Impact of corn silage moisture at harvest on performance of growing steers with supplemental rumen undegradable protein, finishing steer performance, and nutrient digestibility by lambs[1]

F. Henry Hilscher, Dirk B. Burken, Curt J. Bittner, Jana L. Gramkow, Robert G. Bondurant, Melissa L. Jolly-Breithaupt, Andrea K. Watson, Jim C. MacDonald, Terry J. Klopfenstein, and Galen E. Erickson[2]

Department of Animal Science, University of Nebraska, Lincoln, NE 68583

ABSTRACT: Three experiments evaluated delaying corn silage harvest, silage concentration, and source of supplemental protein on performance and nutrient digestibility in growing and finishing diets. Experiment 1 used 180 crossbred yearling steers (body weight [BW] = 428; SD = 39 kg) to evaluate corn silage dry matter (DM) (37% or 43%) and replacing corn with silage (15% or 45% of diet DM) in finishing diets containing 40% modified distillers grains with solubles. Experiment 2 used 60 crossbred steers (BW = 271; SD = 32 kg) to evaluate corn silage harvest DM (37% or 43%) and response to rumen undegradable protein (RUP) supplementation (0.5%, 1.4%, 2.4%, 3.3%, or 4.2% of diet DM) in silage growing diets. Experiment 3 used 9 crossbred lambs (BW = 30.1; SD = 4.1 kg) to evaluate nutrient digestibility of 37% or 43% DM corn silage in silage growing diets fed ad libitum or restricted to 1.5% of BW. In experiment 1, as corn silage concentration increased from 15% to 45%, average daily gain (ADG) and gain-to-feed ratio (G:F) decreased ($P \le 0.04$). Carcass-adjusted final BW and hot carcass weight (HCW) were lower ($P \le 0.04$) for steers fed 45% corn silage compared to 15% when fed for equal days. As DM of corn silage was increased from 37% to 43%, no differences ($P \ge 0.30$) in dry matter intake (DMI), ADG, G:F, or HCW were observed. In experiment 2, as DM of corn silage increased from 37% to 43%, ADG and G:F decreased ($P \le 0.04$). Increasing supplemental RUP in the diet increased ($P \le 0.05$) ending BW, DMI, ADG, and G:F linearly as supplemental RUP increased from 0.5% to 4.2%. In experiment 3, there were no differences ($P \ge 0.56$) in DM digestibility and organic matter digestibility between silage harvest DM and intake level. Neutral detergent fiber (NDF) intake was reduced ($P < 0.01$) for lambs fed the delayed harvest corn silage compared to earlier corn silage harvest. As silage harvest was delayed from 37% to 43% DM, NDF digestibility decreased ($P < 0.01$) from 64.39% to 53.41%. Although increasing corn silage concentration in place of corn in finishing diets reduced ADG and G:F, delayed silage harvest did not affect performance of finishing cattle. Delayed silage harvest in growing cattle resulted in lower ADG and G:F, possibly due to increased starch or maturity leading to decreased NDF digestibility. The addition of RUP to silage-based, growing diets improves performance by supplying more metabolizable protein and suggests RUP of corn silage is limiting.

Key words: corn silage, distillers grains, dry matter, finishing cattle, growing cattle, rumen undegradable protein

Transl. Anim. Sci. 2019.3:761–774
doi: 10.1093/tas/txz011

[1]A contribution of the University of Nebraska Agricultural Research Division supported in part by funds provided through the Hatch Act.

[2]Corresponding author: gerickson4@unl.edu.
Received October 2, 2018.
Accepted February 2, 2019.

