

Alkali addition and roughage inclusion effect on performance and carcass characteristics of feedlot steers fed diets containing 60% dried distillers grains with solubles

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ABSTRACT: Three experiments were conducted to determine the effectiveness of calcium hydroxide (Ca(OH)₂) addition and roughage inclusion on digestibility, performance, and carcass characteristics of steers fed 60% dried distillers grains with solubles (DGS). Statistical analyses for studies were conducted using the MIXED procedures of SAS. In experiment 1, 48 steers (353.5 ± 7.55 kg) were allotted to individual pens and fed 1 of 3 diets (dry matter [DM] basis) containing 60% dried DGS, 20% corn silage, and 4% supplement with: 1) 14.5% corn and no Ca(OH)₂; 2) 14% corn and 2% Ca(OH)₂; and 3) 14.5% additional corn silage and no Ca(OH)₂. Steers fed Ca(OH)₂ consumed the least ($P = 0.03$) and steers fed added corn silage consumed the most and had the least gain:feed ($P = 0.02$). Gain and carcass quality were not affected by treatment ($P \geq 0.48$). In experiment 2, 112 steers (375.3 ± 19.25 kg) were allotted to pens (four pens per treatment; seven steers per pen) arranged as a 2 × 2 factorial (roughage × Ca(OH)₂) and fed one of four diets (DM basis) containing 60% dried DGS, 17% corn silage, and 4% supplement with: 1) 17.5% corn silage and no Ca(OH)₂; 2) 17% corn silage and 2% Ca(OH)₂; 3) 17.25% corn stover and no Ca(OH)₂; and 4) 17% corn stover and 2% Ca(OH)₂. Added stover decreased

average daily gain (ADG) compared to added corn silage ($P = 0.04$). Ca(OH)₂ increased ADG when steers were fed stover, but not when steers were fed only corn silage ($P = 0.05$; interaction). In experiment 3, six ruminally cannulated steers (initial body weight = 352 ± 14.8 kg) were randomly allotted to a 6 × 6 Latin square design to determine the effects of roughage inclusion (corn, corn silage, stover) and Ca(OH)₂ addition (0% or 2%) on ruminal characteristics. Feeding stover decreased total volatile fatty acid(s) (VFA) concentration and DM digestibility compared to corn silage or corn ($P < 0.01$), whereas Ca(OH)₂ resulted in greater total VFA concentrations and DM digestibility ($P \leq 0.02$). Stover increased rate of DM degradation (K_d) and rate of particle outflow from the rumen ($P \leq 0.04$) but decreased extent of DM digestion and mean retention time ($P \leq 0.02$) compared to corn or silage. Ca(OH)₂ increased K_d ($P < 0.01$) and tended to increase ($P = 0.06$) liquid passage rate. In conclusion, added roughage did not improve performance of cattle fed 60% dried DGS. Ca(OH)₂ may decrease intake and maintain performance of cattle fed 60% dried DGS with corn silage as the roughage source and increases ADG when corn stover replaces a portion of the corn silage.

Key words: cattle, calcium hydroxide, digestibility, kinetics, roughage, rumen pH

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INTRODUCTION

Dietary inclusion of large amounts of distillers grains with solubles (DGS) increases ruminal and metabolic acid load post feeding (Felix and Loerch, 2011; Felix et al., 2012b) due to the sulfuric acid used in the production of DGS (McAloon et al., 2000). A decreased ruminal pH inhibits the ability of cellulolytic bacteria to attach to feed (Mould and Orskov, 1983) and impedes their growth, resulting in decreased amounts of cellulases present in the rumen (Hoover, 1986). Increased metabolic acidity can lead to catabolism of tissue protein for production of CO₂ and ammonium to buffer blood acidity (Heitmann and Bergman, 1980). Consequently, it is necessary to mitigate the effect of a greater acid load from DGS on fiber digestibility and metabolic acid–base balance. Ruminal pH can be controlled by the introduction of buffering compounds via saliva to the rumen through the process of ingesting feed and rumination (Owens, 1998). Salivary buffering is an important mechanism for removing the hydrogen ions present in an acidic ruminal environment (Owens, 1998), and added dietary roughage can stimulate salivation (Cassida and Strokes, 1986). Consequently, added dietary roughage could work to increase ruminal pH and buffering capacity in rations with large amounts DGS by increasing the amount of saliva present in the rumen. However, it is common in 90% concentrate-based feedlot diets without DGS that added roughage decreases gain (Ledoux et al., 1985; Gorocica-Buenfil and Loerch, 2005). Distillers grains contain large amounts of fiber which may enhance digestibility of added roughage through a positive associative effect on ruminal fermentation and result in improved gain. For example, Felix and Loerch (2011) reported that replacing a portion of dietary corn with alfalfa haylage in feedlot rations with 60% dried DGS enhanced salivary flow, increased minimum ruminal pH, and resulted in greater fiber digestibility, enhanced feedlot performance, and improved carcass characteristics. Similarly, Benton et al. (2015) reported that feeding 4% or 8% alfalfa hay or an neutral detergent fiber (NDF)

equivalent amount of corn silage or corn stover in rations containing 30% wet DGS resulted in increased average daily gain (ADG) compared to a basal diet without roughage. Thus, an objective of present study was to determine whether the potentially improved ruminal fiber digestibility in 60% DGS rations with greater roughage contents would result in improved animal growth.

Alkaline pretreatment of low quality roughages to enhance digestibility has been recognized for decades. Strong bases degrade a portion of the linkages between lignin and hemicellulose in fiber, thereby increasing availability of fiber carbohydrates for ruminal digestion. However, direct addition of alkali to the ration is less labor intensive and may improve fiber digestibility and performance of feedlot cattle just as effectively as alkaline pretreatment of roughages (Nunez et al., 2014; Duckworth et al., 2014). The mechanism by which direct addition of alkali to the ration improves fiber digestibility is unclear but may be either through increased ruminal pH or by disruption of the linkages between lignin and hemicellulose during the time before consumption of the diet. Nunez et al. (2014) demonstrated an increase in ruminal pH when CaO was added to 60% dried DGS diets of feedlot steers, whereas Boukila et al. (1995) reported a similar pH increase when Ca(OH)₂ or Mg(OH)₂ was added to barley-based rations of feedlot lambs. Increases in ruminal pH from dietary alkali addition increase fiber digestibility and feedlot performance (Duckworth et al., 2014; Nunez et al., 2014; Schroeder et al., 2014). Feeding diets that contain 60% DGS also depress animal growth, decrease urine pH, and result in increased urine volume (Felix et al., 2012b). Nunez et al. (2014) observed that alkali addition to 60% dried DGS diets increased urine pH, decreased urine volume, and decreased urine ammonia, which was indicative of an improved acid–base balance and protein synthesis in the animal. The hypothesis for present study was that the addition of Ca(OH)₂ or additional roughage to a 60% dried DGS feedlot ration would improve ruminal fiber digestibility, metabolic acid–base balance, and increase growth of feedlot cattle. Consequently, the objective of present study was

to examine the effects of Ca(OH)_2 or additional roughage in feedlot diets on steer performance, carcass quality, nitrogen balance, digestibility, and kinetics of digestion.

MATERIAL AND METHODS

Research protocols involving the use of animals followed guidelines set forth in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010) and were approved by the Purdue Animal Care and Use Committee. All studies were conducted at the Purdue University Animal Sciences Research and Education Center (ASREC).

Experiment 1

Animals and diets. Forty-eight Angus \times Simmental feedlot steers (average initial body weight [BW] = 353.5 ± 7.55 kg) were used to determine the effect of 2% calcium hydroxide (Ca(OH)_2), or added roughage (corn silage) on performance and carcass characteristics. Steers were weighed and allotted to one of three treatments (16 steers per treatment) by BW, breed composition, and sire. All diets contained 60% dried DGS,

20% corn silage, and 4% vitamin and mineral supplement and the remaining portion for treatments consisted of: 1) 14.5% corn and no Ca(OH)_2 (corn with no Ca(OH)_2); 2) 14% corn and 2% Ca(OH)_2 (corn with Ca(OH)_2); and 3) 14.5% additional corn silage and no Ca(OH)_2 (silage with no Ca(OH)_2). Diets are provided in Table 1. Diets were formulated to meet or exceed NRC (1996) requirements for protein, vitamins, and minerals of growing beef cattle. Ca(OH)_2 (StoverCal) was provided courtesy of Mississippi Lime (St. Louis, MO). Steers were fed in individual pens located in a curtain-sided, slatted floor finishing barn. Pens were 2.4×0.91 m and provided 0.61 m of bunk space per animal. Total mixed rations were delivered once daily at 0800 h and steers were allowed ad libitum access to feed and water. Daily feed delivery was adjusted using the South Dakota State University 4-point bunk scoring system (Pritchard, 1993) to allow for ad libitum access to feed and water with minimal accumulation of unconsumed feed. Feed delivery was recorded daily for each pen and feed refusals were weighed, recorded, and discarded weekly. Feed samples were collected every other week and dried in a forced air oven at 60 °C for 48 h. As-fed formulations were adjusted for dry matter (DM)

Table 1. Composition of diets (DM basis)

Experiment(s)	1,3		1,2,3		2,3	
	Corn		Silage		Stover	
	0% Ca(OH)_2	2% Ca(OH)_2	0% Ca(OH)_2	2% Ca(OH)_2	0% Ca(OH)_2	2% Ca(OH)_2
Dried DGS ¹	60.0	60.0	60.0	60.0	60.0	60.0
Corn silage	20.0	20.0	34.5	34.0	17.25	17.0
Corn	14.5	14.0	—	—	—	—
Stover	—	—	—	—	17.25	17.0
Supplement ²	4.0	4.0	4.0	4.0	4.0	4.0
Limestone	1.5	—	1.5	—	1.5	—
Ca(OH)_2	—	2.0	—	2.0	—	2.0
Nutrient composition ³						
Protein, %	23.3	23.3	23.2	23.2	22.8	22.8
NDF, %	33.2	33.1	37.2	37.0	41.9	41.6
ADF, %	11.6	11.6	14.5	14.4	18.0	17.8
NEm ⁴ , Mcal/kg	2.03	2.00	1.92	1.92	1.85	1.83
NEg ⁴ , Mcal/kg	1.19	1.17	1.10	1.10	1.04	1.04
Calcium, %	1.10	1.22	1.15	1.25	1.15	1.25
Phosphorus, %	0.70	0.69	0.68	0.68	0.66	0.66
Potassium, %	1.06	1.06	1.15	1.15	1.20	1.19
Sulfur, %	0.45	0.45	0.45	0.45	0.45	0.45

¹Dried DGS (distillers grains with solubles) contained (DM basis): 32.31% CP, 35.98% NDF, 10.38% ADF, 9.17% ether extract, 0.68% S (Iroquois Bio-Energy company, Rensselaer, IN).

