponding author: [gerickson4@unl.edu](mailto:gerickson4@unl.edu)

Received January 21, 2017.

Accepted June 20, 2017.

grains in finishing diets. Distillers grains are a source of highly digestible fiber and minimal starch (Klopfenstein et al., 2008). Due to higher concentrations of highly digestible fiber and a decrease in total dietary starch concentration, there are potential benefits of adding elevated concentrations of corn silage in finishing diets containing distillers grains in terms of rumen environment, fiber digestion, and cattle performance. Distillers grains are commonly used in feedlot diets throughout the ethanol belt as an economical protein source, however when market conditions dictate, distillers grains may be fed as an energy source at dietary concentrations of 30 to 50% (DM; Klopfenstein et al., 2008). Therefore the objectives of these experiments were to determine the effects on digestibility and rumen metabolism, cattle performance, and carcass characteristics of feeding elevated concentrations of both corn silage and modified distillers grains with solubles (MDGS) as a partial replacement of corn in finishing diets.

## MATERIALS AND METHODS

All animal use procedures were reviewed and approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

### Exp. 1 and 2

Upon arrival at the research feedlot, all steers on Exp. 1 were individually identified and processed with: a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza<sub>3</sub>, and bovine respiratory syncytial virus (Bovi-Shield Gold 5, Pfizer Animal Health, New York, NY), a *Haemophilus somnus* bacterin (Somubac, Pfizer Animal Health), and an injectable anthelmintic (Dectomax, Pfizer Animal Health). All steers on Exp. 1 were revaccinated approximately 14 to 28 d after initial processing with Bovi-Shield Gold 5 (Pfizer Animal Health), a killed viral vaccine for clostridial infections (Vision 7 Somnus with SPUR, Merck Animal Health, Summit, NJ), and a killed viral vaccine for pinkeye prevention (Piliguard Pinkeye TriView, Merck Animal Health). At initial processing all steers on Exp. 2 were individually identified and processed with: a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I & II, parainfluenza<sub>3</sub>, bovine respiratory syncytial virus, and bacterins for *Mannheimia haemolytica* and *Pasteurella multocida* (Vista Once SQ, Merck Animal Health), an injectable anthelmintic (Cydectin Injectable, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), and an oral drench for internal parasites (Safe-Guard, Merck Animal Health). All steers on Exp. 2 were revaccinated approximately 12 to 28 d after ini-

tial processing with a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza<sub>3</sub>, and bovine respiratory syncytial virus (Vista 5 SQ, Merck Animal Health) and Vision 7 Somnus with SPUR (Merck Animal Health). All these procedures on both experiments were performed prior to experiment initiation. Steers were limit fed (Watson et al., 2013) to equalize gastro-intestinal fill a diet containing 47.5% sweet bran 47.5% alfalfa hay, and 5.0% supplement (DM basis), at 2.0% of projected BW for 5 d, prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983).

In Exp. 1, crossbred yearling steers ( $n = 295$ ; BW =  $467 \pm 52$  kg) were utilized in a randomized complete block design with 6 BW blocks and 30 pens (9 or 10 steers/pen). For Exp. 2, crossbred steer calves ( $n = 225$ ; BW =  $348 \pm 27$  kg) were separated into 3 BW blocks (randomized block design) and assigned randomly to 1 of 25 pens (9 steers/pen). Treatment design was the same in both Exp. 1 and 2. Treatments were designed as a  $2 \times 2 + 1$  factorial arrangement consisting of 15 or 45% corn silage and 20 or 40% MDGS (15:20 – 15% corn silage, 20% MDGS; 15:40 – 15% corn silage, 40% MDGS; 45:20 – 45% corn silage, 20% MDGS; and 45:40 – 45% corn silage, 40% MDGS; DM basis) and a control diet consisting of 5% cornstalks and 40% MDGS (control; Tables 1 and 2). Elevated concentrations of corn silage and MDGS replaced a 1:1 blend of dry-rolled corn (DRC): high moisture corn (HMC) on a DM basis. Corn silage was harvested from an irrigated cornfield grown for commercial grain corn production, and harvested at a targeted DM content of 35%. Corn silage was not kernel processed. All steers were fed a supplement formulated to provide 33 mg/kg of DM monensin (Elanco Animal Health, Indianapolis, IN) and a targeted intake of 90 mg/steer daily of tylosin (Elanco Animal Health). Thiamine (International Nutrition, Inc., Omaha, NE) was included at a targeted intake of 150 mg/steer daily in Exp. 1. There was no supplemental thiamine included in the diet for Exp. 2. Steers were implanted with Revalor-200 (Merck Animal Health) on d 1 in Exp. 1. For Exp. 2, steers were implanted with Revalor-XS (Merck Animal Health) on d 1. In both experiments, feed bunks were assessed at approximately 0530 h with the goal of trace amounts of feed at the time of feeding. All diets were fed once daily. Feed refusals were removed from feed bunks as necessary on a weekly basis, weighed, and subsampled. All feed refusal subsamples were dried for 48 h in a 60°C forced-air oven for determination of DM (AOAC, 1999; method 4.1.03) and calculation of refusal DM weight. Dietary ingredients were sampled weekly for determination of DM by aforementioned method with dietary as-fed ingredient proportions adjusted weekly. Dietary ingredient samples were analyzed for CP (AOAC, 1990 method 990.06;

**Table 1.** Diet composition (DM basis) in Exp. 1

| Ingredient                        | Treatment <sup>1</sup> |        |        |        |        |
|-----------------------------------|------------------------|--------|--------|--------|--------|
|                                   | Control                | 15:20  | 45:20  | 15:40  | 45:40  |
| Dry-rolled corn                   | 25.0                   | 30.0   | 15.0   | 20.0   | 5.0    |
| High-moisture corn                | 25.0                   | 30.0   | 15.0   | 20.0   | 5.0    |
| Corn Silage                       | 0.0                    | 15.0   | 45.0   | 15.0   | 45.0   |
| Cornstalks                        | 5.0                    | 0.0    | 0.0    | 0.0    | 0.0    |
| MDGS <sup>2</sup>                 | 40.0                   | 20.0   | 20.0   | 40.0   | 40.0   |
| Dry supplement <sup>3</sup>       |                        |        |        |        |        |
| Fine-ground corn                  | 3.0077                 | 3.0077 | 3.0077 | 3.0077 | 3.0077 |
| Limestone                         | 1.4660                 | 1.4660 | 1.4660 | 1.4660 | 1.4660 |
| Salt                              | 0.3000                 | 0.3000 | 0.3000 | 0.3000 | 0.3000 |
| Tallow                            | 0.1250                 | 0.1250 | 0.1250 | 0.1250 | 0.1250 |
| Trace Mineral premix <sup>4</sup> | 0.0500                 | 0.0500 | 0.0500 | 0.0500 | 0.0500 |
| Vitamine ADE premix <sup>5</sup>  | 0.0150                 | 0.0150 | 0.0150 | 0.0150 | 0.0150 |
| Thiamine <sup>6</sup>             | 0.0116                 | 0.0116 | 0.0116 | 0.0116 | 0.0116 |
| Rumensin 90 <sup>7</sup>          | 0.0167                 | 0.0167 | 0.0167 | 0.0167 | 0.0167 |
| Tylan 40 <sup>8</sup>             | 0.0080                 | 0.0080 | 0.0080 | 0.0080 | 0.0080 |
| Nutrient Composition <sup>9</sup> |                        |        |        |        |        |
| Crude Protein, %                  | 17.4                   | 13.2   | 13.3   | 17.6   | 17.7   |
| NDF, %                            | 25.7                   | 23.7   | 37.4   | 29.0   | 42.7   |
| Ether Extract, %                  | 6.2                    | 4.8    | 4.5    | 6.2    | 5.9    |
| Ca, %                             | 0.62                   | 0.65   | 0.73   | 0.65   | 0.73   |
| P, %                              | 0.53                   | 0.42   | 0.40   | 0.54   | 0.52   |
| K, %                              | 0.62                   | 0.62   | 0.98   | 0.76   | 1.13   |
| S, %                              | 0.32                   | 0.23   | 0.24   | 0.33   | 0.34   |

<sup>1</sup>15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS.

<sup>2</sup>MDGS = Modified distillers grains with solubles.

<sup>3</sup>Supplement formulated to be fed at 5.0% of diet DM.

<sup>4</sup>Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.

<sup>5</sup>Premix contained 30,000 IU vitamin A; 6,000 IU vitamin D; 7.5 IU vitamin E per gram.

<sup>6</sup>Premix contained 88 g/kg of thiamine.

<sup>7</sup>Premix contained 198 g/kg monensin.

<sup>8</sup>Premix contained 88 g/kg tylosin.

<sup>9</sup>Based on analyzed nutrients for each ingredient.

TrueSpec N Determinator and TrueSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI), NDF (Van Soest and Marcus, 1964; Van Soest et al., 1991), and ether extract (Bremer, 2010; Tables 1 and 2). Weekly dietary ingredient samples were composited and then analyzed by a commercial laboratory (Ward Laboratories, Inc., Kearney, NE) for Ca, P, K, and S concentration. Dietary mineral concentration was then calculated utilizing ingredient mineral concentration and dietary inclusion of ingredients. Steers in both experiments were harvested at a commercial abattoir (Greater Omaha Pack, Omaha, NE). One block of steers were harvested after 91 DOF in Exp. 1, with the remaining 5 blocks harvested after 98 DOF. For Exp. 2, one block of steers were harvested after 134 DOF and the other 2 blocks were harvested after 148 DOF. On the day of shipping to the commercial abat-

**Table 2.** Diet composition (DM basis) in Exp. 2

| Ingredient                        | Treatment <sup>1</sup> |        |        |        |        |
|-----------------------------------|------------------------|--------|--------|--------|--------|
|                                   | Control                | 15:20  | 45:20  | 15:40  | 45:40  |
| Dry-rolled corn                   | 25.5                   | 30.5   | 15.5   | 20.5   | 5.5    |
| High-moisture corn                | 25.5                   | 30.5   | 15.5   | 20.5   | 5.5    |
| Corn Silage                       | 0.0                    | 15.0   | 45.0   | 15.0   | 45.0   |
| Cornstalks                        | 5.0                    | 0.0    | 0.0    | 0.0    | 0.0    |
| MDGS <sup>2</sup>                 | 40.0                   | 20.0   | 20.0   | 40.0   | 40.0   |
| Dry supplement <sup>3</sup>       |                        |        |        |        |        |
| Fine-ground corn                  | 2.0438                 | 2.0438 | 2.0438 | 2.0438 | 2.0438 |
| Limestone                         | 1.4660                 | 1.4660 | 1.4660 | 1.4660 | 1.4660 |
| Salt                              | 0.3000                 | 0.3000 | 0.3000 | 0.3000 | 0.3000 |
| Tallow                            | 0.1000                 | 0.1000 | 0.1000 | 0.1000 | 0.1000 |
| Trace Mineral premix <sup>4</sup> | 0.0500                 | 0.0500 | 0.0500 | 0.0500 | 0.0500 |
| Vitamine ADE premix <sup>5</sup>  | 0.0150                 | 0.0150 | 0.0150 | 0.0150 | 0.0150 |
| Rumensin 90 <sup>6</sup>          | 0.0165                 | 0.0165 | 0.0165 | 0.0165 | 0.0165 |
| Tylan 40 <sup>7</sup>             | 0.0087                 | 0.0087 | 0.0087 | 0.0087 | 0.0087 |
| Nutrient Composition <sup>8</sup> |                        |        |        |        |        |
| Crude Protein, %                  | 19.2                   | 14.2   | 13.8   | 19.2   | 18.8   |
| NDF, %                            | 24.6                   | 21.4   | 32.2   | 26.2   | 37.0   |
| Ether Extract, %                  | 5.5                    | 4.7    | 4.4    | 5.1    | 5.2    |
| Ca, %                             | 0.62                   | 0.63   | 0.70   | 0.64   | 0.70   |
| P, %                              | 0.61                   | 0.45   | 0.42   | 0.60   | 0.57   |
| K, %                              | 0.73                   | 0.59   | 0.81   | 0.80   | 1.02   |
| S, %                              | 0.31                   | 0.21   | 0.22   | 0.31   | 0.31   |

<sup>1</sup>15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS.