INTRODUCTION

Feeding corn silage allows cattle feeders to take advantage of the entire corn plant at a time of maximum quality and tonnage as well as secure substantial quantities of roughage and grain inventory (Burken et al., 2017b). Corn silage is a moderately high energy, low protein feed that allows for flexibility in growing and finishing cattle feeding programs (Allen et al., 2003). Corn silage typically contains 6.5% to 8.5% crude protein (CP), most of which is in the form of rumen degradable protein (RDP) and is used for microbial protein synthesis. The NASEM (2016) lists the RUP content for corn silage as 25.38% (% of CP). When evaluating the RUP value of forages, Kononoff et al. (2007) estimated RUP of corn silage to be 19.25% of CP, but of that, intestinal RUP digestibility was only 19.9%. An inadequate supply of metabolizable protein (MP) requires supplemental RUP to meet requirements (NASEM, 2016). Thus, source and amount of supplemental protein are important factors affecting growth because supplemental protein provides a significant amount of the total dietary protein (Felix et al., 2014). When corn silage replaces corn in finishing diets, gain-to-feed ratio (G:F) decreases as corn silage increases in the diet (Goodrich et al., 1974; Burken et al., 2017a). Management decisions, such as silage harvest maturity, can affect the quality and yield of corn silage and impact performance in growing and finishing cattle (Chamberlain et al., 1971). Hunt et al. (1989) reported that as silage harvest is delayed whole-plant yield and total digestible nutrients (TDN) in Mg/ha were increased. Allen et al. (2003) summarized these changes as grain development occurring largely at the expense of stover quality. The total amount of starch increases as the plant matures (Andrae et al., 2001). Because starch provides more than 50% of the energy in corn silage (Owens, 2008), this increase in starch content represents a large increase in total energy yield by harvesting corn silage with more maturity. However, as corn silage is harvested later in the harvest season with advanced maturity, whole-plant neutral detergent fiber (NDF) decreases as well as NDF digestibility (Andrae et al, 2001; Owens, 2008). Although incorporating distillers grains and corn silage at greater concentrations in growing and finishing diets has been shown to improve animal performance compared to corn silage alone (Felix et al., 2014; Burken et al., 2017a, 2017b), optimum harvest time to maximize yield and quality and the effects on animal performance have not been evaluated with distillers grains and additional RUP supplementation.

The objectives of the following studies were to 1) evaluate harvest time and concentration of silage in finishing cattle diets containing distillers grains, 2) determine the effects of delaying corn silage harvest on growing steer performance with additional RUP, and 3) determine nutrient digestibility of 37% or 43% dry matter (DM) corn silage at two intakes.

MATERIALS AND METHODS

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

Corn Cultivation, Harvest, and Chemical Composition

A single corn hybrid (P1498AM; Du Pont Pioneer, Johnston, IA) was planted in a single irrigated field at the Eastern Nebraska Research and Extension Center (ENREC) located near Ithaca, NE in 2014. Target planting density was 84,015 seeds/ha. The field was managed in a corn and soybean rotation every year for the previous 6 y. Corn silage was harvested using a self-propelled forage harvester (JD 5400; John Deere, Moline, IL) set for a 1.27-cm theoretical length of chop, without a kernel processing unit.

Harvest DM was targeted to mimic traditional corn silage harvest at 37% DM or a delayed harvest at 43% DM. Harvest for 37% DM corn silage was harvested all on September 4, 2014, when the corn was at approximately ¾ milk line and whole-plant corn silage samples were greater than 35% DM as determined by a moisture tester (Koster Crop Tester, Inc., Brunswick, OH) before harvest. Silage harvest for 43% DM corn silage occurred 2 wk later on September 16, 2014, and all occurred on 1 d. This coincided with black layer formation and moisture tester samples were greater than 42% DM before harvest. Corn silage was harvested in four replications of 0.72 ha each, and within replication, the total weight of silage harvested was recorded for silage yield determination. In addition, high moisture corn (kernel DM 68%) and dry corn (kernel DM 15%) yield strips were harvested within the same field on September 18, 2014 and November 4, 2014, respectively. Both 37% DM and 43% DM silages were stored in separate side-by-side 3-m diameter by 61-m long plastic silos (AgBag, St. Nazianz, WI) and allowed to ferment for 28 d before commencing the feeding trials.

Corn silage was sampled weekly during the feeding trial for DM determination in a 60 °C forced air oven for 48 h (Table 1). Weekly samples (n = 19) within a month were composited (n = 4) and analyzed by a commercial laboratory (Dairyland Laoratories, Inc., Arcadia, WI) for fermentation analysis, starch, and water-soluble carbohydrates. Silage samples were analyzed for CP, NDF, and acid detergent fiber (ADF) by monthly composites (n = 4) at a commercial laboratory (Ward Laboratories, Inc., Kearney, NE).

Harvest data were analyzed using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC). Silage harvest data were analyzed as a completely randomized design with silage strips serving as the experimental unit. There were 4 replications per silage DM harvested, as well as 4 replications per dry-rolled corn (DRC) and high moisture corn (HMC) yield. Significance was declared at $P \leq 0.05$.