²Vitamin and mineral premix contained (DM basis) 1.00% Ca, 0.45% Mg, 2.03% K, 0.25% S, 2.60 mg/kg Co, 252.56 mg/kg Cu, 2.63 mg/kg I, 96.78 mg/kg Fe, 572 mg/kg Mn, 6.32 mg/kg Se, 875.43 mg/kg Zn, 62.9 IU/g vitamin A, 7.48 IU/g vitamin D, 224 IU/kg vitamin E, 640.8 mg/kg monensin (Rumensin 80, Elanco Animal Health, Indianapolis, IN), and 198.4 mg/kg tylosin (Tylan 40, Elanco Animal Health).

³Analyzed by Sure-Tech Laboratories, Richmond, IN.

⁴Calculated based on feed analyses (NRC, 1996).

content accordingly every other week. Dried feed samples were ground using a standard Wiley laboratory mill (1-mm screen; Arthur H. Thomas, Philadelphia, PA), and composited at the end of the experiment for analysis of crude protein (CP; micro-Kjeldahl $N \times 6.25$; method 960.52; AOAC, 2006), ether extract (method 920.39; AOAC, 2006), and minerals (Ca, P, Mg, K, S; method 968.08; AOAC, 2006). The neutral detergent fiber (NDF) was determined using an ANKOM Fiber Analyzer (ANKOM Technology Corp., Fairport, NY) based on the procedure of AOAC (2006, method 2002.04) using heat-stable α -amylase (Termamyl 120 L, Type L, Novozymes A/S) and sodium sulfite, and acid detergent fiber (ADF) was determined based on AOAC (2006, method 973.18) with modifications to each procedure for use in an ANKOM Fiber Analyzer.

Steers were vaccinated against bovine rhinotracheitis, bovine viral diarrhea, parainfluenza-3, and bovine respiratory syncytial virus (Bovi-Shield GOLD FP 5; Zoetis Animal Health, Florham Park, NJ), against *Haemophilus somnus*, *Pasturella*, and *Clostridia* (Vision-7 Somnus; Merck Animal Health, Summit, NJ), and treated with an anthelmintic (Valbazen; Zoetis Animal Health) for internal and external parasites at weaning and at the initiation of the study. Steers were implanted with Revalor-XS (40 mg estradiol and 200 mg trenbolone acetate; provided courtesy of Merck Animal Health) at feedlot entry.

Growth performance and carcass characteristics measurements. Steers were weighed on 2 consecutive days at the initiation and termination of the study for the determination of initial and final BW. During the experiment, steers were weighed monthly to monitor ADG. BWs were taken before feeding. Scales (Tru-Test XR3000; Mineral Wells, TX) weighed to the nearest 0.9 kg (< 453.6 kg) or 2.3 kg (> 453.6 kg) and were checked for accuracy at each weigh date. ADG was determined by the difference between final and initial BW divided by the number of days on feed. Dry matter intake (DMI) was recorded and used to calculate gain:feed by dividing ADG by DMI. Feedlot performance of the steers was calculated for d 0 to 84 (period 1), d 85 to slaughter (period 2), and d 0 to slaughter (overall). Steers were transported 400 km to a United States Department of Agriculture (USDA) inspected commercial packing facility (Tyson Foods, Joslin, IL) and were slaughtered when individuals achieved a target BW of approximately 625 kg. Hot carcass weight and dressing percentage were determined after slaughter and

before chilling. After carcasses were chilled for 24 h, the following measurements were obtained by qualified university personnel: subcutaneous fat thickness taken between the 12th and 13th ribs, longissimus muscle (LM) area obtained by direct grid reading of the LM between the 12th and 13th ribs, internal fat (kidney, pelvic, and heart fat; % KPH) as a percentage of hot carcass weight, marbling score, and USDA quality and yield grades (USDA, 1997).

Statistical analysis Data were analyzed as a completely randomized design using the mixed procedure of SAS (version 9.3, SAS Inst. Inc., Cary, NC) with individual considered the experimental unit. Random effects of individual and the fixed effect of treatment, day, as well as the treatment \times day interaction were included in the model. Performance was analyzed as repeated measures by comparing four covariance structures for each variable (compound symmetric, autoregressive order one, heterogeneous autoregressive order one, and unstructured). The covariance structure that yielded the lowest Bayesian information criterion was used for presented results. Carcass characteristics and overall performance were analyzed using MIXED procedure of SAS as a randomized design and the model included the random effects of pen, and the fixed effect of treatment. Treatment comparisons were made using Fisher's protected least significant difference, and the least square means statement was used to calculate adjusted means. The SLICE function of SAS was used to determine simple effects within time for repeated measures. Simple effects within day are what is presented in the results section. Quality grade percentages were analyzed as binary data using the GLIMMIX procedures of SAS. Statistical significance was determined when $P \leq 0.05$ and tendencies were discussed when $0.05 < P \leq 0.10$.

Experiment 2

Animals and diets. One hundred and twelve Angus \times Simmental steers (average initial BW = 375.1 ± 19.1 kg) were obtained from Feldun Purdue Agriculture Center and transported 290 km to Purdue University ASREC to determine the effects of $\text{Ca}(\text{OH})_2$ addition and stover inclusion on feedlot performance and carcass characteristics of steers fed a 60% dried DGS diet. Steers were weighed, blocked (heavy and light), and allotted by BW, breed composition, and sire to one of four treatments arranged as a 2×2 factorial. All diets contained 60% dried DGS, 17% corn silage,

and 4% vitamin and mineral supplement with the remaining portion for treatments consisting of: 1) 17.5% additional corn silage without $\text{Ca}(\text{OH})_2$ (silage with no $\text{Ca}(\text{OH})_2$); 2) 17% additional corn silage and 2% $\text{Ca}(\text{OH})_2$ (silage with $\text{Ca}(\text{OH})_2$); 3) 17.25% corn stover, 0.25% corn silage, and no $\text{Ca}(\text{OH})_2$ (stover with no $\text{Ca}(\text{OH})_2$); and 4) 17% corn stover and 2% $\text{Ca}(\text{OH})_2$ (stover with $\text{Ca}(\text{OH})_2$). Corn stover was harvested at approximately 80% DM after dry corn harvest. Corn stover was chopped in a windrow and then harvested using a silage chopper equipped with a flail header and stored in an air-tight silage bag (Up North, Cottage Grove, MN) until the initiation of the experiment. Steers were allotted to 16 pens (7 steers per pen, 4 pens per treatment, 28 steers per treatment) located in a curtain-sided, slatted-floor finishing barn. Pen dimensions were 6.1×3.7 m and provided 0.51 m of bunk space per animal. Diets, shown in Table 1, were formulated to meet or exceed NRC (1996) requirements for protein, vitamins, and minerals of growing beef cattle. $\text{Ca}(\text{OH})_2$ (StoverCal) was provided courtesy of Mississippi Lime (St. Louis, MO). Feed delivery, bunk management, diet sampling, and vaccination protocol were the same as those used in experiment 1. Steer BW, ADG, DMI, and gain:feed were determined as in experiment 1 and were calculated for d 0 to 65 (period 1), d 66 to slaughter (period 2), and d 0 to slaughter (overall). Steers were slaughtered at a commercial packing facility (Tyson Foods, Joslin, IL) at four different time points (112, 142, 155, and 184 d on feed) according to when an average pen BW of approximately 628 kg was achieved. Carcass characteristics were determined as in experiment 1.

Statistical analysis Data were analyzed as a randomized block design using the mixed procedure of SAS with pen considered the experimental unit. Random effects of pen and the fixed effects of stover inclusion, $\text{Ca}(\text{OH})_2$ addition, day, and the interactions of stover inclusion and $\text{Ca}(\text{OH})_2$ addition, stover inclusion and day, $\text{Ca}(\text{OH})_2$ addition and day, and stover inclusion, $\text{Ca}(\text{OH})_2$ addition and day were included in the model. The SLICE function of SAS was used to determine simple effects within time for repeated measures. Simple effects within day are what is presented in the Results section. Performance was analyzed as repeated measures by comparing four covariance structures for each variable (compound symmetric, autoregressive order one, heterogeneous autoregressive order one, and unstructured). The covariance structure that yielded the lowest Bayesian information criterion was used for presented results.

Carcass characteristics and overall performance were analyzed using MIXED procedure of SAS as a randomized block design and the model included the random effects of pen, and the fixed effect of stover inclusion, $\text{Ca}(\text{OH})_2$ addition, and the interactions of stover inclusion and $\text{Ca}(\text{OH})_2$ addition. Treatment comparisons were made using Fisher's protected least significant difference, and the least square means statement was used to calculate adjusted means. Statistical significance was determined when $P \leq 0.05$ and tendencies were discussed when $0.05 < P \leq 0.10$.

Experiment 3

Animals and diets. Six ruminally cannulated Angus \times Simmental steers (average initial BW = 352 ± 14.8 kg) were used to determine of the effects of $\text{Ca}(\text{OH})_2$ addition and roughage inclusion on ruminal pH, volatile fatty acid(s) (VFA) concentration, apparent digestibility, digestion kinetics, and nitrogen balance. Steers were fistulated approximately 4 months before the start of the study. Steers were previously adapted to a 60% dried DGS finishing diet and then allotted to a 6×6 Latin square design balanced for carry over effects, such that each experimental diet followed a different diet for each respective period. All dietary treatments contained 60% dried DGS and varied in roughage inclusion and $\text{Ca}(\text{OH})_2$ addition (Table 1) and were used previously in experiments 1 and 2. Six dietary treatments were used, arranged as a 2×3 factorial. Diets contained 60% dried DGS, 17% corn silage, and 4% vitamin and mineral supplement with: 1) 14.5% corn, 3% additional corn silage without $\text{Ca}(\text{OH})_2$ (corn with no $\text{Ca}(\text{OH})_2$); 2) 14% corn, 3% additional corn silage, and 2% $\text{Ca}(\text{OH})_2$ (corn with $\text{Ca}(\text{OH})_2$); 3) 17.5% additional corn silage without $\text{Ca}(\text{OH})_2$ (silage with no $\text{Ca}(\text{OH})_2$); 4) 17% additional corn silage with 2% $\text{Ca}(\text{OH})_2$ (silage with $\text{Ca}(\text{OH})_2$); 5) 0.25% additional corn silage, 17.25% corn stover, without $\text{Ca}(\text{OH})_2$ (stover with no $\text{Ca}(\text{OH})_2$); and 6) 17% corn stover and 2% $\text{Ca}(\text{OH})_2$ (stover with $\text{Ca}(\text{OH})_2$). The experimental periods were 21 d, which was composed of a 16 d adaptation to the respective diet and 5 d of sampling.