<sup>2</sup>MDGS = Modified distillers grains with solubles.

<sup>3</sup>Supplement formulated to be fed at 4.0% of diet DM.

<sup>4</sup>Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.

<sup>5</sup>Premix contained 30,000 IU vitamin A; 6,000 IU vitamin D; 7.5 IU vitamin E per gram.

<sup>6</sup>Premix contained 198 g/kg monensin.

<sup>7</sup>Premix contained 88 g/kg tylosin.

<sup>8</sup>Based on analyzed nutrients for each ingredient.

toir, pens of steers were fed 50% of the previous day's DM offer at regular feeding time. Pens of steers were then weighed on a platform scale at 1500 h prior to being loaded for shipping. A 4% pencil shrink was applied to this weight for final live BW and calculation of dressing percentage. Hot carcass weight and liver scores were obtained the d of harvest. Liver abscesses were categorized from 0 (no abscesses), A-, A, or A+ (severely abscessed) according to the procedures outlined by Brink et al. (1990). Liver abscess categories were then combined to calculate the proportion of steers with abscessed livers in each pen. Carcass-adjusted final BW, used in calculation of ADG and G:F, was calculated from HCW and a common dressing percentage of 63%. Marbling score, 12th rib fat thickness, and LM area were recorded after a 48 h (block 1, Exp. 1; Exp. 2) and 144 h (block 2-6; Exp. 1) carcass chill. Yield grade was calculated according to USDA (2016) using carcass measurements (assuming a

common 2.5% KPH) and the following formula:  $[YG = 2.50 + (0.0017 \times HCW, \text{kg}) + (0.2 \times KPH, \%) + (6.35 \times 12\text{th rib fat, cm}) - (2.06 \times LM \text{ area, cm}^2)]$ .

The feeding value of corn silage and MDGS relative to the corn blend on a DM basis was calculated by the following equation for each inclusion level:  $[1 - (\{G:F \text{ of higher inclusion diet} - G:F \text{ of lower inclusion diet}\} / G:F \text{ of lower inclusion diet}) / \text{amount of inclusion level substitution}] \times 100 + 100$ . The energy value of the diets was calculated by utilizing pen data in the Galyean (2009) Net Energy calculator based on NRC (1996) net energy equations. The calculator utilizes initial BW, final BW, DMI, ADG, and target endpoint (assuming choice quality grade).

Performance, carcass data, and energy values were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit, and BW block was included as a fixed effect. Main effects of corn silage and MDGS inclusion were tested as well as the interaction of corn silage  $\times$  MDGS. For Exp. 2, there were no corn silage  $\times$  MDGS interactions for any of the tested variables; therefore, the interaction term was taken out of the statistical model for Exp. 2. The control was included in the analysis using an overall F-test across all treatments. Prevalence of liver abscesses was analyzed using the GLIMMIX procedure of SAS using a binomial distribution. Treatment differences were evaluated when overall significance was  $P \leq 0.05$ .

### Exp. 3

Six ruminally fistulated steers were used in a  $5 \times 6$  Latin rectangle experiment to determine diet digestibility of 5 diets. Steers were assigned randomly to each dietary treatment for five 21-d periods with a 15-d adaptation period and a 6-d fecal sample collection period. Treatments were designed as a  $2 \times 2 + 1$  factorial arrangement. The  $2 \times 2$  treatment design was the same as in Exp. 1 and 2; however, the +1 diet in Exp. 3 consisted of 95% corn silage and 5% supplement (95:0; Table 3). Elevated levels of corn silage and/or MDGS replaced DRC. Diets were mixed twice weekly and stored in a cooler (0°C) to ensure fresh feed. All steers were fed a supplement formulated for 33 g/kg monensin (DM basis; Elanco Animal Health) and a targeted intake of 90 mg/steer daily of tylosin (DM basis; Elanco Animal Health). Urea was included at 1.66% of the diet in the 95:0 treatment, at 0.50% of the diet in diets containing 20% MDGS, and no urea was included in the supplement for diets containing 40% MDGS.

Titanium dioxide was ruminally dosed at 5 g/steer twice daily at 0800 and 1600 h for 7 d prior to and for the duration of the collection period. Fecal grab samples (approximately 300 g) were collected at 0800,

**Table 3.** Diet composition (DM basis) in Exp. 3

| Ingredient                              | Treatment <sup>1</sup> |        |        |        |        |
|---|------------------------|--------|--------|--------|--------|
|   | Control                | 15:20  | 45:20  | 15:40  | 45:40  |
| Dry-rolled corn                         | 0.0                    | 60.0   | 30.0   | 40.0   | 10.0   |
| Corn Silage                             | 95.0                   | 15.0   | 45.0   | 15.0   | 45.0   |
| MDGS <sup>2</sup>                       | 0.0                    | 20.0   | 20.0   | 40.0   | 40.0   |
| Dry supplement <sup>3</sup>             |                        |        |        |        |        |
| Fine-ground corn                        | 1.6582                 | 2.3222 | 2.3222 | 2.8222 | 2.8222 |
| Limestone                               | 1.1650                 | 1.6610 | 1.6610 | 1.6610 | 1.6610 |
| Urea                                    | 1.6600                 | 0.5000 | 0.5000 | 0.0000 | 0.0000 |
| Salt                                    | 0.3000                 | 0.3000 | 0.3000 | 0.3000 | 0.3000 |
| Tallow                                  | 0.1250                 | 0.1250 | 0.1250 | 0.1250 | 0.1250 |
| Trace Mineral premix <sup>4</sup>       | 0.0500                 | 0.0500 | 0.0500 | 0.0500 | 0.0500 |
| Vitamine ADE premix <sup>5</sup>        | 0.0150                 | 0.0150 | 0.0150 | 0.0150 | 0.0150 |
| Rumensin 90 <sup>6</sup>                | 0.0165                 | 0.0165 | 0.0165 | 0.0165 | 0.0165 |
| Tylan 40 <sup>7</sup>                   | 0.0102                 | 0.0102 | 0.0102 | 0.0102 | 0.0102 |
| <i>Nutrient Composition<sup>8</sup></i> |                        |        |        |        |        |
| Crude Protein, %                        | 13.8                   | 15.7   | 15.7   | 19.4   | 19.3   |
| NDF, %                                  | 38.6                   | 20.5   | 28.8   | 24.6   | 32.8   |
| Ether Extract, %                        | 3.0                    | 4.7    | 4.4    | 5.7    | 5.5    |
| Ca, %                                   | 0.68                   | 0.71   | 0.77   | 0.71   | 0.78   |
| P, %                                    | 0.25                   | 0.38   | 0.38   | 0.51   | 0.52   |
| K, %                                    | 0.80                   | 0.50   | 0.67   | 0.66   | 0.83   |
| S, %                                    | 0.09                   | 0.26   | 0.26   | 0.43   | 0.43   |

<sup>1</sup>15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS.

<sup>2</sup>MDGS = Modified distillers grains with solubles.

<sup>3</sup>Supplement formulated to be fed at 5.0% of diet DM.

<sup>4</sup>Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.

<sup>5</sup>Premix contained 30,000 IU vitamin A; 6,000 IU vitamin D; 7.5 IU vitamin E per gram.

<sup>6</sup>Premix contained 198 g/kg monensin.

<sup>7</sup>Premix contained 88 g/kg tylosin.

<sup>8</sup>Based on analyzed nutrients for each ingredient.

1200, and 1600 h during d 16 through 20 of each period. Fecal samples were composited on a wet basis into daily composites and then lyophilized (Virtis Freezemobile 25ES, SP Industries, Warminster, PA). From daily composites, a steer within period fecal sample composite was prepared and subsequently analyzed for NDF (Van Soest and Marcus, 1964; Van Soest et al., 1991), OM (600°C for 6 h), and Ti concentration (Spectra MAX 250, Molecular Devices, LLC, Sunnyvale, CA; Myers et al., 2004). Ruminant pH was recorded every minute using wireless pH probes (Dascor Inc., Escondido, CA) from d 16 to d 20 of each period. Rumen fluid samples were collected at 0800, 1100, 1400, 1600, and 1900 h on d 21 of each period and were analyzed for ruminal volatile fatty acids (VFA; Trace 1300, Thermo Fisher Scientific Inc., Waltham, MA) using the procedures outlined by Ehrlich et al. (1981). Feeds offered and refused were analyzed for DM, OM, and NDF concentration using the procedures mentioned above. Dry matter

of feed ingredients and orts were determined using a forced-air oven set at 60°C for 48 h.

An in-situ study was conducted concurrently to the digestibility experiment utilizing the same experimental steers and treatments. Dacron bags (5 cm × 10 cm Ankom *in situ* bags (R510) with a 50 µm pore size; Ankom Technology, Macedon, NY) were filled with 1.25 g of dry corn bran, DRC, or corn silage. The DRC and corn silage utilized for the in-situ experiment was from the same source as experimental diets. Dry corn bran and DRC were oven-dried using the methodology above, and corn silage was lyophilized (Virtis Freezemobile 25ES, SP Industries). Dry corn bran, DRC, and corn silage were ground through a 2 mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) prior to being weighed into the Dacron bags. Four bags per feedstuff were placed in mesh bags and incubated in the ventral rumen of each of the 6 steers for incubation time periods of 24 and 36 h. Bags were incubated at different times and all bags were removed at the same time (0800 h on d 6 of the collection period). Two non-incubated bags (0 h) were also prepared for each sample. In-situ bags were rinsed 5 times in a washing machine (39°C water) utilizing 1 minute agitation and 2 minute spin cycles (Whittet et al., 2003). All in-situ bags were then rinsed with distilled water. In-situ bags containing DRC were then dried at 60°C for 48 h and then weighed for determination of DM disappearance. Neutral detergent fiber disappearance was determined for in-situ bags containing corn bran and corn silage by refluxing bags in neutral detergent solution using the ANKOM 200 Fiber Analyzer (Ankom Technology). Samples were agitated in NDF solution for 1 hour at 100°C then rinsed with distilled water for 5 minutes 4 separate times. Dry matter disappearance of DRC and NDF disappearance of corn bran and corn silage within each dietary treatment was calculated by subtracting remaining residue of each sample (24 and 36 h) from the initial value (0 h; non-incubated bags) and then dividing by the original DM (DRC) or NDF percentage (corn bran and corn silage) of the feedstuff.