Experiment 1—Cattle Finishing Experiment

Crossbred yearling steers (n = 180; initial body weight [BW] = 428; SD = 39 kg) were sorted into three BW blocks and assigned randomly to 1 of 20 pens (9 steers/pen; 1 replication in heavy BW block, 3 replications in middle BW block, and 1 replication in light BW block). Before the initiation of the experiment, all steers were individually identified and processed at arrival at the research feedlot with: a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza 3 virus, bovine respiratory syncytial virus, *Mannheimia haemolytica* toxoid (Bovi-Shield Gold One Shot; Zoetis Inc., Kalamazoo, MI), *Histophilus somnus* bacterin (Zoetis Inc.), and an injectable anthelmintic (Dectomax; Zoetis Inc.). All steers were revaccinated approximately 14 to 28 d after initial processing with a modified live viral vaccine for infectious bovine rhinotracheitis, bovine viral diarrhea types I and II, parainfluenza 3 virus, bovine respiratory syncytial virus (Bovi-Shield Gold 5; Zoetis Inc.), and a killed viral vaccine for clostridial infections (Ultrabac 7, Zoetis Inc.). Before the start of the experiment, steers were limit-fed (Watson et al., 2013) a diet containing 50% wet corn gluten feed (Sweet Bran; Cargill Inc., Blair, NE) and 50% alfalfa hay (DM basis) at 2.0% of projected BW for 5 d to equalize gastro-intestinal fill before weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983). Treatments (Table 2) were designed as a 2 × 2 factorial arrangement that consisted of harvested corn silage DM (37% DM or 43% DM) and concentration of corn silage in the finishing diet (15% or 45% DM basis). Corn silage replaced HMC on a dry basis. All steers were fed a supplement formulated for 33 mg/kg monensin (Elanco Animal Health, Greenfield, IN) and a targeted intake of 90 mg/steer daily of tylosin (Elanco Animal Health). Pens were fed once daily at approximately 0830 h. Steers were implanted with 200 mg of trenbolone acetate and 20 mg estradiol (Revalor-200; Merck Animal Health, Summit, NJ) on d 1. Feed bunks were managed to achieve ad libitum intake, 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; and feed refusals were removed from feed bunks when needed, weighed, and subsampled. All feed refusals were subsampled and dried for 48 h in

Table 1. Nutrient and fermentation analysis of 37 and 43% DM silage (DM basis)

	37% DM		43% DM	
Item[a]	Mean	C.V.[b]	Mean	C.V.[b]
DM, %	37.3	3.2	42.7	3.9
CP, % of DM	7.51	3.6	7.50	1.2
NDF, % of DM	31.6	17.5	28.9	5.7
ADF, % of DM	21.4	15.8	18.6	17.9
Starch, % of DM	35.4	16.7	40.8	5.0
Sugar, % of DM	2.6	19.6	2.5	8.7
pH	3.88	1.3	3.85	1.5
Lactic acid, % of DM	3.11	26.9	4.14	28.1
Acetic acid, % of DM	3.98	21.5	2.81	27.1
Propionic acid, % of DM	0.51	26.8	0.28	54.3
Butyric acid, % of DM	<0.01	0.0	<0.01	0.0
Total acids, % of DM	7.61	10.5	7.22	3.3

[a]DM was calculated using weekly samples and oven dried for 48 h at 60 °C. All other samples are based on monthly composites (n = 4) of weekly (n = 19) samples taken during the finishing trial, and analyzed at Dairyland Laboratories (St. Cloud, MN) and Ward Laboratories (Kearney, NE).

[b]C.V. = coefficient of variation and is calculated by dividing the standard deviation by the mean and is expressed as a percentage.

Table 2. Diet composition (% DM basis) for cattle finishing experiment (experiment 1)

	Treatment[a]			
	15% Corn silage		45% Corn silage	
	37% DM	43% DM	37% DM	43% DM
High moisture corn	41.0	41.0	11.0	11.0
Modified distillers grains plus solubles	40.0	40.0	40.0	40.0
37% DM corn silage	15.0	—	45.0	—
43% DM corn silage	—	15.0	—	45.0
Supplement[b]	4.0	4.0	4.0	4.0
Fine ground corn	1.8048	1.8048	1.8048	1.8048
Limestone	1.7050	1.7050	1.7050	1.7050
Tallow	0.1000	0.1000	0.1000	0.1000
Salt	0.3000	0.3000	0.3000	0.3000
Trace Mineral premix[c]	0.0500	0.0500	0.0500	0.0500
Vitamin A-D-E premix[d]	0.0150	0.0150	0.0150	0.0150
Monensin[e]	0.0165	0.0165	0.0165	0.0165
Tylosin[f]	0.0087	0.0087	0.0087	0.0087

[a]Treatments: 15% silage 37 % DM = 15% concentration of 37% DM silage, 15% silage 43% DM = 15 % concentration of 43% DM silage, 45% silage 37% DM = 45% concentration of 37% DM silage, 45% silage 43% DM = 45% concentration of 43% DM silage; all diets contained 40% MDGS.