Steers were housed individually in 3.0×9.1 m outdoor pens of a three-sided barn with concrete floors covered with wood chips for the first 14 d of each period. On d 15, steers were moved into a climate controlled room with temperatures maintained between 17 °C and 21 °C and continuous lighting. Steers were individually housed in $1.0 \times$

2.0 m tie stalls equipped with rubber mats. The individual tie stalls were designed for total urine and fecal collections. Each respective ration was mixed individually and delivered once daily at 0800 h and steers were allowed ad libitum access to feed and water. Feed delivery, bunk management, diet sampling, and vaccination protocol were the same as those used in experiments 1 and 2.

Sampling. On d 17 of each period, 100 g of Cr-mordanted stover and a pulse dose of 200 mL of a solution containing 10 g of Co-EDTA, both prepared according to Uden et al. (1980), were administered into the rumen through the cannula before the morning feeding. Fecal grab samples were collected from the rectum at h 0, 12, 18, 24, 36, 48, 60, 72, 84, and 96 after dosing. Feces were weighed and homogenized and dried in a forced air oven at 60 °C for 48 h and milled through a 1-mm screen. Dried fecal grab samples were stored at room temperature for later analysis of Cr content. Rumen contents were collected via the rumen cannula at 1.5, 3, 6, 9, 12, 18, 24, 36, 48, 72, 84, and 96 h after dosing. Rumen fluid was strained through two layers of cheesecloth and pH was immediately measured and recorded using a pH meter (VWR sympHony SB70P benchtop pH meter with glass combination pH electrode, VWR International, LLC, Batavia, IL). Rumen fluid was then placed in a 50 mL conical tube, immediately capped to prevent volatilization and placed in -20 °C freezer and stored for later analysis of VFA and Co concentrations.

On d 17 of periods 4, 5, and 6, nylon bags (40- μ m pore size) containing 10 g of DM of each individual dietary feed ingredient (except supplement) were placed in the rumen to achieve 0, 3, 6, 9, 12, 18, 24, 48, 72, 96 h of incubation. Feeds were ground in a Wiley mill through a 2-mm screen and bags were placed in the rumen in reverse order such that the greatest incubation time (96 h) was placed first and the shortest incubation time (3 h) was placed last; all bags were removed at h 96. After removal, bags were immediately submerged, rinsed six times in cold water, and dried at 60 °C for 48 h. Weight of the residue was determined after drying. The 0 h incubation samples were washed in the same way but were not incubated in the rumen.

Feces were collected in metal pans built into the floor at the tail end of the tie stall and total output was determined every 24 h for d 17 to 21. A subsample of total feces was collected each day and stored for later analysis of DM, CP, NDF, ADF, and ash content as described previously. Total daily urine production was also collected during the 24 h periods on days 17 to 21 of each respective period.

Total urinary output was collected into metal pans built into the floor in the middle of the tie stall. The metal collection pans were sloped to one side where there was an output hole, allowing urine to flow into a plastic collection container below. One hundred milliliter of a 3 N HCl solution was added to the plastic collection bins before urinary collection to acidify the urine and avoid N volatilization and a subsample of the total urine was stored in a 50 mL conical tube at -20° until analysis of N.

Chemical analysis. For VFA analysis, ruminal fluid samples were thawed, centrifuged at 12,000 \times g for 20 min, filtered through a 0.45- μ filter, then shell frozen and freeze-dried after addition of 8% sodium hydroxide. Volatile fatty acids (VFAs) were extracted from the freeze-dried ruminal fluid, derivatized as butyl esters, and quantified on a gas chromatograph equipped with a flame ionization detector (Model 7890A; Agilent Technologies, Santa Clara, CA) according to Salanitro and Muirhead (1975). For Co and Cr analysis, approximately 250 mg of freeze-dried rumen fluid and dried feces were solubilized in a solution containing 5 mL of nitric acid, heated at 100 °C, then diluted in distilled water. Rumen fluid was analyzed for Co and feces and mordanted stover were analyzed for Cr using inductively coupled plasma mass spectrometry (Optima 5300-DV; PerkinElmer, Waltham, MA). Feces were analyzed for DM, CP, NDF, and ADF as described previously in experiments 1 and 2 and for organic matter (OM), which was calculated as the difference between DM and ash content (AOAC, 2006). Urine samples were analyzed for total N (block digestion followed by steam distillation), and ammonia N (steam distillation) using a Kjeltec 2300 micro-Kjeldahl Analyzer Unit (Foss Tecator, AB, Foss North America). Urinary urea output was calculated as the difference between total N output and ammonia N output. Before feeding and acidification of urine, fresh urine was collected and used to determine urine pH using the previously described pH meter.

Calculations. Digestibility of the diets was determined using the following equation:

$$\left[\frac{\text{nutrient in feed} - \text{nutrient in feces}}{\text{nutrient in feed}} \right] * 100$$

Solid passage rate was determined by plotting concentrations of Cr in feces against the time of collection after dosing the marker and fitting the generated fecal marker excretion curve using the procedure proposed by Grovum and Williams (1973a,b) based on the model of Blaxter et al. (1956). This model has two pools within the gastrointestinal tract with

longer and shorter retention times, respectively, and a tubular compartment corresponding to the omasum, small intestine, and distal part of the large intestine. The model is defined as follows:

$$\text{if } t > TT, \text{ then } Y = Ae^{-k_1(t-TT)} - Ae^{-k_2(t-TT)},$$

else $Y = 0$, where Y is Cr concentration in feces (mg/kg of fecal DM); A is a scale parameter; the irrational constant e is the base of the natural logarithm; k_1 (h^{-1}) is the fractional outflow rate from the reticulorumen (the smaller rate constant for the pool with a longer retention time); k_2 (h^{-1}) is the fractional outflow rate from the hindgut (the larger rate constant for the pool with a shorter retention time); and TT (h) represents the transit time through the omasum, small intestine, and distal part of the large intestine and can be considered the minimum time taken by a particle to transit between the point of its introduction and sampling. The time between marker dosage and feces collection is represented by t (h). Transit time and mean retention time of solids were estimated according to Grovum and Phillips (1973). Liquid passage rate (k_L , h^{-1}) was calculated by fitting a linear regression to the natural logarithm of Co concentration in the rumen liquid (mg/L) against sampling time (h), according to the method of Warner and Stacy (1968).

Ruminal DM degradation data of diets were calculated using individual in situ residue weights from individual feed ingredients. Degradation data of diets were fitted to the modified first-order kinetics equation with lag time to determine rate and extent of feed degradation (Ørskov and McDonald 1979; Robinson et al. 1986):

$$R(t) = U + D(-Kd^*(t-T_0))$$

where $R(t)$ is the residue of the incubated material after t h of rumen incubation (g), U is the undegradable fraction (%), D is the potentially degradable fraction (%), T_0 is the lag time (h), and k_d is the degradation rate (%/h). Effective degradability (ED; g/kg) of DM was determined using the nonlinear parameters (U , D , and k_d) calculated by the earlier equation and also the following equation:

$$ED = S + D * \left[\frac{Kd}{Kp + Kd} \right]$$

where S is the soluble fraction (%) as determined by the samples incubated for 0 h and k_p is the rate of passage fixed at 3.0% according to Ørskov and McDonald (1979). A nonlinear regression method

of SAS (SAS Inst., Inc., Cary, NC) was used to estimate degradability coefficients.

Statistical analysis Data were analyzed as a 6×6 Latin square design utilizing the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with steer within period considered the experimental unit. Repeated measures were used to analyze the data. For rumen pH and VFA concentrations, the model included the random effects of steer and period and fixed effects of the time of collection, Ca(OH)_2 addition, roughage inclusion, and the interactions between time of collection and Ca(OH)_2 addition, between time of collection and roughage inclusion, and between time of collection, roughage inclusion and Ca(OH)_2 addition. For digestibility, rate and extent of digestion, and passage rates, the model included the random effects of steer and fixed effects of Ca(OH)_2 addition, roughage inclusion, and the interactions between period and Ca(OH)_2 addition, between period and roughage inclusion, and between period, Ca(OH)_2 addition, and roughage inclusion. Four covariance structures were tested for each variable (compound symmetric, autoregressive order one, heterogeneous autoregressive order one, and unstructured) and the covariance structure that yielded the lowest Bayesian information criterion was used for the presented results. Treatment comparisons were made using Fisher's protected least significant difference, and the least square means statement was used to calculate adjusted means. The SLICE function of SAS was used to determine simple effects within time for repeated measures. Differences were considered statistically significant when $P \leq 0.05$ and tendencies were discussed when $0.05 < P \leq 0.10$.

RESULTS

Experiment 1

Performance data for experiment 1 are summarized in Table 2. BW and ADG of steers did not differ among treatments throughout the study ($P \geq 0.35$). Days on feed for steers did not differ among treatments ($P = 0.24$). DMI tended to be least for steers fed corn with Ca(OH)_2 during period 1 ($P = 0.09$) and was greatest for steers fed silage with no Ca(OH)_2 during period 2 ($P = 0.01$). As a result, overall DMI was greatest for steers fed silage with no Ca(OH)_2 and least for steers fed corn with Ca(OH)_2 ($P = 0.03$). Steers fed corn with no Ca(OH)_2 had an intermediate overall DMI that did not differ from steers fed corn with Ca(OH)_2 or

from steers fed silage with no $\text{Ca}(\text{OH})_2$. Gain:feed of steers did not differ among treatments for period 1 ($P = 0.17$). However, period 2 gain:feed was least for steers fed silage with no $\text{Ca}(\text{OH})_2$ ($P = 0.02$),

resulting in overall gain:feed that was least for steers fed silage with no $\text{Ca}(\text{OH})_2$ ($P = 0.02$).