Total tract nutrient intake and digestibility data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with period and treatment as fixed effects. Steer was included as a random effect. Main effects of corn silage and MDGS inclusion and the interaction between corn silage and MDGS inclusion were also tested for the 2 × 2 factorial. The interaction was removed from the model due to lack of significance ( $P > 0.10$ ). The MIXED procedure of SAS was used for analysis of ruminal VFA data with fixed effects of treatment, time of incubation (24 or 36 h), and period. Treatment × time was included as a fixed effect in the analysis of ruminal VFA data but was removed from the model due to lack of significance ( $P > 0.10$ ). The same model was used in

the analysis of in-situ data, but the treatment × time interaction was included in the model when significant ( $P < 0.10$ ). In-situ bag was the experimental unit. Steer was used as a random effect in the in-situ analysis. Period was removed from the model in the analysis of in-situ data due to variability across periods and the inaccurate statistical prediction of least square means relative to observed means. Ruminal pH data were analyzed as a repeated measure using the GLIMMIX procedure of SAS with d as the repeated measure. An autoregressive covariance structure was used for pH variables (Littell et al., 1998). Treatment was the fixed effect, and steer was utilized as a random effect. Period was removed from the model due to missing data points within period and the subsequent inaccurate statistical prediction of least square means relative to observed means. An autoregressive covariance structure was utilized for pH repeated measures analysis. Main effects of corn silage and MDGS inclusion and the interaction between corn silage and MDGS inclusion were also tested. Treatment differences were evaluated when overall significance was less than  $P = 0.10$ .

## RESULTS AND DISCUSSION

Due to the similar treatment designs between Exp. 1 and 2, the experiment × corn silage × MDGS interaction was tested for pooling of experiments. There was an experiment × corn silage × MDGS interaction for ADG ( $P = 0.04$ ) and tendencies for experiment × corn silage × MDGS interactions for HCW ( $P = 0.06$ ) and G:F ( $P = 0.07$ ). Therefore Exp. 1 and 2 were analyzed and will be presented separately.

### Exp. 1

There was no interaction between corn silage and MDGS for DMI ( $P = 0.24$ ; Table 4), and therefore the main effects of corn silage and MDGS will be presented. There was no difference in DMI as corn silage increased from 15 to 45% of the diet ( $P = 0.34$ ). There was also no difference in DMI due to concentration of MDGS ( $P = 0.47$ ). There was a tendency for a corn silage × MDGS interaction for ADG ( $P = 0.08$ ), and therefore the simple effects will be presented. For diets containing 20% MDGS, ADG decreased by 13.6% ( $P = 0.01$ ) as corn silage increased from 15 to 45% of the diet. In diets containing 40% MDGS diets, there was no difference in ADG ( $P = 0.87$ ). When steers were fed 40% MDGS compared to 20% MDGS in diets containing 15% corn silage, there was an 8.3% numerical decrease in ADG from 1.69 kg/d to 1.55 kg/d ( $P = 0.11$ ). In 45% corn silage diets, there was a 4.8% numerical increase in ADG as MDGS increased from 20 to 40% of the diet (1.46 kg/d for 45:20 compared to 1.53 kg/d for 45:40;  $P = 0.36$ ).

**Table 4.** Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on cattle performance and carcass characteristics (Exp. 1)

| Item                           | Treatment <sup>1</sup> |                    |                    |                     |                     | SEM   | P-value <sup>2</sup> |      |        |      |
|--------------------------------|------------------------|--------------------|--------------------|---------------------|---------------------|-------|----------------------|------|--------|------|
|                                | Control                | 15:20              | 45:20              | 15:40               | 45:40               |       | F-test               | Int. | Silage | MDGS |
| <i>Performance</i>             |                        |                    |                    |                     |                     |       |                      |      |        |      |
| Initial BW, kg                 | 470                    | 468                | 469                | 468                 | 469                 | 1     | 0.17                 | 0.30 | 0.09   | 0.72 |
| Final BW, kg <sup>3</sup>      | 622                    | 631                | 610                | 618                 | 618                 | 5     | 0.11                 | 0.08 | 0.08   | 0.61 |
| Live final BW, kg              | 650                    | 660                | 650                | 645                 | 653                 | 6     | 0.48                 | 0.18 | 0.84   | 0.34 |
| DMI, kg/d                      | 13.2                   | 13.4               | 13.4               | 13.0                | 13.5                | 0.2   | 0.48                 | 0.24 | 0.34   | 0.47 |
| ADG, kg <sup>3</sup>           | 1.57                   | 1.69               | 1.46               | 1.55                | 1.53                | 0.05  | 0.08                 | 0.08 | 0.05   | 0.59 |
| G:F <sup>3</sup>               | 0.119 <sup>ab</sup>    | 0.126 <sup>a</sup> | 0.109 <sup>c</sup> | 0.118 <sup>ab</sup> | 0.114 <sup>bc</sup> | 0.003 | 0.01                 | 0.07 | < 0.01 | 0.69 |
| NE <sub>m</sub> <sup>4</sup>   | 1.64 <sup>ab</sup>     | 1.69 <sup>a</sup>  | 1.56 <sup>c</sup>  | 1.64 <sup>ab</sup>  | 1.60 <sup>bc</sup>  | 0.02  | < 0.01               | 0.09 | < 0.01 | 0.83 |
| NE <sub>g</sub> <sup>4</sup>   | 1.03 <sup>ab</sup>     | 1.07 <sup>a</sup>  | 0.96 <sup>c</sup>  | 1.03 <sup>ab</sup>  | 0.99 <sup>bc</sup>  | 0.02  | < 0.01               | 0.09 | < 0.01 | 0.83 |
| <i>Carcass Characteristics</i> |                        |                    |                    |                     |                     |       |                      |      |        |      |
| HCW, kg                        | 392                    | 398                | 384                | 389                 | 389                 | 3     | 0.12                 | 0.09 | 0.08   | 0.57 |
| Dressing %                     | 60.3 <sup>a</sup>      | 60.3 <sup>a</sup>  | 59.1 <sup>b</sup>  | 60.3 <sup>a</sup>   | 59.6 <sup>ab</sup>  | 0.3   | 0.01                 | 0.37 | < 0.01 | 0.40 |
| LM area, cm <sup>2</sup>       | 89.7 <sup>b</sup>      | 90.2 <sup>a</sup>  | 87.2 <sup>bc</sup> | 86.7 <sup>c</sup>   | 87.3 <sup>bc</sup>  | 0.9   | 0.04                 | 0.09 | 0.27   | 0.11 |
| 12 <sup>th</sup> -rib fat, cm  | 1.19                   | 1.19               | 1.18               | 1.26                | 1.23                | 0.04  | 0.65                 | 0.82 | 0.65   | 0.20 |
| Calculated YG <sup>5</sup>     | 3.01                   | 3.03               | 3.06               | 3.20                | 3.14                | 0.08  | 0.38                 | 0.58 | 0.84   | 0.15 |
| Marbling Score <sup>6</sup>    | 440 <sup>b</sup>       | 483 <sup>a</sup>   | 454 <sup>ab</sup>  | 448 <sup>b</sup>    | 432 <sup>b</sup>    | 11    | 0.03                 | 0.54 | 0.05   | 0.02 |

<sup>a-c</sup>Within a row, values lacking common superscripts differ when F-test was significant ( $P < 0.05$ ).

<sup>1</sup>15:40 = 15% Corn Silage, 40% MDGS; 30:40 = 30% Corn Silage, 40% MDGS; 45:40 = 45% Corn Silage, 40% MDGS; 55:40 = 55% Corn Silage, 40% MDGS; 30:65 = 30% Corn Silage, 65% MDGS; 45:0 = 45% Corn Silage, 0% MDGS.

<sup>2</sup>F-test =  $P$ -value for the overall F-test of all diets. Int. =  $P$ -value for the interaction of corn silage  $\times$  MDGS. Silage =  $P$ -value for the main effect of corn silage inclusion. MDGS =  $P$ -value for the main effect of MDGS inclusion.

<sup>3</sup>Calculated from hot carcass weight, adjusted to a common 63% dressing percentage.

<sup>4</sup>NE<sub>m</sub> and NE<sub>g</sub> calculated using methodology of NRC (1996) using a tool developed by Galyean (2009).

<sup>5</sup>Calculated YG (yield grade) =  $[2.5 + (6.35 \times \text{fat thickness, cm}) + (0.2 \times 2.5\% \text{ KPH}) + (0.0017 \times \text{HCW, kg}) - (2.06 \times \text{LM area, cm}^2)]$ ; (USDA, 2016).

<sup>6</sup>Marbling Score: 400 = Small<sup>00</sup>, 500 = Modest<sup>00</sup>.

There was a tendency for a corn silage  $\times$  MDGS interaction for G:F ( $P = 0.07$ ), and thus the simple effects will be discussed. In diets containing 20% MDGS, G:F decreased from 0.126 to 0.109 as corn silage increased from 15 to 45% of the diet ( $P < 0.01$ ). However in 40% MDGS diets, there was a slight numerical decrease in G:F as corn silage increased from 15 to 45% of the diet (0.118 compared to 0.114;  $P = 0.38$ ). For diets containing 15% corn silage, there was a numerical decrease in G:F from 0.126 to 0.118 as MDGS increased from 20 to 40% of the diet ( $P = 0.12$ ). Conversely, in 45% corn silage diets, there was a numerical increase in G:F as MDGS increased from 20 to 40% of the diet (0.109 for 45:20 compared to 0.114 for 45:40;  $P = 0.30$ ). Feeding values relative to the corn blend (1:1 blend of HMC and DRC on a DM basis) were calculated as the decrease in G:F of the diet containing 45% corn silage compared with the diet containing 15% corn silage divided by the level of inclusion of corn silage (30%) that substituted the corn blend in the diet. For the 30% replacement of corn by corn silage, the feeding value of corn silage was 56% in 20% MDGS diets and 88% in 40% MDGS diets. Using the same feeding value calculation methodology mentioned above, the 20% replacement of the corn blend by MDGS resulted in the feeding value of

MDGS being 70% in 15% corn silage diets and 122% in 45% corn silage diets.