[b]Supplement was formulated to be fed at 4% of diet DM.

[c]Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 2.00% Cu, 0.29% Mg, 0.2% I, and 0.05% Co.

[d]Vitamin A-D-E premix contained 30,000 IU of Vitamin A, 6,000 IU of Vitamin D, 7.5 IU of Vitamin E per gram.

[e]Monensin (Rumensin-90; Elanco Animal Health, Indianapolis, IN) premix contained 198 g/kg monensin.

[f]Tylosin (Tylan-40; Elanco Animal Health, Indianapolis, IN) premix contained 88 g/kg tylosin.

a 60 ºC forced-air oven for determination of DM and calculation of refusal DM weight (AOAC, 1999 method 4.1.03). Dietary ingredients were sampled weekly for determination of DM content. Dietary as-fed ingredient proportions were adjusted weekly. Steers were on feed for an average of 108 d (97 d block 1, 111 d block 2 and 3) and were harvested at a commercial abattoir (Greater Omaha Packing, Omaha, NE). On the day of shipping to the commercial abattoir, pens of steers were fed 50% of the previous day's DM offering at regular feeding time. Pens of steers were weighed on a platform scale at 1500 h before being loaded for shipping. A 4% pencil shrink was applied to this BW for final live BW and calculation of dressing percentage dressing percentage, calculated as hot carcass weight (HCW) divided by shrunk live final BW. HCW and liver abscess scores were obtained the day of harvest. Liver abscesses were categorized as 0 (no abscesses), A–, A, or A+ (severely abscessed) according to the procedures outlined by Brink et al. (1990). Liver abscess categories were combined to calculate the proportion of steers with abscessed livers in each pen. Carcass-adjusted final BW, used in the calculation of ADG and G:F, was calculated from HCW and a 63% common dressing percentage. Marbling score, 12th rib fat thickness, and longissimus muscle (LM) area were recorded after a 48 h carcass chill. The energy value of the diets was calculated by using pen data in the Galyean (2009) Net energy calculator based on NRC (1996) net energy equations. The calculator uses initial BW, final BW, dry matter intake (DMI), average daily gain (ADG), and a target endpoint (assuming choice quality grade).

Performance and carcass data were analyzed using the GLIMMIX procedure of SAS (SAS Inst. Inc.) with pen serving as the experimental unit (n = 5 per treatment) and block (n = 3) as a fixed effect. Data were analyzed as a randomized block design with BW sort as block. Initial BW was significantly different between silage DM treatments (1.7 kg) and included as a covariate in the model if significant. Inclusion of initial BW was not a significant covariate for any variables and was removed from the model as a covariate. Significance of effects was determined at $P \leq 0.05$.

Experiment 2—Cattle Growing Experiment

An 83-d growing study was conducted at the ENREC near Mead, NE using 60 crossbred steers (BW = 271; SD = 32 kg). Steers were individually fed using Calan gate feeders (American Calan Inc., Northwood, NH). On arrival and before initiation of the experiment, steers were identified and processed as described previously. Cattle were limit-fed a diet of 50% Sweet Bran and 50% alfalfa hay at