Carcass characteristics for experiment 1 are presented in Table 3. Hot carcass weight, fat thickness,

Table 2. Effect of $\text{Ca}(\text{OH})_2$ or added corn silage on performance of steers fed 60% distillers grains (experiment 1)

	Treatments ¹			SEM	P
	Corn		Silage		
	0% $\text{Ca}(\text{OH})_2$	2% $\text{Ca}(\text{OH})_2$	0% $\text{Ca}(\text{OH})_2$		
n	16	16	16		
Weight, kg					
Day 0	350.1	350.6	350.6	7.49	0.99
Day 84	496.3	490.5	494.0	7.49	0.86
Day 167	629.0	623.2	623.5	7.49	0.83
ADG, kg					
Period 1	1.75	1.67	1.71	0.059	0.67
Period 2	1.62	1.51	1.56	0.059	0.35
Overall	1.68	1.58	1.62	0.059	0.48
DMI, kg/d					
Period 1	8.2 ^x	7.5 ^y	8.2 ^x	0.26	0.09
Period 2	10.6 ^a	10.2 ^a	11.6 ^b	0.26	0.01
Overall	9.4 ^{ab}	8.9 ^a	9.8 ^b	0.26	0.03
Gain:feed, kg/kg					
Period 1	0.213	0.224	0.211	0.0051	0.17
Period 2	0.153 ^a	0.148 ^a	0.134 ^b	0.0051	0.02
Overall	0.180 ^a	0.179 ^a	0.165 ^b	0.004	0.02
Days on feed	165.8	173.1	169.1	3.03	0.24

^{ab}Values within row with different superscripts differ ($P \leq 0.05$)

^{xy}Values within row with different superscripts differ ($P \leq 0.10$)

¹All treatment diets contained 60% dried DGS, 20% corn silage and a 4% vitamin and mineral supplement and the remaining portion for treatments consisted of: 1) 14.5% corn and no $\text{Ca}(\text{OH})_2$ (corn with no $\text{Ca}(\text{OH})_2$); 2) 14% corn and 2% $\text{Ca}(\text{OH})_2$ (corn with $\text{Ca}(\text{OH})_2$); and 3) 14.5% additional corn silage and no $\text{Ca}(\text{OH})_2$ (silage with no $\text{Ca}(\text{OH})_2$).

Table 3. Effect of $\text{Ca}(\text{OH})_2$ or added corn silage on carcass characteristics of steers fed 60% distillers grains (experiment 1)

	Treatments ¹			SEM	P
	Corn		Silage		
	0% $\text{Ca}(\text{OH})_2$	2% $\text{Ca}(\text{OH})_2$	0% $\text{Ca}(\text{OH})_2$		
n	16	16	16		
Hot carcass weight, kg	387.2	390.0	382.5	5.44	0.62
Dressing percent	61.6 ^a	62.6 ^b	61.4 ^a	0.31	0.01
Fat thickness, cm	1.24	1.40	1.42	0.122	0.50
LM area, cm ²	81.6	81.4	80.3	1.14	0.68
Kidney, pelvic, heart fat, %	1.97	1.97	2.00	0.052	0.89
Yield grade	3.3	3.5	3.6	0.16	0.57
Marbling score ²	367.5	350.0	363.8	11.23	0.52
Quality grade					
Select, %	6.3	12.5	6.3	7.10	0.77
Choice, %	81.3	75.0	75.0	10.83	0.90
Choice ^o , %	12.5	12.5	18.8	9.08	0.85

^{ab}Values within a row with different superscripts differ ($P \leq 0.05$)

¹All treatment diets contained 60% dried DGS, 20% corn silage and a 4% vitamin and mineral supplement and the remaining portion for treatments consisted of: 1) 14.5% corn and no $\text{Ca}(\text{OH})_2$ (corn with no $\text{Ca}(\text{OH})_2$); 2) 14% corn and 2% $\text{Ca}(\text{OH})_2$ (corn with $\text{Ca}(\text{OH})_2$); and 3) 14.5% additional corn silage and no $\text{Ca}(\text{OH})_2$ (silage with no $\text{Ca}(\text{OH})_2$).

²Practically devoid = 100 to 199; slight = 200 to 299; small = 300 to 399; modest = 400 to 499; moderate = 600 to 699.

LM area, % KPH, yield grade, marbling score, and quality grade of steers did not differ among treatments ($P \geq 0.50$). Dressing percentage was greatest for steers fed corn with Ca(OH)_2 ($P = 0.01$).

Experiment 2

Performance data for experiment 2 are presented in Table 4. No differences in steer BW were detected for stover inclusion or Ca(OH)_2 addition and the two variables did not interact for BW throughout the study ($P \geq 0.64$). Stover inclusion decreased ($P = 0.04$) and Ca(OH)_2 addition increased ($P = 0.02$) ADG in period 1. In addition, an interaction ($P = 0.01$) for ADG occurred in period 1 where Ca(OH)_2 addition improved gain by 19.4% in steers fed stover but did not affect gain in cattle fed only corn silage. Inclusion of stover tended to decrease ADG in period 2 ($P = 0.08$). An interaction ($P = 0.05$) for overall ADG occurred where Ca(OH)_2 addition improved gain by 9.3% in steers fed stover but did not affect gain in cattle fed only corn silage. No differences were detected for days on feed among treatments ($P \geq 0.45$). No differences were detected for DMI throughout the study

($P \geq 0.23$) for Ca(OH)_2 addition or stover inclusion. In period 1, gain:feed was increased for steers fed Ca(OH)_2 ($P = 0.05$) and was not affected by stover inclusion ($P = 0.19$). No differences were noted in period 2 gain:feed measures ($P \geq 0.30$) for Ca(OH)_2 addition or stover inclusion. Overall gain:feed was greatest for steers fed only corn silage ($P = 0.01$) and was not affected by Ca(OH)_2 addition ($P = 0.17$).

Data for carcass characteristics of steers from experiment 2 are shown in Table 5. No differences were detected for stover inclusion, Ca(OH)_2 addition, nor was there an interaction between the two for hot carcass weight, dressing percentage, fat thickness, LM area, % KPH, yield grade, or marbling score ($P \geq 0.15$). A higher percentage of animals graded Choice average with Ca(OH)_2 addition ($P = 0.10$); however, no other differences were detected for quality grade distribution ($P \geq 0.33$).

Experiment 3

When corn stover served as the roughage source, ruminal pH was increased ($P \leq 0.04$) at 0, 9, 12, and 18 h post-feeding and tended ($P = 0.08$) to be increased at 6 h (Figure 1). Ca(OH)_2 addition tended

Table 4. Effect of Ca(OH)_2 and corn stover addition on steer performance (experiment 2)

	Treatments ¹				SEM	P-value		
	No Stover		Stover			Roughage ²	Alkali ³	R × A ⁴
	0% Ca(OH)_2	2% Ca(OH)_2	0% Ca(OH)_2	2% Ca(OH)_2				
<i>n</i>	28	28	28	28				
Weight, kg								
Day 0	371.6	371.2	372.2	373.1	19.08	0.95	0.99	0.99
Day 65	500.2	499.1	481.0	503.0	21.55	0.73	0.64	0.88
Day 153	627.1	626.2	629.5	629.4	6.62	0.68	0.94	0.98
ADG, kg								
Period 1	1.98 ^a	1.97 ^a	1.67 ^b	2.00 ^a	0.063	0.04	0.02	0.01
Period 2	1.53	1.56	1.45	1.44	0.054	0.08	0.90	0.33
Overall	1.74 ^a	1.74 ^a	1.55 ^b	1.70 ^a	0.050	0.04	0.15	0.05
DMI, kg/d								
Period 1	9.6	9.3	9.0	10.0	0.34	0.94	0.25	0.25
Period 2	11.5	12.1	11.6	11.9	0.34	0.87	0.23	0.64
Overall	10.6	10.8	10.5	11.1	0.34	0.84	0.32	0.72
Gain:feed, kg/kg								
Period 1	0.199	0.217	0.209	0.221	0.0075	0.37	0.05	0.19
Period 2	0.134	0.129	0.126	0.121	0.0075	0.30	0.55	0.69
Overall	0.163	0.161	0.148	0.154	0.0028	0.01	0.52	0.17
Days on feed	148.3	148.3	166.3	152.9	14.35	0.45	0.65	0.65

¹All treatment diets contained 60% dried DGS, 17% corn silage and 4% vitamin and mineral supplement with the remaining portion for treatments consisting of: 1) 17.5% additional corn silage without Ca(OH)_2 (silage with no Ca(OH)_2); 2) 17% additional corn silage and 2% Ca(OH)_2 (silage with Ca(OH)_2); 3) 17.25% corn stover, 0.25% corn silage, and no Ca(OH)_2 (stover with no Ca(OH)_2); and 4) 17% corn stover and 2% Ca(OH)_2 (stover with Ca(OH)_2).

²Effect of stover inclusion

³Effect of Ca(OH)_2 addition

⁴Roughage inclusion × Ca(OH)_2 addition

Table 5. Effect of $\text{Ca}(\text{OH})_2$ and corn stover addition on carcass characteristics of steers (experiment 2)

	Treatments ¹				SEM	<i>P</i> -value		
	No Stover		Stover			Roughage ²	Alkali ³	R x A ⁴
	0% $\text{Ca}(\text{OH})_2$	2% $\text{Ca}(\text{OH})_2$	0% $\text{Ca}(\text{OH})_2$	2% $\text{Ca}(\text{OH})_2$				
<i>n</i>	28	28	28	28				
Hot carcass weight, kg	387.1	392.4	383.2	389.3	4.94	0.48	0.27	0.94
Dressing percent	61.7	62.4	60.9	61.9	0.55	0.23	0.15	0.82
Fat thickness, cm	1.37	1.35	1.14	1.45	0.178	0.68	0.45	0.37
LM area, cm ²	85.2	85.6	84.6	84.6	1.10	0.47	0.89	0.85
Kidney, pelvic, heart fat, %	1.98	1.97	1.98	2.02	0.024	0.31	0.68	0.27
Yield grade	3.3	3.3	3.0	3.4	0.21	0.78	0.41	0.38
Marbling score ⁵	361.8	373.6	371.2	369.2	19.41	0.90	0.81	0.73
Quality grade								
Select, %	28.6	10.7	26.2	25.0	9.39	0.54	0.33	0.39
Choice ⁻ , %	50.0	53.6	47.6	44.0	10.75	0.59	0.98	0.75
Choice ^o , %	7.1	35.7	14.9	23.2	10.25	0.82	0.10	0.34
Choice ⁺ , %	10.7	0.0	11.3	7.7	9.09	0.68	0.48	0.72
Prime, %	3.6	0.0	0.0	0.0	1.79	0.34	0.34	0.34

¹All treatment diets contained 60% dried DGS, 17% corn silage and 4% vitamin and mineral supplement with the remaining portion for treatments consisting of: 1) 17.5% additional corn silage without $\text{Ca}(\text{OH})_2$ (silage with no $\text{Ca}(\text{OH})_2$); 2) 17% additional corn silage and 2% $\text{Ca}(\text{OH})_2$ (silage with $\text{Ca}(\text{OH})_2$); 3) 17.25% corn stover, 0.25% corn silage, and no $\text{Ca}(\text{OH})_2$ (stover with no $\text{Ca}(\text{OH})_2$); and 4) 17% corn stover and 2% $\text{Ca}(\text{OH})_2$ (stover with $\text{Ca}(\text{OH})_2$).