There was a tendency for a corn silage  $\times$  MDGS interaction for HCW ( $P = 0.09$ ). For diets containing 20% MDGS, HCW was decreased (398 compared to 384 kg;  $P = 0.02$ ) as corn silage increased from 15 to 45% of the diet. In 40% MDGS diets, there was no difference in HCW ( $P = 1.00$ ). With diets containing 15% corn silage, HCW numerically decreased from 398 to 389 kg when MDGS increased from 20 to 40% of the diet ( $P = 0.11$ ). In 45% corn silage diets, there was a numerical increase of 5 kg of HCW as MDGS was increased from 20 to 40% of the diet ( $P = 0.38$ ). A tendency was also observed for the interaction between corn silage and MDGS for LM area ( $P = 0.09$ ). There was a tendency for LM area to decrease as corn silage increased from 15 to 45% in 20% MDGS diets ( $P = 0.05$ ). There was no difference in LM area in 40% MDGS diets ( $P = 0.66$ ). Comparing steers fed 20% MDGS to steers fed 40% MDGS, there was a decrease in LM area ( $P = 0.03$ ) in 15% corn silage diets, however in 45% corn silage diets, there was no difference in LM area across MDGS inclusions ( $P = 0.94$ ).

There was no corn silage  $\times$  MDGS interaction for all other carcass characteristics ( $P \geq 0.37$ ). Dressing percentage for steers fed 45% corn silage compared to

15% corn silage was less (60.3 compared to 59.4%;  $P < 0.01$ ). There was no difference in dressing percentage due to MDGS inclusion ( $P = 0.40$ ). There was no effect of corn silage or MDGS concentration on 12th rib fat thickness or calculated yield grade ( $P \geq 0.15$ ). Marbling scores were improved from 443 for steers fed 45% corn silage to 466 for steers fed 15% corn silage ( $P = 0.05$ ). As MDGS increased in the diet from 20 to 40%, marbling scores decreased from 469 to 440 ( $P = 0.02$ ). Vander Pol et al. (2005) reported no marbling score response as WDGS increased from 0 to 50% of the diet. Corrigan et al. (2009) reported a quadratic response for marbling scores as MDGS increased in the diet, with marbling scores increasing and then decreasing when WDGS was increased from 0 and 40% of the diet. Agreeing with Exp. 1, these researchers reported numerically less marbling score when DGS was fed at 40% compared to 15 or 27.5% (Corrigan et al., 2009) or compared to 20% (Vander Pol et al. 2005).

Comparing the control to all other treatments with an overall F-test (Table 4), no differences in DMI was observed across treatments ( $P = 0.48$ ). There was a tendency for steers fed 15:20 to have greater ADG than steers fed 15:40, 45:20, or 45:40 ( $P = 0.08$ ), with the control ADG not different from any other treatment ( $P \geq 0.15$ ). For G:F, there were no differences between the control treatment and 15:20, 15:40, or 45:40 ( $P \geq 0.15$ ), however, steers fed the control treatment had increased G:F compared to steers fed 45:20 treatment diets ( $P = 0.03$ ).

There was no difference in carcass-adjusted final BW, live final BW, or HCW across treatments according to the overall F-test ( $P \geq 0.11$ ). These steers were finished during an unseasonably warm and wet winter and consequently went to slaughter with a high degree of mud and tag on the cattle, but these should be equal across all treatments. Dressing percentage for the control (60.3%) was not different from that of 15:20 (60.3%) or 15:40 (60.3%;  $P \geq 0.96$ ). There was a tendency for cattle fed the control diet to have increased dressing percentage compared to 45:40 (59.6%;  $P = 0.07$ ). Dressing percentage for the control, 15:20, and 15:40 treatments were all greater than 45:20 (59.1%;  $P < 0.01$ ). Cattle that are finished on higher concentrations of roughage usually have decreased dressing percentages compared to cattle fed lower concentrations of roughage, and this has been reported when corn silage has replaced corn grain in finishing diets (Peterson et al., 1973; Danner et al., 1980). This is due to a slower rate of passage for roughage compared to concentrate and consequently greater gastro-intestinal tract fill in cattle fed higher roughage diets (Danner et al., 1980). Control steers had greater LM area compared to 15:40 steers ( $P = 0.03$ ) and tended to have greater LM area compared to 45:20 and 45:40 steers ( $P \leq 0.08$ ). There was no difference in LM area

for the control and 15:20 steers ( $P = 0.72$ ). Steers on 15:20 had greater marbling scores compared to the steers on the control, 15:40, and 45:40 ( $P \leq 0.03$ ). Steers on 15:20 tended to have greater marbling scores compared to 45:20 ( $P = 0.07$ ). There were no other differences between treatments for marbling score ( $P \geq 0.17$ ). There were no differences across treatments for 12th rib fat thickness or calculated yield grade ( $P \geq 0.38$ ). There were no differences in liver abscess prevalence due to dietary treatment ( $P \geq 0.74$ ; data not presented).

## Exp. 2

There were no interactions between corn silage and MDGS inclusion for any of the tested variables ( $P \geq 0.12$ ; Table 5). For the main effect of corn silage inclusion, steers fed 45% corn silage instead of 15% tended to have slightly greater DMI (12.2 vs. 12.0 kg/d;  $P = 0.07$ ) and decreased ADG (1.91 vs. 1.96 kg/d;  $P = 0.01$ ). This translated to steers fed 45% corn silage being 5.2% less efficient in comparison to steers fed 15% corn silage (0.157 G:F for steers fed 45% corn silage compared to 0.165 for steers fed 15% corn silage;  $P < 0.01$ ). The 30% substitution of corn silage for corn (1:1 blend of HMC:DRC) in this experiment resulted in a calculated feeding value for corn silage of 84% that of the corn blend. In previous research with corn silage replacing corn grain in diets containing no distillers grains, G:F was linearly decreased due to the lower energy content of corn silage compared to corn grain (Preston, 1975; NRC, 1996). In diets containing increased concentrations of corn silage, G:F decreased due to an increase in DMI and constant ADG across corn silage inclusion (DiCostanzo et al., 1997), constant DMI with decreased ADG (DiCostanzo et al., 1998b; Exp. 1 and 2 - Erickson, 2001), or both DMI and ADG decreases (Exp. 3 - Erickson, 2001). When calculating feeding values of corn silage from past data, the study by DiCostanzo et al. (1997) results in feeding values of 61, 61, and 51% that of corn (for the 12, 24, and 36% substitution of corn by corn silage, respectively). In the experiments conducted by Erickson (2001), the calculated feeding value of corn silage would be 60 to 75% that of a HMC:DRC blend in yearling steers (Exp. 1 and 2 - Erickson, 2001) and 42 to 48% in calf-fed steers (Exp. 3 - Erickson, 2001).

Burken et al. (2017) compared 15, 30, 45, and 55% corn silage in diets containing 40% MDGS. Dry matter intake and ADG linearly decreased as corn silage was increased in the diet. Gain:feed also decreased linearly with increasing corn silage in the diet. In this experiment, steers on the 15% corn silage treatment were 1.5, 5.0, and 7.7% more efficient than steers on treatments containing 30, 45, or 55% corn silage, respectively. This resulted in feeding values of 91, 83,

**Table 5.** Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on cattle performance and carcass characteristics (Exp. 2)

| Item                           | Treatment <sup>1</sup> |                     |                    |                    |                    | SEM   | P-value <sup>2</sup> |      |        |      |
|--------------------------------|------------------------|---------------------|--------------------|--------------------|--------------------|-------|----------------------|------|--------|------|
|                                | Control                | 15:20               | 45:20              | 15:40              | 45:40              |       | F-test               | Int. | Silage | MDGS |
| <i>Performance</i>             |                        |                     |                    |                    |                    |       |                      |      |        |      |
| Initial BW, kg                 | 348                    | 348                 | 347                | 346                | 348                | 1     | 0.51                 | 0.18 | 0.85   | 0.40 |
| Final BW, kg <sup>3</sup>      | 633                    | 629                 | 623                | 637                | 626                | 4     | 0.18                 | 0.41 | 0.01   | 0.12 |
| Live final BW, kg              | 645                    | 646                 | 643                | 652                | 640                | 4     | 0.35                 | 0.20 | 0.04   | 0.75 |
| DMI, kg/d                      | 12.3                   | 11.9                | 12.2               | 12.0               | 12.1               | 0.1   | 0.13                 | 0.41 | 0.07   | 0.86 |
| ADG, kg <sup>3</sup>           | 1.96                   | 1.93                | 1.90               | 2.00               | 1.92               | 0.03  | 0.11                 | 0.18 | 0.01   | 0.06 |
| G:F <sup>3</sup>               | 0.159 <sup>bc</sup>    | 0.163 <sup>ab</sup> | 0.156 <sup>c</sup> | 0.167 <sup>a</sup> | 0.158 <sup>c</sup> | 0.002 | < 0.01               | 0.61 | < 0.01 | 0.07 |
| NE <sub>m</sub> <sup>4</sup>   | 1.85 <sup>c</sup>      | 1.89 <sup>ab</sup>  | 1.83 <sup>c</sup>  | 1.92 <sup>a</sup>  | 1.86 <sup>bc</sup> | 0.01  | < 0.01               | 0.81 | < 0.01 | 0.06 |
| NE <sub>g</sub> <sup>4</sup>   | 1.21 <sup>c</sup>      | 1.25 <sup>ab</sup>  | 1.19 <sup>c</sup>  | 1.27 <sup>a</sup>  | 1.22 <sup>bc</sup> | 0.01  | < 0.01               | 0.81 | < 0.01 | 0.06 |
| <i>Carcass Characteristics</i> |                        |                     |                    |                    |                    |       |                      |      |        |      |
| HCW, kg                        | 399                    | 396                 | 393                | 401                | 394                | 3     | 0.18                 | 0.41 | 0.01   | 0.12 |
| Dressing %                     | 61.9                   | 61.3                | 61.1               | 61.6               | 61.6               | 0.2   | 0.22                 | 0.54 | 0.51   | 0.08 |
| LM area, cm <sup>2</sup>       | 84.1                   | 84.3                | 84.3               | 83.7               | 81.8               | 1.4   | 0.62                 | 0.39 | 0.38   | 0.15 |
| 12 <sup>th</sup> -rib fat, cm  | 1.66                   | 1.61                | 1.60               | 1.77               | 1.61               | 0.07  | 0.43                 | 0.27 | 0.25   | 0.26 |
| Calculated YG <sup>5</sup>     | 3.81                   | 3.72                | 3.69               | 3.96               | 3.83               | 0.12  | 0.54                 | 0.66 | 0.43   | 0.09 |
| Marbling Score <sup>6</sup>    | 451                    | 437                 | 455                | 459                | 432                | 17    | 0.74                 | 0.12 | 0.74   | 0.99 |

<sup>a-c</sup>Within a row, values lacking common superscripts differ when F-test was significant ( $P < 0.05$ ).

<sup>1</sup>15:40= 15% Corn Silage, 40% MDGS; 30:40= 30% Corn Silage, 40% MDGS; 45:40= 45% Corn Silage, 40% MDGS; 55:40= 55% Corn Silage, 40% MDGS; 30:65= 30% Corn Silage, 65% MDGS; 45:0= 45% Corn Silage, 0% MDGS.

<sup>2</sup>F-test =  $P$ -value for the overall F-test of all diets. Int. =  $P$ -value for the interaction of corn silage  $\times$  MDGS. Silage =  $P$ -value for the main effect of corn silage inclusion. MDGS =  $P$ -value for the main effect of MDGS inclusion.

<sup>3</sup>Calculated from hot carcass weight, adjusted to a common 63% dressing percentage.