2.0% of projected BW for 5 d before trial initiation to equalize gut fill (Watson et al., 2013). Steers were weighed 3 consecutive days, with the average of the 3 d used as initial BW (Stock et al., 1983). A randomized block experimental design was used with treatments arranged in an unbalanced 2 × 5 factorial arrangement. The first factor was the base corn silage growing diet fed at 88% of the diet DM, which consisted of corn silage harvested at either 37% or 43% DM (Table 3). The second factor was response to RUP supplementation at 0.5%, 1.4%, 2.4%, 3.3%, or 4.2% of the diet DM. The RUP supplementation consisted of top dressing a blend of 0/100, 25/75, 50/50, 75/25, or 100/0 combination of an RDP and RUP supplement (Table 3). The supplement included RUP source, urea, minerals, vitamins A-D-E, and soybean hulls. Soybean hulls were the carrier that along with urea was replaced with the RUP sources. The supplement also included monensin (Elanco Animal Health) and was formulated to provide 200 mg/steer daily. The RUP supplement consisted of 52% SoyPass (50% CP; 75% RUP as % CP; Borregaard Lignotech, Rothschild, WI) and 34.7% Empyreal (75% CP; 65% RUP as % of CP; Cargill Inc.) and provided RUP in a blend of amino acids from soybean meal and corn gluten meal. SoyPass is an enzymatically browned soybean meal and Empyreal is a concentrated corn gluten meal. Steers were stratified by day –1 and day 0 BW, and assigned randomly to 1 of 10 treatments arranged in a 2 × 5 factorial arrangement. Steers per level of RUP supplementation included $n = 8$ for 0.5% RUP; $n = 5$ for 1.4% and 2.4 % RUP; $n = 6$ for 3.3% and 4.2% RUP treatments. With a limited number of bunks, a greater number of animals were fed at 0.5% RUP concentration (0% RUP supplement, 100% RDP supplement) to better compare the response curve to RUP supplementation. In addition, a greater number of animals were fed at 3.3% and 4.2% RUP concentration as it was hypothesized the steers MP needs would be met at greater levels of RUP concentration. When evaluating response curves to increasing supplementation of RUP, the curves are greatly influenced by the response on either end of the curve. Therefore, to ensure accuracy of estimate, steers were not equally distributed across supplementation concentrations. However, blocks were balanced within each supplementation treatment and across the two silage harvest treatments. The hypothesis is that a nonlinear breakpoint analysis will establish the dietary requirement for RUP supplementation, thus

Table 3. Diet composition (% DM basis) for cattle growing experiment (experiment 2)

	Treatment[a]									
	37% DM					43% Corn silage				
Ingredient	0.5%	1.4%	2.4%	3.3%	4.2%	0.5%	1.4%	2.4%	3.3%	4.2%
37% DM corn silage	88.0	88.0	88.0	88.0	88.0	—	—	—	—	—
43% DM corn silage	—	—	—	—	—	88.0	88.0	88.0	88.0	88.0
Rumen degradable protein supplement[b]	12.0	9.0	6.0	3.0	0.0	12.0	9.0	6.0	3.0	0.0
Rumen undegradable protein supplement[b]	0.0	3.0	6.0	9.0	12.0	0.0	3.0	6.0	9.0	12.0
Soybean hulls	9.3552	7.1225	4.8897	2.6570	0.4242	9.3552	7.1225	4.8897	2.6570	0.4242
Limestone	0.2120	0.2583	0.3045	0.3508	0.3970	0.2120	0.2583	0.3045	0.3508	0.3970
Salt	0.4000	0.3750	0.3500	0.3250	0.3000	0.4000	0.3750	0.3500	0.3250	0.3000
Urea	1.2000	0.9750	0.7500	0.5250	0.3000	1.2000	0.9750	0.7500	0.5250	0.3000
Tallow	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
Dicalcium phosphate	0.4540	0.3905	0.3270	0.2635	0.2000	0.4540	0.3905	0.3270	0.2635	0.2000
Trace mineral premix[c]	0.0500	0.1625	0.2750	0.3875	0.5000	0.0500	0.1625	0.2750	0.3875	0.5000
Vitamin A-D-E premix[d]	0.0150	0.0488	0.0825	0.1163	0.1500	0.0150	0.0488	0.0825	0.1163	0.1500
Monensin[e]	0.0138	0.0138	0.0138	0.0138	0.0138	0.0138	0.0138	0.0138	0.0138	0.0138
Bypass soy[f]	—	1.5000	3.0000	4.5000	6.0000	—	1.5000	3.0000	4.5000	6.0000
Concentrated corn gluten meal[g]	—	1.0000	2.0000	3.0000	4.0000	—	1.0000	2.0000	3.0000	4.0000

[a]Treatments: Diets contained 88% of either 37% or 43% DM corn silage and formulated to contain 0.5%, 1.4%, 2.4%, 3.3%, or 4.2% RUP as a % of total diet.

[b]RDP and RUP supplement were formulated for a target concentration of 12%. Combinations of both were used to achieve desired RUP % of the diet DM.

[c]Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 2.00% Cu, 0.29% Mg, 0.2% I, and 0.05% Co.