²Effect of stover inclusion

³Effect of $\text{Ca}(\text{OH})_2$ addition

⁴Roughage inclusion × $\text{Ca}(\text{OH})_2$ addition

⁵Practically devoid = 100 to 199; slight = 200 to 299; small = 300 to 399; modest = 400 to 499; moderate = 600 to 699.

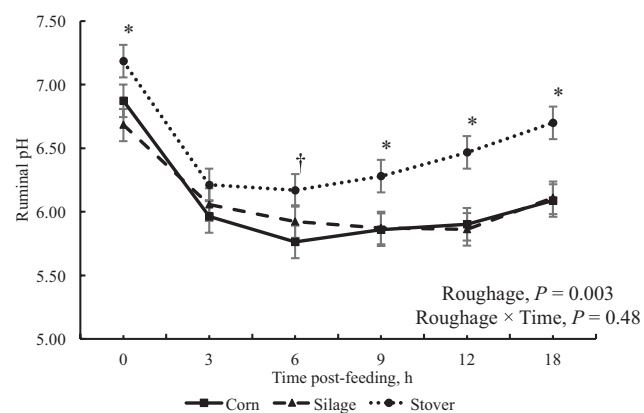


Figure 1. Effect of roughage inclusion on ruminal pH (experiment 3); *n* = 6. *Differences in ruminal pH due to roughage inclusion ($P \leq 0.05$). At 0, 9, 12, and 18 h post-feeding, corn stover inclusion increased ruminal pH, whereas corn silage inclusion resulted in a ruminal pH similar to that of steers fed corn. †Differences in ruminal pH due to roughage inclusion ($0.05 \leq P \leq 0.10$). At 6 h post-feeding corn stover inclusion tended to increase ruminal pH.

($P = 0.06$) to decrease ruminal pH at 18 h but had no effect ($P \geq 0.29$) at any other time point (Figure 2). An interaction between roughage source and $\text{Ca}(\text{OH})_2$ addition was detected at 12 and 18 h post-feeding ($P \leq 0.01$). At 12 h post-feeding, $\text{Ca}(\text{OH})_2$ addition to rations with stover decreased ruminal pH but had no impact in corn and silage diets. At 18 h, $\text{Ca}(\text{OH})_2$ addition to silage and stover diets decreased ruminal pH but had no effect in corn diets.

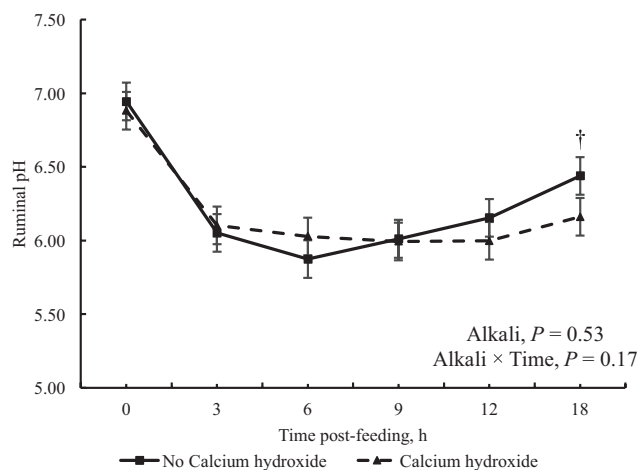


Figure 2. Effect of $\text{Ca}(\text{OH})_2$ addition on ruminal pH (experiment 3); *n* = 6. †Differences in ruminal pH due to $\text{Ca}(\text{OH})_2$ addition ($0.05 \leq P \leq 0.10$). At 18 h post-feeding addition of $\text{Ca}(\text{OH})_2$ tended to increase ruminal pH.

Ruminal VFA data for experiment 3 are summarized in Table 6. No interactions between roughage inclusion and $\text{Ca}(\text{OH})_2$ addition were detected for any VFA parameter ($P \geq 0.12$). Total ruminal VFA concentrations (mM) were greatest for steers fed corn silage, intermediate for steers fed corn, and least for steers fed corn stover ($P < 0.01$). Total VFA concentrations were also greater for steers fed rations with $\text{Ca}(\text{OH})_2$ ($P < 0.0001$). Ruminal concentrations of formate were not affected by

Table 6. Effect of Ca(OH)₂ and roughage inclusion on ruminal volatile fatty acids (experiment 3)

	Treatments ¹						SEM	<i>P</i> -value		
	Corn		Silage		Stover			Roughage ²	Alkali ³	R x A ⁴
	0% Ca(OH) ₂	2% Ca(OH) ₂	0% Ca(OH) ₂	2% Ca(OH) ₂	0% Ca(OH) ₂	2% Ca(OH) ₂				
<i>n</i>	6	6	6	6	6	6				
Total VFA, mM	100.8	129.2	118.7	131.4	91.9	117.5	4.03	< 0.0001	< 0.0001	0.12
Formate, mM	0.90	1.15	0.89	1.02	1.50	1.02	1.504	0.44	0.86	0.29
Acetate, mM	49.9	69.1	60.8	72.0	50.7	65.0	4.38	0.14	< 0.001	0.65
Propionate, mM	33.5	36.4	38.8	38.1	26.7	31.4	2.84	< 0.01	0.32	0.63
Acetate:Propionate	1.7	2.1	1.7	2.1	2.3	2.4	0.14	< 0.01	0.01	0.50
Butyrate, mM	10.7	15.9	11.7	15.3	7.9	12.8	1.37	0.05	< 0.001	0.81
Isobutyrate, mM	0.64	0.95	0.60	0.82	0.69	0.92	0.124	0.70	0.02	0.93
Valerate, mM	0.77	1.75	1.13	0.59	0.50	0.69	0.464	0.36	0.59	0.28
Isovalerate, mM	0.40	1.11	0.98	0.72	0.86	0.93	0.865	0.93	0.59	0.47

¹All treatment diets contained 60% dried DGS, 17% corn silage, and 4% vitamin and mineral supplement with: 1) 14.5% corn, 3% additional corn silage without Ca(OH)₂ (corn with no Ca(OH)₂); 2) 14% corn, 3% additional corn silage and 2% Ca(OH)₂ (corn with Ca(OH)₂); 3) 17.5% additional corn silage without Ca(OH)₂ (silage with no Ca(OH)₂); 4) 17% additional corn silage with 2% Ca(OH)₂ (silage with Ca(OH)₂); 5) 0.25% additional corn silage, 17.25% corn stover, without Ca(OH)₂ (stover with no Ca(OH)₂); and 6) 17% corn stover and 2% Ca(OH)₂ (stover with Ca(OH)₂).

²Effect of roughage inclusion

³Effect of Ca(OH)₂ addition

⁴Roughage inclusion × Ca(OH)₂ addition

roughage inclusion ($P = 0.44$) or by Ca(OH)₂ addition ($P = 0.86$). Acetate concentrations were greater in steers fed rations with added Ca(OH)₂ ($P < 0.001$) but were not affected by roughage inclusion ($P = 0.14$). Propionate concentrations were greatest for steers fed corn silage, intermediate for steers fed corn and least for steers fed corn stover ($P < 0.01$), but propionate concentrations were not affected by dietary Ca(OH)₂ addition ($P = 0.32$). Consequently, acetate:propionate was greater for steers consuming corn stover than for steers fed corn or corn silage ($P < 0.01$) and was greater with Ca(OH)₂ addition ($P = 0.01$). In addition, acetate:propionate demonstrated a roughage inclusion × time interaction ($P < 0.01$), where steers fed corn stover displayed a quicker decline in acetate:propionate from 0 to 3 h post-feeding and a more rapid increase in acetate:propionate from 3 to 18 h post-feeding compared to steers fed corn or silage. Butyrate concentrations were lesser for steers consuming corn stover than steers consuming corn or corn silage ($P = 0.05$), and butyrate concentrations were increased with dietary Ca(OH)₂ addition ($P < 0.001$). Furthermore, a roughage inclusion × time interaction was detected for butyrate concentrations ($P < 0.01$), where steers consuming corn stover had a more rapid increase in butyrate concentrations from 0 to 3 h post-feeding and a quicker decline in butyrate concentrations from 3 to 18 h post-feeding compared to steers fed corn or silage. Valerate and isovalerate concentrations did not

differ for roughage inclusion or Ca(OH)₂ addition ($P \geq 0.36$). However, valerate concentrations tended to display a roughage × time interaction ($P = 0.08$) where steers fed corn stover had valerate concentrations that remained stable from 0 to 18 h post-feeding and steers fed corn and silage diets had valerate concentrations that increased from 0 to 6 h then decreased from 6 to 18 h post-feeding. In addition, isovalerate concentrations tended to exhibit a roughage inclusion × alkali addition × time interaction ($P = 0.07$) where Ca(OH)₂ addition to diets containing corn or corn stover increased steer ruminal isovalerate concentrations at 3 h post-feeding and addition of Ca(OH)₂ to diets containing corn silage decreased ruminal isovalerate concentrations at 3 h.

Intake and digestibility data for experiment 3 are summarized in Table 7. No interactions were detected for any intake parameter ($P \geq 0.55$). Intake of DM and OM did not differ because of roughage inclusion or Ca(OH)₂ addition ($P \geq 0.13$). Intake of CP tended to be greatest for steers consuming corn silage, intermediate for steers consuming corn, and lowest for steers consuming corn stover ($P = 0.08$). NDF intake was least for steers consuming corn ($P < 0.01$) compared to steers consuming corn silage or stover. Intake of ADF was greatest for steers consuming corn stover, intermediate for steers consuming corn silage, and lowest for steers consuming corn ($P < 0.001$). Ca(OH)₂ addition did not affect DM, OM, CP, NDF, or ADF intake ($P \geq 0.73$).