<sup>4</sup>NE<sub>m</sub> and NE<sub>g</sub> calculated using methodology of NRC (1996) using a tool developed by Galyean (2009).

<sup>5</sup>Calculated YG (yield grade) =  $[2.5 + (6.35 \times \text{fat thickness, cm}) + (0.2 \times 2.5\% \text{ KPH}) + (0.0017 \times \text{HCW, kg}) - (2.06 \times \text{LM area, cm}^2)]$ ; (USDA, 2016).

<sup>6</sup>Marbling Score: 400 = Small<sup>00</sup>, 500 = Modest<sup>00</sup>.

and 81% that of corn for the 15, 30, and 40% replacement of corn (Burken et al., 2017).

For the purpose of comparing the present Exp. 1 and 2, the feeding value of corn silage was 85% that of the corn blend in 20% MDGS diets and 83% in 40% MDGS diets in Exp. 2. This feeding value for corn silage in 20% MDGS diets calculated from Exp. 2 differs from that of Exp. 1 (56%). There are differences in cattle types across experiments with long yearling cattle fed through the winter used in Exp. 1 and short yearling cattle fed through the summer used in Exp. 2. Further, the different feeding period weather may have affected feedlot performance and calculated feeding values (warm, wet winter; 2012-2013) in Exp. 1 compared to normal, dry summer (2013) in Exp. 2. Performance data were considerably worse compared to the historical data for the cattle type utilized in Exp. 1, but performance data was normal to improved compared to historical data for Exp. 2. Regardless, these environment factors should have affected all treatments equally. The feeding value for corn silage in 40% MDGS diets are quite similar across experiments (88% for Exp. 1 and 83% for Exp. 2), which further complicates the reasoning for the discrepancy in corn silage feeding values in 20% MDGS diets across experiments. In the experiment conducted by Burken

et al. (2017) with calf-fed steers finished during the time period of November to May, the reported feeding value for corn silage was 83% that of a corn blend (1:1 blend of HMC:DRC) for the 30% replacement of corn (15 compared to 45% corn silage) in finishing diets containing 40% MDGS. The feeding value of corn silage in finishing diets containing distillers grains are greater compared to past experiments (DiCostanzo et al., 1997, 1998b; Erickson, 2001), which may be attributed to improved digestibility when increased concentrations of corn silage are fed with distillers grains or there are differences in nutrient content of the dietary ingredients across experiments, however, the lack of reported feedstuff nutrient values limit these comparisons.

For Exp. 2, carcass-adjusted final BW ( $P = 0.01$ ) and HCW ( $P = 0.01$ ) were 8.8 and 5.5 kg less, respectively, for steers fed 45% corn silage compared to steers fed 15% corn silage. Unexpectedly and not agreeing with results in Exp. 1 or previous research with increased dietary concentrations of corn silage (Peterson et al., 1973; Danner et al., 1980), dressing percentage was not different between corn silage inclusions ( $P = 0.51$ ) suggesting equal gastro-intestinal tract fill and fatness across treatments. All other carcass characteristics were not different across corn silage dietary concentrations ( $P \geq 0.25$ ).



For the main effect of MDGS in Exp. 2, there was no difference in DMI when steers were fed 20 or 40% MDGS ( $P = 0.86$ ). When MDGS was increased in the diet from 20 to 40%, ADG tended to increase from 1.91 to 1.97 kg/d ( $P = 0.06$ ). For G:F, there was a tendency for steers fed 40% MDGS compared to 20% MDGS to be 2.3% more efficient, with steers fed 40% MDGS having a G:F of 0.165 in comparison to a G:F of 0.157 for steers fed 20% MDGS ( $P = 0.07$ ). When calculating a feeding value relative to the corn blend for the 20% substitution of MDGS for corn (1:1 blend of HMC:DRC) in this experiment, the resultant feeding value was 110% of corn for MDGS. This feeding value for MDGS agrees well with the 109% calculated feeding value for MDGS for the 20% substitution of corn between dietary inclusion concentrations of 20 and 40% MDGS reported in the meta-analysis conducted by Bremer et al. (2011). The feeding value of MDGS in 15% corn silage diets in Exp. 1 does not agree with Exp. 2 or the meta-analysis by Bremer et al. (2011). This discrepancy was not expected and may be partially due to poor feeding conditions in Exp. 1. For Exp. 2, there was no difference in carcass-adjusted final BW ( $P = 0.12$ ) between MDGS concentrations, however, there was a numerical increase of 5.2 kg for cattle fed 40% in comparison to 20% MDGS. There was a tendency for a slight increase in dressing percentage and calculated yield grade for cattle fed 40% MDGS in comparison to 20% MDGS ( $P = 0.08$  and  $0.09$ , respectively). There were no differences in LM area, 12th rib fat thickness, or marbling score for cattle fed either 20 or 40% MDGS ( $P \geq 0.15$ ).

The control treatment, which consisted of 5% cornstalks and 40% MDGS, was compared with all other treatments in the analysis of the overall F-test. There were no differences in DMI, ADG, or final BW across all treatments in Exp. 2 ( $P \geq 0.11$ ). Using the overall F-test statistics, steers fed the 15:20 and 15:40 treatment diets were not different for G:F ( $P = 0.13$ ). Although G:F of steers fed the control diet were not different from 15:20, 45:20, and 45:40 treatments ( $P \geq 0.15$ ), steers fed the control had 4.8% poorer G:F compared to steers fed the 15:40 treatment ( $P < 0.01$ ). The control and 15:40 diets both contained 40% MDGS with the control containing 5% cornstalks compared to the 15% corn silage used as the roughage source in 15:40. This difference in G:F between roughage sources in Exp. 2 disagrees with results in Exp. 1 as well as previous research evaluating roughage source in diets containing wet distillers grains with solubles (WDGS; Benton et al., 2015). Benton et al. (2015) evaluated the effect of roughage source utilizing alfalfa, cornstalks, and corn silage on an equal NDF basis (with corn silage NDF calculated from the whole plant and not just stover fraction) in

diets containing 30% WDGS. Contrary to the Exp. 2 results, these researchers reported no differences in G:F across roughage sources (Benton et al., 2015). In Exp. 1, the roughage NDF percentage was 4.2% in the control diet compared to 8.6% in the 15:40 diet, and in Exp. 2 the roughage NDF percentage was 4.4 compared to 7.1% for the control and 15:40 diets, respectively. This compares to 4.6% for the 6% cornstalk diet and 5.3% for the 12% corn silage diet reported in the experiment conducted by Benton et al. (2015). There were no differences across treatments in Exp. 2 for HCW, dressing percentage, LM area, 12th rib fat thickness, calculated YG, or marbling score according to the overall F-test ( $P \geq 0.18$ ). There were also no differences in liver abscess prevalence either due to dietary treatment ( $P \geq 0.53$ ).

### Exp. 3

There were no corn silage  $\times$  MDGS interactions for intake and total tract digestibility data ( $P \geq 0.31$ ; Table 6). For the main effect of corn silage, there was an increase in DMI from 9.9 kg/d to 11.0 kg/d ( $P = 0.09$ ) and a tendency for an increase in organic matter intake (OMI;  $P = 0.12$ ) when corn silage was increased from 15 to 45% of the diet. For diets containing 15% corn silage compared to 45% corn silage, there was greater DM digestibility (73.4% to 69.3%; DMD;  $P = 0.03$ ) and OM digestibility (75.3 to 71.5%; OMD;  $P = 0.03$ ). There was an increase in NDF intake from 2.2 kg/d to 3.4 kg/d as corn silage increased in the diet ( $P < 0.01$ ), however, there was no difference across corn silage concentration for NDF digestibility (53.3% for 15% corn silage diets compared to 56.4% for 45% corn silage diets; NDFD;  $P = 0.15$ ). The increase in DMI with increased corn silage in the diet has been reported by DiCostanzo et al. (1997). Vance and Preston (1971) conducted a digestibility experiment and reported that OMD decreased from 85.0 to 76.7% and from 87.1 to 80.7% in whole corn and crimped corn diets (respectively) when corn silage was increased from approximately 2 to 61% of the diet. The difference in OMD in this experiment was 3.8% units for a replacement of 30% corn grain, compared to the 8.3 and 6.4% units difference in OMD reported in the study by Vance and Preston (1971) for the approximately 60% replacement of corn grain.

For the main effect of MDGS inclusion, there was no difference in DMI or OMI ( $P \geq 0.94$ ). There was also no difference in DMD ( $P = 0.27$ ) or OMD ( $P = 0.44$ ) across MDGS concentrations, but there was a numerical decrease in DMD (72.2 compared to 70.5%) and OMD (74.0 compared to 72.8%) as MDGS increased from 20 to 40% of the diet. The numerical decrease in DMD observed in this experiment as MDGS increased from 20 to 40% agrees with Corrigan et al. (2009), Vander Pol

**Table 6.** Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on intake and digestibility of nutrients (Exp. 3)

| Item                 | Treatment <sup>1</sup> |                   |                    |                    |                    | SEM  | P-value <sup>2</sup> |      |        |      |
|----------------------|------------------------|-------------------|--------------------|--------------------|--------------------|------|----------------------|------|--------|------|
|                      | 95:0                   | 15:20             | 45:20              | 15:40              | 45:40              |      | F-test               | Int. | Silage | MDGS |
| DM intake, kg/d      | 7.5 <sup>c</sup>       | 9.6 <sup>b</sup>  | 11.2 <sup>a</sup>  | 10.2 <sup>ab</sup> | 10.8 <sup>ab</sup> | 0.8  | < 0.01               | 0.48 | 0.09   | 0.94 |
| DM excretion, kg/d   | 2.54 <sup>b</sup>      | 2.52 <sup>b</sup> | 3.33 <sup>a</sup>  | 2.76 <sup>ab</sup> | 3.42 <sup>a</sup>  | 3.13 | 0.08                 | 0.71 | 0.03   | 0.56 |
| DM digestibility, %  | 65.2 <sup>b</sup>      | 74.3 <sup>a</sup> | 70.1 <sup>a</sup>  | 72.5 <sup>a</sup>  | 68.4 <sup>a</sup>  | 1.9  | 0.03                 | 0.72 | 0.03   | 0.27 |
| OM intake, kg/d      | 7.0 <sup>c</sup>       | 9.2 <sup>b</sup>  | 10.6 <sup>a</sup>  | 9.6 <sup>ab</sup>  | 10.1 <sup>ab</sup> | 0.7  | < 0.01               | 0.48 | 0.12   | 0.96 |
| OM excretion, kg/d   | 2.18                   | 2.26              | 2.94               | 2.41               | 2.95               | 2.82 | 0.10                 | 0.73 | 0.04   | 0.76 |
| OM digestibility, %  | 68.0 <sup>b</sup>      | 75.8 <sup>a</sup> | 72.1 <sup>a</sup>  | 74.7 <sup>a</sup>  | 70.9 <sup>ab</sup> | 1.8  | 0.06                 | 0.76 | 0.03   | 0.44 |
| NDF intake, kg/d     | 2.94 <sup>b</sup>      | 1.97 <sup>d</sup> | 3.19 <sup>ab</sup> | 2.48 <sup>c</sup>  | 3.54 <sup>a</sup>  | 0.21 | < 0.01               | 0.56 | < 0.01 | 0.02 |
| NDF excretion, kg/d  | 1.38 <sup>ab</sup>     | 0.91 <sup>c</sup> | 1.45 <sup>a</sup>  | 1.16 <sup>bc</sup> | 1.46 <sup>ab</sup> | 1.21 | 0.01                 | 0.27 | < 0.01 | 0.28 |
| NDF digestibility, % | 50.9                   | 54.3              | 54.1               | 52.3               | 58.7               | 3.6  | 0.53                 | 0.31 | 0.15   | 0.54 |

<sup>a-d</sup>Within a row, values lacking common superscripts differ when F-test was significant ( $P < 0.10$ ).