[d]Vitamin A-D-E premix contained 30,000 IU of Vitamin A, 6,000 IU of Vitamin D, 7.5 IU of Vitamin E per gram.

[e]Monensin (Rumensin-90; Elanco Animal Health, Indianapolis, IN) premix contained 198 g/kg monensin.

[f]Enzymatically browned soybean meal 50% CP; 75% RUP as % CP (SoyPass; Borregaard Lignotech, Rothschild, WI)

[g]Concentrated corn gluten meal 75% CP; 65% RUP as % of CP (Cargill Inc., Blair, NE).

increased replications were used to establish the baseline (0.5% RUP) and the maximum response line (3.3% and 4.2% RUP). Steers were treated for external parasites (StandGuard; Elanco Animal Health) and were implanted with 36 mg zeranol (Ralgro; Merck) on d 1. Feed bunks were assessed at approximately 0600 h and managed to allow for ad libitum intake. Steers were fed ad libitum once daily at 0800 h. Feed refusals were collected weekly, weighed, and then dried in a 60 °C forced-air oven for 48 h to calculate an accurate DMI for individual steers. Feed ingredients were sampled weekly and analyzed in the same manner for DM, with as-fed ingredient proportions adjusted weekly. At the conclusion of the study, steers were again limit-fed for 5 d as described earlier and weighed 3 consecutive days to determine ending BW. The energy value of the diets was calculated by using pen data in the Galyean (2009) Net energy calculator based on NRC (1996) net energy equations. The calculator uses initial BW, final BW, DMI, ADG, and target endpoint (assuming choice quality grade).

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.) as a randomized block design in a 2 × 5 factorial arrangement testing for linear and quadratic interactions between silage DM and RUP level with steer serving as the experimental unit and weight block (n = 5) as a fixed effect. If no interactions were detected, the main effects of silage DM and RUP concentration were evaluated. To evaluate RUP level, linear and quadratic contrasts were developed to evaluate the effect of increasing RUP level. Significance was declared at $P \leq 0.05$.

Experiment 3—Lamb Digestion Experiment

An 85-d metabolism study using 9 crossbred wether lambs (BW = 30.1; SD = 4.1 kg) was conducted to determine the extent of nutrient digestibility in corn silage at two different levels of DM and intake. Lambs were blocked into two blocks based on BW and arranged in a 4 × 5 Latin rectangle. The metabolism study was five periods in length with one of four treatments assigned randomly to lambs within each period, allowing each lamb to receive each treatment at least once. Treatments were arranged in a 2 × 2 factorial arrangement. Factors included corn silage harvested at either 37% or 43% DM and intake of corn silage ad libitum or restricted to 1.5% of BW. The basel diet consisted of 92% corn silage and 8% supplement (Table 4).

The periods were 17 d in length allowing for 10 d of adaptation and 7 d for total fecal collection.

Table 4. Diet composition (% DM basis) for lamb digestion experiment (experiment 3)

	Treatment[a]	
Ingredient	37% DM	43% Corn silage
37% DM corn silage	92.140	—
43% DM corn silage	—	92.140
Bypass soy[b]	3.000	3.000
Concentrated corn gluten meal[c]	2.000	2.000
Urea	0.750	0.750
Limestone	0.100	0.100
Trace mineral premix[d]	2.000	2.000
Vitamin A-D-E premix[e]	0.015	0.015

[a]Treatments: Diets contained 92.14% of either 37% or 43% DM corn silage and fed at ad libitum or restricted at 1.5% of BW.

[b]Enzymatically browned soybean meal 50% CP; 75% RUP as % CP (SoyPass; Borregaard Lignotech, Rothschild, WI).

[c]Concentrated corn gluten meal 75% CP; 65% RUP as % of CP (Cargill Inc., Blair, NE).

[d]Trace mineral premix contained 6% Zn, 5.0% Fe, 4.0% Mn, 0.29% Mg, 0.2% I, and 0.05% Co.

[e]Vitamin A-D-E premix contained 30,000 IU of Vitamin A, 6,000 IU of Vitamin D, 7.5 IU of Vitamin E per gram.

Intake restriction to 1.5% of BW began on d 8 of the period 3 d before collection. BW was determined by weighing 2 consecutive days at the end of a period for subsequent restriction calculations in the next period. During the adaptation period, lambs were housed in individual pens with grated floors, individual feed bunks, and automatic waterers. Feeding occurred twice daily at approximately 0800 and 1500 h, and orts were collected, weighed, and fed back during the adaptation period.