Table 7. Effect of $\text{Ca}(\text{OH})_2$ and roughage inclusion on diet digestibility (experiment 3)

	Treatments ¹						SEM	<i>P</i> -value		
	Corn		Silage		Stover			Roughage ²	Alkali ³	R x A ⁴
	0% $\text{Ca}(\text{OH})_2$	2% $\text{Ca}(\text{OH})_2$	0% $\text{Ca}(\text{OH})_2$	2% $\text{Ca}(\text{OH})_2$	0% $\text{Ca}(\text{OH})_2$	2% $\text{Ca}(\text{OH})_2$				
<i>n</i>	6	6	6	6	6	6				
Intake, kg/d										
DM	8.0	7.9	8.9	9.1	7.8	8.4	0.48	0.13	0.76	0.56
OM	7.8	7.3	8.3	8.4	7.3	7.8	0.45	0.13	0.88	0.56
CP	1.9	1.8	2.1	2.1	1.8	1.9	0.11	0.08	0.73	0.55
NDF	2.8	2.6	3.3	3.4	3.3	3.5	0.18	< 0.01	0.76	0.56
ADF	1.0	0.9	1.3	1.3	1.4	1.5	0.07	< 0.001	0.73	0.58
Apparent digestibility, %										
DM	82.0	85.0	79.6	82.6	77.0	80.1	1.45	< 0.01	0.02	0.99
OM	82.4	86.2	81.3	84.3	77.3	80.6	1.42	< 0.01	< 0.01	0.96
CP	87.0	89.1	86.8	88.0	85.5	86.2	0.93	0.07	0.09	0.74
NDF	70.7	77.2	70.9	75.7	66.2	71.1	2.25	0.06	< 0.01	0.93
ADF	70.4	76.3	70.3	75.9	66.3	72.9	2.16	0.17	< 0.01	0.97

¹All treatment diets contained 60% dried DGS, 17% corn silage, and 4% vitamin and mineral supplement with: 1) 14.5% corn, 3% additional corn silage without $\text{Ca}(\text{OH})_2$ (corn with no $\text{Ca}(\text{OH})_2$); 2) 14% corn, 3% additional corn silage and 2% $\text{Ca}(\text{OH})_2$ (corn with $\text{Ca}(\text{OH})_2$); 3) 17.5% additional corn silage without $\text{Ca}(\text{OH})_2$ (silage with no $\text{Ca}(\text{OH})_2$); 4) 17% additional corn silage with 2% $\text{Ca}(\text{OH})_2$ (silage with $\text{Ca}(\text{OH})_2$); 5) 0.25% additional corn silage, 17.25% corn stover, without $\text{Ca}(\text{OH})_2$ (stover with no $\text{Ca}(\text{OH})_2$); and 6) 17% corn stover and 2% $\text{Ca}(\text{OH})_2$ (stover with $\text{Ca}(\text{OH})_2$).

²Effect of roughage inclusion

³Effect of $\text{Ca}(\text{OH})_2$ addition

⁴Roughage inclusion × $\text{Ca}(\text{OH})_2$ addition

No interactions were detected for apparent digestibility of DM, OM, CP, NDF, or ADF ($P \geq 0.74$). Apparent DM and OM digestibility were greatest for steers fed corn, intermediate for steers fed corn silage, and least for steers fed corn stover ($P < 0.01$) and were increased for steers fed $\text{Ca}(\text{OH})_2$ compared to steers not fed $\text{Ca}(\text{OH})_2$ ($P \leq 0.02$). Apparent digestibility of CP and NDF tended to be greatest for steers fed corn, intermediate for steers fed corn silage, and least for steers fed corn stover ($P \leq 0.07$), whereas apparent digestibility of ADF did not differ among steers because of roughage inclusion ($P = 0.17$). Apparent digestibility of NDF and ADF increased ($P < 0.01$) and apparent digestibility of CP tended to increase ($P = 0.09$) because of supplementation of $\text{Ca}(\text{OH})_2$.

Digestion kinetics data are presented in Table 8. Ruminant DM degradation rate (k_d) was greater ($P < 0.001$) for steers fed stover compared to steers fed corn or corn silage and tended ($P < 0.10$) to be greater for steers fed corn silage compared to corn. $\text{Ca}(\text{OH})_2$ inclusion increased k_d ($P < 0.01$) and there was an interaction ($P < 0.01$) between roughage inclusion and $\text{Ca}(\text{OH})_2$ addition for k_d , where $\text{Ca}(\text{OH})_2$ had no effect on k_d in corn diets, increased k_d in corn silage diets, and tended to increase k_d in stover diets. Stover decreased the extent of digestion compared to corn and silage diets ($P = 0.01$) and $\text{Ca}(\text{OH})_2$ had no effect on extent of digestion ($P = 0.81$). However, there tended to

be an interaction between roughage inclusion and $\text{Ca}(\text{OH})_2$ addition for extent of digestion, where $\text{Ca}(\text{OH})_2$ did not influence extent of digestion for steers fed corn and silage, but increased extent of digestion for steers fed stover. Fractional outflow of particulate matter from the reticulo-rumen (k_1) was greater for steers fed stover compared with steers fed corn or silage ($P = 0.04$). $\text{Ca}(\text{OH})_2$ did not affect k_1 and an interaction did not occur ($P \geq 0.42$). Fractional outflow of particulate matter from the cecum-colon (k_2) was not affected by roughage inclusion, $\text{Ca}(\text{OH})_2$ addition, or their interaction ($P \geq 0.29$). Liquid passage rate (k_L) tended ($P = 0.09$) to be lesser for steers fed corn compared to steers fed silage, with steers fed stover having an intermediate k_L . $\text{Ca}(\text{OH})_2$ tended to increase k_L ($P = 0.06$). Mean retention time was decreased ($P = 0.02$) in steers fed stover compared to corn or silage diets.

Nitrogen balance data are presented in Table 9. Nitrogen intake tended to be greatest for steers consuming corn silage, intermediate for steers consuming corn, and least for steers consuming corn stover ($P = 0.08$). Nitrogen excretion did not differ among steers due to roughage inclusion or $\text{Ca}(\text{OH})_2$ addition and there was not an interaction between roughage inclusion and $\text{Ca}(\text{OH})_2$ addition ($P \geq 0.51$). Fecal DM excretion tended to be greatest for steers fed corn stover, intermediate for steers fed corn silage, and least for steers fed corn ($P = 0.08$). Total fecal nitrogen excretion did not differ because

Table 8. Effect of Ca(OH)₂ and roughage inclusion on kinetics of digestion (experiment 3)

	Treatments ¹						SEM	P-value		
	Corn		Silage		Stover			Roughage ²	Alkali ³	R x A ⁴
	0% Ca(OH) ₂	2% Ca(OH) ₂	0% Ca(OH) ₂	2% Ca(OH) ₂	0% Ca(OH) ₂	2% Ca(OH) ₂				
Degradation (<i>n</i> = 3 animals)										
K _d ⁵ , proportion per h	2.17 ^{aw}	1.72 ^{aw}	1.25 ^{ax}	3.78 ^{by}	4.04 ^{bcy}	4.97 ^{cz}	0.284	<0.001	<0.01	<0.01
Extent, %	85.2	81.3	81.4	78.0	67.2	71.9	4.41	0.01	0.81	0.07
Passage (<i>n</i> = 6 animals)										
K1 ⁶ , proportion per h	0.035	0.030	0.036	0.034	0.041	0.048	0.0045	0.04	0.98	0.42
K2 ⁷ , proportion per h	0.068	0.055	0.072	0.073	0.071	0.076	0.0082	0.29	0.79	0.52
KL ⁸ , proportion per h	0.074	0.083	0.089	0.103	0.077	0.091	0.0084	0.09	0.06	0.92
Mean retention time, h	50.9	67.6	49.6	54.8	44.7	40.0	5.61	0.02	0.23	0.18

¹All treatment diets contained 60% dried DGS, 17% corn silage, and 4% vitamin and mineral supplement with: 1) 14.5% corn, 3% additional corn silage without Ca(OH)₂ (corn with no Ca(OH)₂); 2) 14% corn, 3% additional corn silage and 2% Ca(OH)₂ (corn with Ca(OH)₂); 3) 17.5% additional corn silage without Ca(OH)₂ (silage with no Ca(OH)₂); 4) 17% additional corn silage with 2% Ca(OH)₂ (silage with Ca(OH)₂); 5) 0.25% additional corn silage, 17.25% corn stover, without Ca(OH)₂ (stover with no Ca(OH)₂); and 6) 17% corn stover and 2% Ca(OH)₂ (stover with Ca(OH)₂).

²Effect of roughage inclusion

³Effect of Ca(OH)₂ addition

⁴Roughage inclusion × Ca(OH)₂ addition

⁵K_d is the rate of degradation

⁶K1 is the fractional outflow rate from the reticulorumen (the smaller rate constant for the pool with a longer retention time).

⁷K2 is the fractional outflow rate from the hindgut (the larger rate constant for the pool with a shorter retention time).

⁸KL is the liquid passage rate

^{abc}Values within a row with different superscripts differ (*P* ≤ 0.05).

^{wxyz}Values within a row with different superscripts tend to differ (*P* ≤ 0.10).