<sup>1</sup>95:0 = 95% corn silage, 0% MDGS; 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS.

<sup>2</sup>F-test =  $P$ -value for the overall F-test of all diets. Int. =  $P$ -value for the interaction of corn silage  $\times$  MDGS. Silage =  $P$ -value for the main effect of corn silage inclusion. MDGS =  $P$ -value for the main effect of MDGS inclusion.

et al. (2009), and Bremer (2010) who reported DM digestibility of WDGS diets to be at least numerically less than DM digestibility of corn control diets. As MDGS increased from 20 to 40% of the diet in the present experiment, NDF intake (NDFI) increased from 2.58 to 3.01 kg/d ( $P = 0.02$ ), but there was no difference in NDFD (54.2% for 20% MDGS diets compared to 55.5% for 40% MDGS diets;  $P = 0.54$ ) across MDGS concentrations. Corrigan et al. (2009), Vander Pol et al. (2009), and Bremer (2010) have all reported WDGS diet NDF digestibility to be numerically greater than corn diet NDF digestibility. Total tract digestibility of NDF was reported by Ham et al. (1994) to be significantly greater for a diet containing 40% wet distillers grains (69.6%) compared to a corn control finishing diet (62.5%).

When cattle were fed the 95:0 diet (95% corn silage), DMI and OMI were substantially decreased (7.5 and 7.0 kg/d, respectively;  $P < 0.01$ ) compared to all other treatments. According to the overall F-test, steers fed 45:20 had greater DMI ( $P = 0.05$ ) and OMI ( $P = 0.07$ ) compared to 15:20. For DMI and OMI, there was no difference between 45:20 and 15:40 or 45:40, as well, there was no differences between 15:20 and 15:40 or 45:40 ( $P \geq 0.13$ ). For DMD, the 95:0 treatment had the lowest DMD across all treatments ( $P = 0.03$ ). The 95:0 treatment also had lower OMD compared to 15:20, 15:40, and 45:20 ( $P \geq 0.08$ ) but was not different from 45:40 for OMD ( $P = 0.12$ ). Steers fed 45:20 and 45:40 were not different for NDFI ( $P = 0.14$ ), but 45:40 had greater NDFI compared to 95:0, 15:20, and 15:40 ( $P < 0.01$ ). The 95:0 treatment was not different from 45:20 for NDFI ( $P = 0.12$ ), but 95:0 had greater NDFI compared to 15:20 or 15:40 ( $P \leq 0.04$ ). Steers fed 15:20 had the least NDFI ( $P \leq 0.03$ ). There was no difference in NDFD across treatments according to the overall F-test

( $P = 0.33$ ), however the 95:0 treatment had the numerically lowest total tract NDFD (50.9%).

There was no interaction between corn silage and MDGS concentration for any of the measured ruminal pH variables ( $P \geq 0.35$ ; Table 7). As corn silage was increased in the diet from 15 to 45%, there was an increase in average (5.69 for 15% corn silage diets compared to 6.10 for 45% corn silage diets;  $P = 0.01$ ) and maximum pH (6.62 and 6.90 for 15 and 45% corn silage diets, respectively;  $P = 0.04$ ). Minimum pH also increased as corn silage was increased in the diet (5.04 for 15% corn silage diets compared to 5.29 for 45% corn silage diets;  $P = 0.03$ ). There was no difference across corn silage concentrations for magnitude of pH change or ruminal pH variance ( $P \geq 0.70$ ). Time spent below a ruminal pH of 5.60 ( $P < 0.01$ ) was greater for steers fed 15% corn silage compared to steers fed 45% corn silage. Area below a ruminal pH of 5.60 was also greater for steers fed 15% compared to 45% corn silage ( $P = 0.06$ ).

When MDGS was increased in the diet from 20 to 40% in diets containing 15 or 45% corn silage, there was no difference in minimum, average, or maximum ruminal pH ( $P \geq 0.31$ ). The replacement of corn by distillers grains has been reported to numerically increase (Bremer et al., 2011) or numerically decrease (Ham et al., 1994; Corrigan et al., 2009; VanderPol et al., 2009) average ruminal pH. In this experiment, the increase in MDGS from 20 to 40% of the diet numerically increased minimum (5.12 vs. 5.21;  $P = 0.31$ ), average (5.86 vs. 5.94;  $P = 0.41$ ), and maximum pH (6.71 vs. 6.80;  $P = 0.88$ ). There was no difference across MDGS concentrations for magnitude of pH change or ruminal pH variance ( $P \geq 0.13$ ). There was also no difference in time or area below a ruminal pH of 5.60 across MDGS concentrations ( $P \geq 0.42$ ).

**Table 7.** Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on pH and ruminal volatile fatty acid measurements (Exp. 3)

| Item                           | Treatment <sup>1</sup> |                    |                    |                    |                    | SEM  | P-value <sup>2</sup> |        |        |      |
|--------------------------------|------------------------|--------------------|--------------------|--------------------|--------------------|------|----------------------|--------|--------|------|
|                                | 95:0                   | 15:20              | 45:20              | 15:40              | 45:40              |      | F-test               | Int.   | Silage | MDGS |
| <i>Ruminal pH</i>              |                        |                    |                    |                    |                    |      |                      |        |        |      |
| Maximum pH                     | 7.24 <sup>a</sup>      | 6.65 <sup>bc</sup> | 6.77 <sup>b</sup>  | 6.58 <sup>c</sup>  | 7.02 <sup>b</sup>  | 0.18 | < 0.01               | 0.49   | 0.04   | 0.88 |
| Average pH                     | 6.69 <sup>a</sup>      | 5.72 <sup>cd</sup> | 5.99 <sup>bc</sup> | 5.67 <sup>d</sup>  | 6.20 <sup>b</sup>  | 0.18 | < 0.01               | 0.35   | 0.01   | 0.41 |
| Minimum pH                     | 5.94 <sup>a</sup>      | 5.01 <sup>c</sup>  | 5.22 <sup>bc</sup> | 5.06 <sup>c</sup>  | 5.36 <sup>b</sup>  | 0.14 | < 0.01               | 0.55   | 0.03   | 0.31 |
| Magnitude                      | 1.30 <sup>b</sup>      | 1.64 <sup>a</sup>  | 1.55 <sup>a</sup>  | 1.52 <sup>a</sup>  | 1.67 <sup>a</sup>  | 0.15 | 0.02                 | 0.98   | 0.70   | 0.16 |
| Variance                       | 0.12                   | 0.22               | 0.18               | 0.13               | 0.16               | 0.06 | 0.20                 | 0.80   | 0.95   | 0.13 |
| Time < 5.6, min/d              | 7 <sup>c</sup>         | 690 <sup>a</sup>   | 335 <sup>b</sup>   | 752 <sup>a</sup>   | 212 <sup>bc</sup>  | 149  | < 0.01               | 0.61   | < 0.01 | 0.57 |
| Area < 5.6 <sup>3</sup>        | 1 <sup>b</sup>         | 247 <sup>a</sup>   | 92 <sup>ab</sup>   | 215 <sup>a</sup>   | 39 <sup>b</sup>    | 84   | 0.04                 | 0.81   | 0.06   | 0.42 |
| <i>Ruminal VFA<sup>4</sup></i> |                        |                    |                    |                    |                    |      |                      |        |        |      |
| Total, mM                      | 91.3 <sup>c</sup>      | 113.2 <sup>a</sup> | 106.6 <sup>b</sup> | 102.1 <sup>b</sup> | 95.0 <sup>bc</sup> | 6.5  | < 0.01               | 0.61   | 0.01   | 0.03 |
| Acetate <sup>5</sup>           | 59.2 <sup>a</sup>      | 50.1 <sup>c</sup>  | 54.0 <sup>b</sup>  | 48.3 <sup>c</sup>  | 53.0 <sup>b</sup>  | 1.7  | < 0.01               | 0.31   | < 0.01 | 0.54 |
| Propionate <sup>5</sup>        | 28.5 <sup>c</sup>      | 35.3 <sup>a</sup>  | 31.5 <sup>b</sup>  | 38.2 <sup>a</sup>  | 30.4 <sup>bc</sup> | 2.3  | < 0.01               | 0.11   | < 0.01 | 0.68 |
| Butyrate <sup>5</sup>          | 9.4 <sup>bc</sup>      | 11.6 <sup>ab</sup> | 11.3 <sup>bc</sup> | 10.4 <sup>c</sup>  | 12.9 <sup>a</sup>  | 1.7  | < 0.01               | < 0.01 | 0.07   | 0.51 |
| A:P <sup>6</sup>               | 2.26 <sup>a</sup>      | 1.53 <sup>c</sup>  | 1.86 <sup>b</sup>  | 1.40 <sup>c</sup>  | 1.85 <sup>b</sup>  | 0.16 | < 0.01               | 0.95   | 0.01   | 0.31 |

<sup>a-d</sup>Within a row, values lacking common superscripts differ when F-test was significant ( $P < 0.10$ ).

<sup>1</sup>95:0 = 95% corn silage, 0% MDGS; 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS.

<sup>2</sup>F-test =  $P$ -value for the overall F-test of all diets. Int. =  $P$ -value for the interaction of corn silage  $\times$  MDGS. Silage =  $P$ -value for the main effect of corn silage inclusion. MDGS =  $P$ -value for the main effect of MDGS inclusion.

<sup>3</sup>Area < 5.6 = ruminal pH units below 5.6 by minute.

<sup>4</sup>Ruminal volatile fatty acids (VFA).

<sup>5</sup>VFA concentration in mol/100 mol.

<sup>6</sup>Acetate:Propionate.

When comparing the 95:0 treatment to all other treatments using the overall F-test, the 95:0 treatment had the highest average, minimum, and maximum ruminal pH ( $P < 0.01$ ). The 95:0 treatment had less magnitude of pH change compared to all other treatments ( $P = 0.02$ ). There was no difference in ruminal pH variance across treatments when using the overall F-test ( $P = 0.20$ ). For time spent below a ruminal pH of 5.60, the 95:0 treatment was not different from 45:40 ( $P = 0.32$ ), however steers fed 95:0 spent less time with a ruminal pH below 5.60 compared to 15:20, 15:40, or 45:20 ( $P \leq 0.06$ ). There was no difference between 95:0, 45:20, or 45:40 for area spent below a pH of 5.60 ( $P \geq 0.24$ ), but 95:0 and 45:40 had less area below a ruminal pH of 5.60 compared to 15:20 or 15:40 ( $P \leq 0.10$ ).

There were no interactions between corn silage and MDGS inclusion for total ruminal VFA concentration or molar proportions of acetate or propionate ( $P \geq 0.11$ ; Table 7). As corn silage was increased from 15 to 45% of the diet, total ruminal VFA concentration decreased from 107.7 mM to 100.8 mM ( $P = 0.01$ ). There was an increase in the VFA profile proportion of acetate ( $P < 0.01$ ) and a corresponding decrease in the proportion of propionate ( $P < 0.01$ ) as corn silage was increased from 15 to 45% of the diet.

There was a decrease in total ruminal VFA concentration as MDGS increased from 20 to 40% of

the diet ( $P = 0.03$ ). There was no difference in VFA profile proportions of acetate and propionate across MDGS inclusions ( $P \geq 0.54$ ).

There was a corn silage  $\times$  MDGS interaction for the VFA profile proportion of butyrate ( $P < 0.01$ ). In 15% corn silage diets, the molar proportion of butyrate decreased from 11.6 to 10.4% ( $P = 0.06$ ) when MDGS increased from 20 to 40% of the diet, however, when 45% corn silage diets were fed, the molar proportion of butyrate increased from 11.3 to 12.9% when MDGS increased from 20 to 40% of the diet ( $P < 0.01$ ). In 20% MDGS diets, there was no difference in proportion of butyrate due to corn silage concentration ( $P = 0.26$ ). When 40% MDGS diets were fed, proportion of butyrate increased from 10.4 to 12.9% ( $P < 0.01$ ) as corn silage increased from 15 to 45% of the diet. There was no corn silage  $\times$  MDGS interaction for acetate to propionate ratio (A:P;  $P = 0.95$ ). As corn silage increased in the diet, the acetate to propionate ratio increased (1.47 to 1.86;  $P = 0.01$ ). For the main effect of MDGS, there was no difference in the acetate to propionate ratio ( $P = 0.31$ ). Ham et al. (1994) reported that distillers grains replacing corn in finishing diets results in no differences in molar proportions of VFA. In contrast, the addition of distillers grains resulted in an increase in the molar proportion of propionate and a decrease in acetate in an experiment conducted by Vander Pol et al. (2009).

In the overall F-test analysis, 15:20 had the greatest concentration of total VFA, with 15:40, 45:20, and 45:40 being intermediate, and 45:40 and 95:0 having the least total concentration of VFA ( $P < 0.01$ ). Steers fed the 95:0 treatment had the greatest ruminal VFA profile proportion of acetate (59.2%;  $P < 0.01$ ). When evaluating the ruminal VFA profile proportion of propionate, steers fed diets containing 15% corn silage had the greatest proportion of propionate, followed by treatments 45:20 and 45:40 ( $P < 0.01$ ). The 95:0 treatment was not different from 45:40 ( $P = 0.15$ ) but had a lower proportion of propionate compared to all other treatments ( $P < 0.01$ ). The 95:0 treatment also had the greatest A:P compared to all other treatments (2.26;  $P < 0.01$ ). The lowest A:P was calculated for steers consuming 15% corn silage diets, with steers fed 45% corn silage diets being intermediate according to the overall F-test ( $P < 0.01$ ). Corn silage contains a greater concentration of NDF compared to corn (41 compared to 9%; NRC, 1996), and therefore the reduction in total VFA and the proportional shift towards greater proportions of acetate compared to propionate was expected due to the change in dietary substrate (Firkins et al., 2006) and ruminal pH (Esdale and Satter, 1972).

There was no corn silage  $\times$  MDGS interaction for ruminal NDF disappearance for corn bran ( $P = 0.30$ ; Table 8). For the main effect of dietary corn silage, there was an increase in ruminal NDF disappearance of corn bran (40.39% compared to 49.68%;  $P < 0.01$ ) as corn silage increased from 15 to 45% of the diet. As MDGS increased from 20 to 40% of the diet, there was an increase in ruminal NDF disappearance of corn bran (42.97% compared to 47.10;  $P < 0.01$ ). Bremer (2010)

reported numerically lower ruminal NDF disappearance of corn bran for WDGS (56% of the diet; 19.1 and 24.7% for 24 and 48 h, respectively) compared to a corn control diet (22.6 and 31.6% for 24 and 48 h, respectively). Conversely and agreeing with the current experiment, Corrigan et al. (2009) reported an increase in in-situ NDF disappearance of WDGS and corn bran in a 40% WDGS diet (35.6% NDF disappearance) compared to a corn control diet (32.5% NDF disappearance).

For the overall F-test, a treatment  $\times$  time interaction was observed for NDF disappearance of corn bran ( $P = 0.03$ ). At an incubation period of 24 h, the greatest NDF disappearance of corn bran was observed in steers fed 45:40 ( $P \leq 0.07$ ). Incubating corn bran in steers fed 95:0, 15:40, and 45:20 resulted in no difference in NDF disappearance at 24 h ( $P \geq 0.31$ ). Incubating corn bran (24 h) in steers fed 15:20 resulted in lower NDF disappearance than 45:20 and 45:40 ( $P \geq 0.05$ ), but there was no difference in NDF disappearance from corn bran between 95:0, 15:20, and 15:40 ( $P \geq 0.13$ ). At an incubation period of 36 h, the greatest NDF disappearance of corn bran was observed in 95:0 and 45:40 ( $P \leq 0.10$ ). NDF disappearance of corn bran was intermediate for 45:20 ( $P \leq 0.10$ ), with 15:20 and 15:40 having the least NDF disappearance of corn bran ( $P \leq 0.05$ ).

There was no interaction between corn silage and MDGS for NDF disappearance from corn silage ( $P = 0.48$ ). As well, there was no effect from corn silage ( $P = 0.24$ ) or MDGS ( $P = 0.24$ ) inclusion on NDF disappearance from corn silage. In the evaluation of the overall F-test for NDF disappearance of corn silage, there was no interaction between treatment and time

**Table 8.** Effect of corn silage and modified distillers grains with solubles (MDGS) inclusion on NDF disappearance from corn bran and corn silage and DM disappearance from corn (Exp. 3)

| Item                             | Treatment <sup>1</sup> |                    |                    |                     |                     | SEM  | P-value <sup>2</sup> |      |        |        |
|----------------------------------|------------------------|--------------------|--------------------|---------------------|---------------------|------|----------------------|------|--------|--------|
|                                  | 95:0                   | 15:20              | 45:20              | 15:40               | 45:40               |      | F-test               | Int. | Silage | MDGS   |
| Corn bran, % NDFD <sup>3</sup>   |                        |                    |                    |                     |                     |      |                      |      |        |        |
| 24 h                             | 41.36 <sup>de</sup>    | 36.12 <sup>e</sup> | 42.77 <sup>d</sup> | 39.52 <sup>de</sup> | 48.60 <sup>bc</sup> | 2.91 | < 0.01               | 0.30 | < 0.01 | < 0.01 |
| 36 h                             | 59.81 <sup>a</sup>     | 42.17 <sup>d</sup> | 50.82 <sup>b</sup> | 43.74 <sup>cd</sup> | 56.52 <sup>a</sup>  |      |                      |      |        |        |
| Corn silage, % NDFD <sup>4</sup> |                        |                    |                    |                     |                     |      |                      |      |        |        |
| 24 h                             | 41.03                  | 39.25              | 37.82              | 38.07               | 45.53               | 6.38 | 0.42                 | 0.48 | 0.24   | 0.24   |
| 36 h                             | 51.16                  | 41.57              | 44.33              | 44.55               | 53.61               |      |                      |      |        |        |
| Corn, % DMD <sup>5</sup>         |                        |                    |                    |                     |                     |      |                      |      |        |        |
| 24 h                             | 62.05 <sup>e</sup>     | 73.78 <sup>b</sup> | 77.72 <sup>a</sup> | 74.06 <sup>b</sup>  | 79.52 <sup>a</sup>  | 1.79 | < 0.01               | 0.92 | < 0.01 | 0.86   |
| 36 h                             | 71.95                  | 81.11              | 85.43              | 80.60               | 83.14               |      |                      |      |        |        |

<sup>a-c</sup>Within a row and column, values lacking common superscripts differ when F-test was significant ( $P < 0.10$ ).

<sup>1</sup>95:0 = 95% corn silage, 0% MDGS; 15:20 = 15% Corn Silage, 20% MDGS; 15:40 = 15% Corn Silage, 40% MDGS; 45:20 = 45% Corn Silage, 20% MDGS; 45:40 = 45% Corn Silage, 40% MDGS.

<sup>2</sup>F-test = P-value for the overall F-test of all diets. Int. = P-value for the interaction of corn silage  $\times$  MDGS. Silage = P-value for the main effect of corn silage inclusion. MDGS = P-value for the main effect of MDGS inclusion.

<sup>3</sup>Interaction between treatment and time point ( $P = 0.03$ ).

<sup>4</sup>Interaction between treatment and time point ( $P = 0.98$ ).

<sup>5</sup>Interaction between treatment and time point ( $P = 0.37$ ).

( $P = 0.98$ ), as well as, no effect of treatment ( $P = 0.42$ ). The lack of significance in the evaluation of NDF disappearance of corn silage was most likely due to the increased variability, as shown in the standard error of the mean, associated with NDF disappearance from corn silage in an *in situ* procedure. Corn silage is not a homogenous feedstuff, but is made up of many parts of the corn plant that vary widely in digestibility (McGee, 2013). Due to this heterogeneity, corn silage is not a good indicator of NDF digestibility across treatment diets utilizing the *in situ* disappearance methodology.

There was no corn silage  $\times$  MDGS interaction for ruminal DM disappearance of corn ( $P = 0.79$ ). For the main effect of corn silage, there was an increase in ruminal DM disappearance of corn (77.39 to 81.45%;  $P < 0.01$ ) as corn silage increased from 15 to 45% of the diet. There was no difference across MDGS concentrations for ruminal DM disappearance of corn ( $P = 0.86$ ). In the overall F-test evaluation, there was no treatment  $\times$  time interaction ( $P = 0.37$ ) for DM disappearance of corn. The greatest DM disappearance of corn was observed in diets 45:20 and 45:40; intermediate for diets 15:20 and 15:40; and least for 95:0 ( $P < 0.01$ ).

The increases in ruminal pH as corn silage increases in the diet in the present study show the classical response of added roughage in high-grain diets. Ruminal pH results from the balance of acid production by fermentation of organic matter, absorption of these acids from the rumen, and the neutralization of these acids by salivary bicarbonate and phosphate buffers (Allen, 1997). As forage:concentrate ratio is increased, ruminal pH is usually increased due to less fermentable substrate, and increases in mastication time and production of salivary buffers (Galyean and Defoor, 2003). Allen (1997) reported that although dietary NDF alone is not related to ruminal pH, forage NDF as a percentage of the DM was significantly correlated to ruminal pH. This explains the ruminal pH results in Exp. 3 when corn silage and MDGS were added to the diet. Corn silage is a source of roughage NDF and effective NDF (NRC, 1996). Distillers grains increase the dietary concentration of NDF when replacing corn, however, distillers grains have a fine particle size and are not stimulating mastication time (Clark and Armentano, 1993; Penner et al., 2009; Zhang et al., 2010) and subsequent saliva secretion. The results of Ham et al. (1994) and Vander Pol et al. (2009) agree with the present results in that the addition of distillers grains to finishing diets have little effect on ruminal pH.