Table 9. Effect of Ca(OH)₂ and roughage inclusion on nitrogen balance (experiment 3)

	Treatments ¹						SEM	P-value		
	Corn		Silage		Stover			Roughage ²	Alkali ³	R x A ⁴
	0% Ca(OH) ₂	2% Ca(OH) ₂	0% Ca(OH) ₂	2% Ca(OH) ₂	0% Ca(OH) ₂	2% Ca(OH) ₂				
<i>n</i>	6	6	6	6	6	6				
N intake, g/d	310.1	293.3	330.5	341.1	285.8	307.8	17.94	0.08	0.73	0.55
N excretion, g/d	174.8	164.1	186.1	186.3	166.0	184.5	14.56	0.51	0.83	0.61
Fecal excretion										
DM, kg/d	1.5	1.2	1.8	1.6	1.8	1.7	0.18	0.08	0.14	0.88
Total N, g/d	39.6	32.6	43.2	41.0	41.8	42.5	4.27	0.28	0.43	0.66
Total N, % N excretion	22.9	19.3	23.6	22.3	25.0	23.0	1.30	0.10	0.04	0.65
Urinary excretion										
Volume, L/d	11.2	12.3	13.6	13.3	12.0	11.3	1.24	0.28	0.99	0.72
Total N, g/d	135.2	131.5	142.9	145.3	124.3	142.0	11.26	0.55	0.56	0.62
Total N, % N excretion	77.1	80.7	76.4	77.7	75.0	77.0	1.30	0.10	0.04	0.65
Urea N, g/d	105.4	99.0	107.9	103.8	93.8	106.9	11.41	0.89	0.93	0.65
Ammonia N, g/d	39.1	38.1	35.0	47.9	32.9	39.8	7.79	0.81	0.33	0.68
Urine pH	6.9	7.0	6.5	7.4	6.6	7.4	0.23	0.98	< 0.01	0.19

¹All treatment diets contained 60% dried DGS, 17% corn silage, and 4% vitamin and mineral supplement with: 1) 14.5% corn, 3% additional corn silage without Ca(OH)₂ (corn with no Ca(OH)₂); 2) 14% corn, 3% additional corn silage and 2% Ca(OH)₂ (corn with Ca(OH)₂); 3) 17.5% additional corn silage without Ca(OH)₂ (silage with no Ca(OH)₂); 4) 17% additional corn silage with 2% Ca(OH)₂ (silage with Ca(OH)₂); 5) 0.25% additional corn silage, 17.25% corn stover, without Ca(OH)₂ (stover with no Ca(OH)₂); and 6) 17% corn stover and 2% Ca(OH)₂ (stover with Ca(OH)₂).

²Effect of roughage inclusion

³Effect of Ca(OH)₂ addition

⁴Roughage inclusion × Ca(OH)₂ addition interaction

of roughage inclusion or $\text{Ca}(\text{OH})_2$ addition and there was no interaction between roughage inclusion and $\text{Ca}(\text{OH})_2$ addition ($P \geq 0.28$). However, total fecal nitrogen excreted as a percent of total nitrogen excreted (feces + urine) tended to be greatest for steers fed corn stover, intermediate for steers fed corn silage, and least for steers fed corn ($P = 0.10$), and was decreased by $\text{Ca}(\text{OH})_2$ addition ($P = 0.04$). Volume of urine excreted, weight of total nitrogen excreted in urine, and ammonia and urea N in urine did not differ among steers because of roughage inclusion or $\text{Ca}(\text{OH})_2$ addition, nor was there an interaction between roughage inclusion and $\text{Ca}(\text{OH})_2$ addition ($P \geq 0.28$). Steers fed corn tended ($P = 0.10$) to have greater urinary total nitrogen excretion as a percent of total nitrogen excreted by the animal (feces + urine), whereas steers fed corn silage had an intermediate percentage, and steers fed corn stover tended to have the least percentage. $\text{Ca}(\text{OH})_2$ addition increased the percent of N excreted in urine ($P = 0.04$). Urine pH was not affected by roughage inclusion, but was increased when $\text{Ca}(\text{OH})_2$ was supplemented ($P < 0.01$).

DISCUSSION

Although there were no differences in ADG in experiment 1, steers consuming corn silage had a greater DMI during period 2 than steers fed either corn treatment, leading to a decreased gain:feed during period 2 and overall for steers consuming corn silage. However, in experiment 2 added stover decreased ADG and gain:feed but did not affect DMI. As anticipated, NDF and ADF intake was greater in experiment 3 for steers fed rations with corn silage or corn stover than for steers fed corn, which can be attributed to the inherent fiber content of the feedstuffs. It is common in 90% concentrate-based feedlot diets with no DGS that added roughage decreases gain (Ledoux et al., 1985; Gorocica-Buenfil and Loerch, 2005). However, Felix and Loerch (2011) demonstrated that addition of 10% alfalfa haylage to a 10% corn silage, 60% dried DGS resulted in increased DMI and ADG, but poorer gain:feed. Similarly, Benton et al. (2015) reported that feeding 4% or 8% alfalfa hay or an NDF equivalent amount of corn silage or corn stover in rations containing 30% wet DGS resulted in increased DMI and ADG, but gain:feed did not differ compared to a basal diet without roughage. Roughage content of the diets in present study were large and DMI (and resultant ADG) was likely limited by digestibility and rate of passage of the diet. Indeed, adding corn silage or stover to 60% dried DGS diets in present study

decreased mean retention time in the digestive tract, resulting in lessened digestion and depressed DM, OM, and NDF digestibility. Burken et al. (2017) similarly demonstrated that increasing corn silage from 15% to 55% in corn-based diets containing 40% modified DGS linearly decreased DMI, ADG, and gain:feed of steers.

Digestibility is inherently complex in that it is dependent on several factors, including the amount and composition of fiber in the diet, intake level, passage rate, and particle size (Van Soest, 1982). In moderate-to-low roughage diets, Gorocica-Buenfil and Loerch (2005) observed no differences in apparent digestibility of DM, OM, or NDF, but a tendency for greater ADF digestibility when corn silage was included in corn-based feedlot rations at 18.2% compared 5.2% of the diet DM. Felix and Loerch (2011) demonstrated that addition of 10% alfalfa haylage to a 10% corn silage, 60% dried DGS resulted in increased DM digestibility. Benton et al. (2015) did not detect a difference in DM or OM digestibility between feeding 4% or 8% alfalfa hay or an NDF equivalent amount of corn silage or corn stover in rations containing 30% wet DGS but did observe that NDF digestibility was greater for alfalfa hay. In contrast, when roughage levels are increased to a greater extent, depressions in digestibility are noted. Zinn and Plascencia (1996) observed that ruminal, post-ruminal, and total tract OM digestibility decreased when alfalfa content of steam-flaked corn diets was increased from 10% to 30% of the diet DM. Ledoux et al. (1985) demonstrated that in whole-shelled corn-based diets that solid and liquid passage rate decreased as fescue hay inclusion was increased from 4% to 8% of the diet DM, but then was increased as fescue hay inclusion was increased from 8% to 16% to 24% of the diet DM. Faster solid and liquid passage rates as roughage content increases, which was seen in the present study, are often reported (Colucci et al., 1982, 1990; Owens and Goetsch, 1986; Poore et al., 1990; Huhtanen and Jaakkola, 1993). Increased passage rates for the silage and stover diets in present study suggest that more of the soluble nutrients were carried to the small intestine rather than digested in the rumen and is consistent with the decreases observed for extent of digestion and diet digestibility.

Although increasing roughage content of diets increased rates of passage, increased ruminal DM degradation rates for diets containing greater amounts of roughage, as seen in present study, has been previously reported (Uden, 1984; Wattiaux et al., 1991; Huhtanen and Jaakkola, 1993). These

researchers observed that fractional degradation rates of DM and fiber for hay and silage increased as the proportion of concentrate decreased from approximately 70% to 40% of the diet DM. [Poore et al. \(1990\)](#) observed that fractional degradation of an alfalfa hay, wheat straw mix (50:50) was increased as flaked milo decreased from 90% to 60% or 30% of the diet DM. However, increases in rates of DM degradation by adding roughage to diets generally do not compensate for increases in rates of passage, resulting in lessened extent of digestion. Greater DM degradation rates for stover versus silage in present study may also have been due to the lack of ensiling. Although [Wattiaux et al. \(1991\)](#) observed that method of alfalfa preservation did not influence rate of digestion, [Huhtanen and Jaakkola \(1993\)](#) reported that fractional rate of NDF and hemicellulose degradation were greater for grass hay based diets than with the grass silage-based diets prepared from the same sward. Ensiling grass did not affect rate of passage ([Huhtanen and Jaakkola, 1993](#)). Stover diets in present study produced consistently greater pH compared to silage or corn diets. It is possible that the dry forage contained less acid (from silage fermentation) and may have also increased rumination in order to decrease particle size. In turn, rumination may have increased salivation and thus buffering capacity of the rumen, which could improve conditions for fiber digestion ([Hoover, 1986](#)).

Addition of hydrolytic chemical agents, such as $\text{Ca}(\text{OH})_2$, to highly lignified feedstuffs have been shown to break bonds between lignin and structural carbohydrates, resulting in increased microbial fermentation of the feedstuff ([Jung, 1993](#)). Although the roughages in present study were not pretreated with a strong base, direct addition of an alkali to a feedlot ration has been demonstrated to improved fiber digestibility, possibly through degradation of the linkages between lignin and hemicellulose in addition to increased ruminal pH ([Nunez et al., 2014](#)). It appears from experiment 1 data that direct addition of $\text{Ca}(\text{OH})_2$ to the ration was not as effective in diets that contained lesser amounts of roughage. Indeed, we observed a fiber inclusion \times $\text{Ca}(\text{OH})_2$ addition interaction in experiment 2, where $\text{Ca}(\text{OH})_2$ addition to stover diets improved period 1 and overall ADG but $\text{Ca}(\text{OH})_2$ addition to silage diets had no effect on performance. [Nunez et al. \(2014\)](#), similar to experiment 1 in present study, reported no change in ADG, a linear decrease in DMI, and a linear improvement in gain:feed when CaO was added to diets up to 2.4% to 60% dried DGS diets. [Schroeder et al. \(2014\)](#) reported

no change in ADG, a decrease in DMI, and an improvement in gain:feed when dried or modified DGS was pretreated with CaO such that 50% DGS rations contained 1.2% CaO. Furthermore, [Boukila et al. \(1995\)](#) reported an increase in digestible DMI for feedlot sheep fed 75% barley based rations that with 1% $\text{Ca}(\text{OH})_2$ or 0.39% $\text{Mg}(\text{OH})_2$ added.