As ruminal pH is decreased, fiber digestibility is decreased (Terry et al., 1969; Hoover, 1986). In the present study, there was no difference in dietary total tract NDFD across treatments. However, ruminal pH was increased as corn silage increased in the diet, suggesting less inhibition of fiber digestion. Our lack of difference in NDFD

across diets may be explained by the differences between sources of NDF. Corn and corn silage NDF would differ substantially in terms of NDF components and particle size, and therefore passage rate and digestibility of NDF would likely be different. The *in-situ* digestibility data utilizing NDF from corn bran is a better indicator of the ruminal fiber fermentation environment across treatment diets. These results suggest that ruminal NDF digestion is improved as corn silage is increased in diet. In the assessment of the corn DMD data, there was an improvement in corn DMD as corn silage increased from 15 to 45% of the diet. This may be a function of ruminal pH. Diets containing 15% corn silage in comparison to 45% corn silage had lower ruminal pH and over 2 times greater time and area below a ruminal pH of 5.6. The reduction in corn bran NDFD as corn silage is decreased from 45 to 15% of the diet would explain a 0.8 percentage unit decrease in corn DMD assuming corn is 9% NDF (NRC, 1996). The rest of the difference in DMD between corn silage concentrations is unexplainable. When 95% corn silage was fed, corn DMD decreased substantially. The change in microbial community due to change in substrate may have caused the substantial decline in corn DMD when the 95:0 treatment diet was fed.

## Conclusions

Although feedlot performance was variable across experiments, corn silage and MDGS can replace corn in finishing diets. Data from these experiments suggest that feeding greater concentrations of corn silage (45% instead of 15%) in finishing diets containing distillers grains results in decreases in ADG and G:F. Increasing the concentration of corn silage in distillers grains diets results in increased ruminal pH and improvements in the rumen environment for enhanced fiber digestion.

## LITERATURE CITED

- Allen, M. S. 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. *J. Dairy Sci.* 80:1447–1462. doi:10.3168/jds.S0022-0302(97)76074-0
- AOAC. 1990. Official methods of analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.
- AOAC. 1999. Official methods of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.
- Benton, J. R., A. K. Watson, G. E. Erickson, T. J. Klopfenstein, K. J. Vander Pol, N. F. Meyer, and M. A. Greenquist. 2015. Effects of roughage source and inclusion in beef finishing diets containing corn wet distillers grains plus solubles. *J. Anim. Sci.* 93:4358-4367 doi: 10.2527/jas2015-9211
- Bremer, V. R. 2010. Distillers grains with solubles for feedlot cattle - finishing performance, lipid metabolism, and ethanol greenhouse gas balance. Ph.D Diss. Univ. of Nebraska. Lincoln, NE.

- 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 corn-ethanol-livestock life cycle. *Prof. Anim. Sci.* 27:449–455.
- Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrott. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. *J. Anim. Sci.* 68:1201–1207. doi:10.2527/1990.6851201x
- Burken, D. B., B. L. Nuttelman, J. L. Gramkow, A. L. McGee, K. M. Sudbeck, S. E. Gardine, T. C. Hoegemeyer, T. J. Klopfenstein, and G. E. Erickson. 2017. Effects of agronomic factors on yield and quality of whole corn plants and the impact of feeding high concentrations of corn silage in diets containing distillers grains to finishing cattle. *Transl. Anim. Sci.* 1:3. doi:10.2527/tas2017.0045
- Clark, P. W., and L. E. Armentano. 1993. Effectiveness of neutral detergent fiber in whole cottonseed and dried distillers grains compared with alfalfa haylage. *J. Dairy Sci.* 76:2644–2650. doi:10.3168/jds.S0022-0302(93)77600-6
- Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebke, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vaness, 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
- Danner, M. L., D. G. Fox, and J. R. Black. 1980. Effect of feeding system on performance and carcass characteristics of yearling steers, steer calves, and heifer calves. *J. Anim. Sci.* 50:394–404. doi:10.2527/jas1980.503394x
- DiCostanzo, A., C. M. Zehnder, H. Chester-Jones, D. Ziegler, and R. Greenwald. 1997. Effect of dietary com silage proportion on yearling steer performance and economic returns. *Univ. of MN, St. Paul, MN. B-442:14–20.*
- DiCostanzo, A., C. M. Zehnder, and H. Chester-Jones. 1998a. Economics of feeding com silage in feedlot diets. *Univ. of MN, St. Paul, MN. B-456:28–37.*
- DiCostanzo, A., C. M. Zehnder, J. M. Cassady, H. Chester-Jones, D. Ziegler, and R. Greenwald. 1998b. Effects of com silage hybrid or dietary proportion on yearling steer performance. *Univ. of MN, St. Paul, MN. B-451:l-5.*
- Ehrlich, G. G., D. F. Goerlitz, J. H. Bourell, G. V. Eisen, and E. M. Godsy. 1981. Liquid chromatographic procedure for fermentation product analysis in the identification of anaerobic bacteria. *Appl. Environ. Microbiol.* 33:955.
- Erickson, G. E. 2001. Designing beef feedlot nutrition programs to solve environmental challenges related to nitrogen and phosphorus. Ph.D. Diss. Univ. of Nebraska, Lincoln.
- ERS. 2014. U.S. domestic corn use. USDA, Economic Research Service. <http://www.ers.usda.gov/media/866543/cornuse-table.html>. (Accessed 12 September 2014.)
- Esdale, W. J., and L. D. Satter. 1972. Manipulation of ruminal fermentation IV. Effect of altering ruminal pH on volatile fatty acid production. *J. Dairy Sci.* 55:964–970. doi:10.3168/jds.S0022-0302(72)85603-0
- Firkins, J. L., A. N. Hristov, M. B. Hall, G. A. Varga, and N. R. St-Pierre. 2006. Integration of Ruminant Metabolism in Dairy Cattle. *J. Dairy Sci.* 89:E31–E51 (E-supplement). doi:10.3168/jds.S0022-0302(06)72362-1
- Galyean, M. L., and P. J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. *J. Anim. Sci.* 81:E8–E16.
- Galyean, M. 2009. The Home Page of Michael Galyean. NEM and NEg Calculations. <http://www.depts.ttu.edu/afs/home/mgalyean/>. (Accessed 14 October 2014.)
- Gill, D. R., J. R. Martin, and R. Lake. 1976. High, medium, and low corn silage diets with and without monensin for feedlot steers. *J. Anim. Sci.* 43:363–368. doi:10.2527/jas1976.432363x
- Goodrich, R. D., D. W. Crawford, M. L. Thonney, and J. C. Meiske. 1974. Influence of corn silage level on the performance and economic returns of steer calves. *MN Cattle Feeder Rep. Univ. of MN, St. Paul, MN. B-195:14–19.*
- 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.
- Hoover, W. H. 1986. Chemical Factors Involved in Ruminant Fiber Digestion. *J. Dairy Sci.* 69:2755–2766. doi:10.3168/jds.S0022-0302(86)80724-X
- 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
- Littell, R. C., P. R. Henry, and C. B. Ammerman. 1998. Statistical analysis of repeated measures data using the SAS procedures. *J. Anim. Sci.* 76:1216–1231. doi:10.2527/1998.7641216x
- Myers, W. D., P. A. Ludden, V. Navighug, 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. doi:10.2527/2004.821179x
- McGee, A. L. 2013. Effect of residue removal on subsequent year quality and quantity of corn residue and cattle performance while grazing corn residue at different stocking rates. M.S. Thesis. Univ. of Nebraska. Lincoln, NE.
- NRC. 1996. Nutrient Requirements of Beef Cattle, 7th ed. National Academy Press, Washington, DC.
- Penner, G. B., P. Yu, and D. A. Christensen. 2009. Effect of replacing forage or concentrate with wet or dry distillers' grains on the productivity and chewing activity of dairy cattle. *Anim. Feed Sci. Technol.* 153(1–2):1–10. doi:10.1016/j.anifeedsci.2009.05.006
- Peterson, L. A., E. E. Hatfield, and U. S. Garrigus. 1973. Influence of concentration of dietary energy on protein needs of growing-finishing cattle. *J. Anim. Sci.* 36:772–781. doi:10.2527/jas1973.364772x
- Preston, R. L. 1975. Net energy evaluation of cattle finishing rations containing varying proportions of com grain and com silage. *J. Anim. Sci.* 41:622–624. doi:10.2527/jas1975.412622x
- Stock, R., T. Klopfenstein, D. Brink, S. Lowry, D. Rock, and S. Abrams. 1983. Impact of weighting procedures ad variation in protein degradation rate on measured performance of growing lambs and cattle. *J. Anim. Sci.* 57:1276–1285. doi:10.2527/jas1983.571276x
- Terry, R. A., J. M. A. Tilley, and G. E. Outen. 1969. Effect of pH on cellulose digestion under in vitro conditions. *J. Sci. Food Agric.* 20:317–320. doi:10.1002/jsfa.2740200514
- USDA. 2016. United States Standards for Grades of Carcass Beef. <https://www.ams.usda.gov/sites/default/files/media/Carcass%20Beef%20Standard.pdf>. (Accessed 6 December 2016.)
- Vance, R. D., and R. L. Preston. 1971. Digestibility of whole shelled and crimped corn grain by growing, finishing steers. Summary 52:7-10. Ohio State Univ. Columbus, OH
- 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
- Vander Pol, K. J., G. E. Erickson, T. J. Klopfenstein, and M. A. Greenquist. 2005. Effect of level of wet distillers grains on feedlot performance of finishing cattle and energy value relative to corn. *J. Anim. Sci.* 83(Suppl. 2):55.

- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2
- Van Soest, P. J. and W. C. Marcus. 1964. Methods for the determination of cell wall constituents in forages using detergents and the relationship between this fraction and voluntary intake and digestibility. *J. Dairy Sci.* 47:704. (Abstr.).
- Watson, A. K., T. J. Klopfenstein, L. W. Lomas, G. E. Erickson, and B. L. Nuttelman. 2013. Limit feeding to decrease variation and increase accuracy of cattle weight. *J. Anim. Sci.* 91:5507–5517. doi:10.2527/jas.2013-6349
- Whittet, K. M., K. W. Creighton, K. J. Vander Pol, G. E. Erickson, and T. J. Klopfenstein. 2003. Influence of rinsing technique and sample size on *in situ* protein degradation. Univ. of Nebraska, Lincoln, NE. 80A:86–88.
- Zhang, S. Z., G. B. Penner, W. Z. Yang, and M. Oba. 2010. Effects of partially replacing barley silage or barley grain with dried distillers grains with solubles on rumen fermentation and milk production of lactating dairy cows. *J. Dairy Sci.* 93:3231–3242. doi:10.3168/jds.2009-3005