Steers supplemented with $\text{Ca}(\text{OH})_2$ in present study had greater apparent digestibility values for DM, NDF, and ADF when compared to steers not supplemented with $\text{Ca}(\text{OH})_2$. Similarly, [Nunez et al. \(2014\)](#) reported an increase in ADF digestibility and a tendency for increased NDF digestibility as CaO inclusion increased from 0% to 2.4% in 60% dried DGS rations and [Boukila et al. \(1995\)](#) reported that adding 1% of the diet DM as $\text{Ca}(\text{OH})_2$ to 75% barley-based feedlot lamb rations increased diet DM digestibility. DM and ADF digestibility were also greater when corn stover in 20% corn stover, 40% modified DGS diets was pre-treated with CaO or when CaO was added to a ration at 1% DM ([Duckworth et al., 2014](#)). Because stover has greater cross-linking of lignin and hemicellulose compared to silage or corn and is less digestible, it was not surprising that in present study, direct addition of $\text{Ca}(\text{OH})_2$ to the ration improved rate of DM degradation in stover and silage diets but not in corn diets and increased extent of DM degradation in stover diets. Forage substrates differ in rates of hydration or rates of chemical or physical alteration before enzymatic degradation ([Mertens and Ely, 1982](#)). It is possible that addition of $\text{Ca}(\text{OH})_2$ to the ration removed some chemical or physical inhibitors in the roughage or increased the capability of the fibers to swell via hydration which is needed before enzymes can contact and react with fiber molecules ([Allen and Mertens, 1988](#)). In agreement with present study, [Henriques et al. \(2007\)](#) reported that pretreatment of sugarcane with CaO such that the DM content of CaO in the diet was increased up to 20 g/kg, increased fractional degradation rate of NDF. When a lower dose of CaO was used (5 or 10 g/kg) to pretreat sugarcane for 0 to 72 h, [Pina et al. \(2009\)](#) observed a decreased indigestible fraction (C fraction), but no effect on rate of degradation. [Oliveros et al. \(1993\)](#) reported that pretreatment of corn stover in 90% corn stover diets with 40 g/kg of $\text{Ca}(\text{OH})_2$ did not affect rate of degradation of NDF and ADF but increased 72-h extent of NDF and ADF digestion. Extent of degradation is also a function of how quickly feed particles exit the rumen, because digestion and passage are competing processes ([Mertens, 1977](#)); particles with slower passage rates may be digested

more extensively in the rumen. Results from present study suggest that increased extent of DM degradation in stover diets was a result of increased rate of DM degradation with only nonsignificant increases solid passage rates.

Although alkali addition to the ration did not affect solid passage rates, liquid passage rates were increased in present study. [Aines \(1985\)](#) observed that pretreating wheat straw with 4% or 8% Ca(OH)_2 and feeding 90% wheat straw diets did not have an effect on solid or liquid passage rates; however, [Oliveros et al. \(1993\)](#) similar to present study noted that even though solid passage rate was not affected, liquid passage rate was increased when corn stover in 90% corn stover diets was pretreated with 40 g/kg of Ca(OH)_2 . In addition, [Casperson \(2017\)](#) observed that replacement of a portion of haylage and corn silage with 9.6% of the diet DM as corn stover pretreated with 6.2% Ca(OH)_2 did not affect solid passage rate but increased liquid passage rate in lactating dairy cows. Increased liquid passage rate as a result of alkaline treatment indicates that more soluble nutrients were carried to the small intestine for digestion. An increased flow of soluble nutrients to the small intestine caused by Ca(OH)_2 addition in the present study may have been responsible for the lesser extent of ruminal digestion in corn and silage diets; however, shifting the site of starch digestion, in particular, to the small intestine has been shown to improve feed efficiency ([Harmon and McLeod, 2001](#)). A potential shift of nutrient digestion from the rumen to the small intestine caused by Ca(OH)_2 in present study may be partly responsible for the increase in total tract digestibility and the increase in ADG and gain:feed observed in period 1 of experiment 2.

Steers consuming diets containing corn stover in this studies tended to exhibit lesser digestibility of CP, which is consistent with the shifts in N excretion that were seen. Though nitrogen excretion did not differ among treatments, there was a tendency for steers fed corn stover to have greater fecal N excretion as a percent of total nitrogen excretion and a lesser urinary N excretion as a percentage of total N when compared to corn. This difference is likely related to the greater digestibility of CP for corn and corn silage when compared to corn stover, meaning less undigested N was excreted in the feces and more of it was metabolized and excreted as urinary N. In agreement, [Zinn and Plascencia \(1996\)](#) observed that total tract N digestion was decreased when alfalfa content of steam-flaked corn diets was increased from 10% to 30% of the diet DM. Furthermore, [Burken et al. \(2017\)](#)

demonstrated that increasing maturity of whole corn plants used for silage decreased total digestible nutrient availability for feedlot steers. However, [Benton et al. \(2015\)](#) reported no differences in CP digestibility between alfalfa hay and corn stover for steers fed diets containing 30% wet DGS. In present study Ca(OH)_2 addition tended to increase the apparent digestibility of CP, decrease the percentage of N excreted in feces, and increase the percentage of N excreted in urine. [Nunez et al. \(2014\)](#) reported that CaO addition to 60% dried DGS with 20% corn silage diets had no effect on CP digestibility or fecal, urinary, or total N excretion. However, [Nunez et al. \(2014\)](#) did see a quadratic effect of CaO on urinary urea excretion, where excretion increased from 0% to 0.8% CaO inclusion and decreased from 1.6% to 2.4% inclusion.

Total VFA concentrations in present study were lesser for steers fed corn stover and were most likely caused by lesser butyrate and propionate concentrations for steers consuming corn stover. Decreased concentrations of butyrate and propionate with corn stover inclusion is consistent with decreased digestibility and may be linked to differences in ruminal pH. [Zinn et al \(1994\)](#) observed that increasing dietary forage (alfalfa hay and sundangrass hay) from 10% to 20% increased acetate and decreased propionate concentrations. Steers fed rations with added Ca(OH)_2 had greater total ruminal VFA concentrations in present study. Ruminal propionate was not affected by Ca(OH)_2 and the increase in total VFA was mainly due to increases in ruminal acetate and butyrate concentrations. [Duckworth et al. \(2014\)](#) reported that corn-based diets with modified DGS and 20% corn stover pretreated with 5% CaO resulted in greater total VFA and acetate concentrations than diets with untreated corn stover. [Nunez et al. \(2014\)](#) also demonstrated an increase in acetate concentrations when up to 2.4% of the diet DM of CaO, was added to steer rations, as well as no change in propionate concentrations. [Boukila et al. \(1995\)](#) demonstrated that direct supplementation of 1% Ca(OH)_2 or 0.39% Mg hydroxide to 75% barley-based diets resulted in greater ruminal VFA concentrations with increased acetate concentrations and no change in propionate concentrations. Increases in ruminal acetate and butyrate concentrations are indicative of increased ruminal fiber fermentation, as these two VFAs are primary end products of fiber degradation ([Van Soest, 1994](#)). Propionate fermentation is more energetically efficient than fermentation of acetate or butyrate ([Chalupa, 1977](#)); however, increases in ruminal acetate and butyrate

concentrations without decreased ruminal propionate concentration is indicative of an improved utilization of dietary energy with added $\text{Ca}(\text{OH})_2$.

Ruminal pH can be controlled by the introduction of buffering compounds via saliva to the rumen through the process of ingesting feed and rumination (Owens, 1998). In addition, feed components themselves can alleviate ruminal acidity by displacement of hydrogen ions in the rumen from increased rumen fill (Mertens, 1997). Of the three fiber sources included in present study (corn, corn silage, and corn stover), corn stover was the driest and least compact feedstuff. Therefore, corn stover would induce more salivation, leading to increased salivary buffering compounds entering the rumen. In addition, the bulkiness of corn stover inside the rumen would work to displace the hydrogen ions. In present study, ruminal pH was greater for steers fed corn stover than for steers fed corn or corn silage, while corn and corn silage resulted in similar ruminal pH values. Thus, it would appear that corn stover could have induced more salivation and increased rumen fill to increase ruminal pH. Crawford et al. (2008) similarly demonstrated that increasing dietary roughage was an effective means of increasing ruminal pH. Furthermore, replacing a portion of corn with alfalfa haylage in a 60% dried DGS feedlot ration enhanced salivary flow and increased ruminal pH, resulting in greater fiber digestibility (Felix and Loerch, 2011). However, the increase in ruminal pH seen in cattle fed stover diets in present study did not improve fiber digestibility, did not alter urine pH, or result in improved cattle performance, indicating that increased salivary buffering is not adequate enough for ruminal bacteria to digest stover or change metabolic acid–base balance.

Hoover (1986) stated that lower ruminal pH levels would inhibit fiber and protein fermentation. Though ruminal pH only tended to be increased by $\text{Ca}(\text{OH})_2$ addition at 18 h post-feeding, $\text{Ca}(\text{OH})_2$ still seems to be effective at increasing fiber and protein fermentation. Felix et al. (2012a) demonstrated that treating dried DGS based rations with 2% sodium hydroxide increased mean ruminal pH, leading to greater NDF degradation. Lack of ruminal pH increases with $\text{Ca}(\text{OH})_2$ addition in present study could be due to increased VFA production as feeds are fermented, resulting in a cancellation in the effects of added $\text{Ca}(\text{OH})_2$. However, the fact that urine pH was increased by $\text{Ca}(\text{OH})_2$ addition indicates that $\text{Ca}(\text{OH})_2$ was having a positive impact on metabolic acid–base balance. Urine pH is one of the most sensitive indicators of deregulations in

acid–base homeostasis. Increased metabolic acidity can lead to catabolism of proteins to buffer blood resulting in increased urine ammonia concentrations (Heitman and Bergman, 1980). Nunez et al. (2014) similarly reported that CaO addition up to 2.4% of the diet DM to 60% dried DGS diets linearly increased urinary pH.

No differences in carcass characteristics among treatments were noted, with the exception of experiment 1 where addition of $\text{Ca}(\text{OH})_2$ to corn rations increased dressing percentage and experiment 2 where steers fed $\text{Ca}(\text{OH})_2$ produced carcasses with a greater percentage grading Choice[®]. Nunez et al. (2014) did not observe an impact of CaO on carcass characteristics but did note an increased dressing percentage for steers fed 1.6% CaO, though the reason for this is unclear. Previous work has demonstrated that increasing dietary DGS inclusion above 40% of the diet DM can decrease marbling scores (Schoonmaker et al., 2010), and although it appears in present study that $\text{Ca}(\text{OH})_2$ increased the number of carcasses grading Choice in diets that did not contain stover, it did not differ.

In conclusion, feeding 2% $\text{Ca}(\text{OH})_2$ improved rate and extent of DM digestion, digestibility, and performance in cattle fed stover and produced performance values similar to those not fed stover. Thus, feeding corn stover with 2% $\text{Ca}(\text{OH})_2$ could be a cost-effective replacement for a portion of corn in feedlot diets when corn prices are elevated. Although $\text{Ca}(\text{OH})_2$ improved digestibility in corn and silage diets, benefits to performance appear to be lesser.

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