At the end of adaptation, lambs were placed in individual metabolism crates and fitted with harnesses and fecal collection bags on the evening of d 10. Total fecal output was collected twice daily beginning on d 10 at 0800 and 1600 h, weighed, and retained individually in a cooler until the end of the period. Orts were collected at feeding, weighed, and retained individually until the end of the period. At the end of each period, feces and orts were individually composited and mixed on an as-is basis. Three 100 g subsamples were taken and dried in a 60 °C forced-air oven for 48 h for orts and 72 h for feces. Dried samples were ground through a 1-mm screen of a Wiley mill. Samples of individual feedstuffs were taken on d 10 and d 14 and dried to correct for DM of each period. Feedstuff samples were ground first through a 2-mm screen of a Wiley mill, composited by period, and a subset of period composites were ground through a 1-mm screen of a Wiley mill. Diet and fecal samples were analyzed for DM, organic matter (OM), and NDF. Ground feed and fecal samples were dried in a 100 °C oven for 24 h to determine laboratory-adjusted DM and then incinerated in a muffle furnace at 600 °C for 6 h to determine the ash content to calculate OM. Neutral detergent fiber was determined by refluxing samples in beakers for 1 h (Van Soest and Marcus, 1964; Van Soest et al., 1991). Total tract apparent digestibility was calculated using DM, OM, and NDF disappearance.

Total tract digestibility data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.) with period and block as fixed effects. Lamb was included as a random effect. Lamb served as the experimental unit, and the model included corn silage DM, intake, and corn silage DM by intake interaction. Significance was declared at $P \leq 0.05$.

RESULTS AND DISCUSSION

Corn Silage and Grain Harvest

There was an increase ($P < 0.01$) in yield of DM megagrams per hectare comparing 37% DM to 43% DM corn silage with yields of 21.41 and 22.58 Mg/ha (DM), respectively (Table 5). There was no difference ($P = 0.64$) in yield between HMC and dry corn grain with 13.72 and 13.80 Mg/ha DM yields, respectively (data not presented). The increase in DM yield is the result of increased grain development, as the plant matures, the grain fraction of the plant is increased as more nutrients are shuttled into the corn kernels for them to fully develop. Suazo et al. (1991) reported that across multiple hybrids, whole-plant DM yield in this study was maximized at black layer formation and grain yield in megagrams per hectare did not differ from black layer to corn grain harvest. Darby and Lauer (2002) reported that whole-plant DM yield increased as the growing season was lengthened and more growing degree days occurred. Maximum DM yield was achieved when whole-plant DM reached 42% DM, which occurred at the latest date the researchers harvested. Burken et al. (2017a) harvested corn plants at three different time points coinciding with traditional silage harvest with a whole-plant DM of 35.8%, physiological maturity with a whole-plant DM of 42.4%, and corn grain harvest. In year 1 of the experiment, stover yield and whole-plant yields responded in a quadratic fashion with both stover and whole-plant yields maximized at physiological maturity and decreased at corn grain harvest. The authors suggested that this could be due to senescence and abscission as the stover portion of the plant became dry and brittle after physiological maturity. In year 2 of the experiment, Burken et al. (2017a) noted linear increases in whole-plant and stover yields as harvest was delayed from traditional silage harvest to corn grain harvest. Year-to-year variation will occur in corn silage yield because of management and environmental factors; however, Burken et al. (2017a) reported greater whole-plant yield at physiological maturity compared to traditional corn silage harvest in both years. Filya (2004) also reported DM yield in megagrams per hectare was maximized at black layer formation that coincided with 42% whole-plant DM. In addition, Hunt et al. (1989) reported that as harvest was delayed, whole-plant yield and TDN in megagrams per hectare increased. These data suggest that grain yield was maximized when delaying corn silage harvest until black layer formation. In addition, high-moisture corn was harvested 3 d after the 43% DM silage was harvested further suggesting grain yield was maximized. No further yield increase for grain was observed between this time point and dry grain harvest.

Experiment 1—Cattle Finishing Experiment

There were no interactions between corn silage DM and corn silage concentration ($P \geq 0.47$) for feedlot performance or carcass characteristics (Table 6). As concentration of corn silage in the

Table 5. Delayed corn silage dry matter and yield

	Treatments[a]					
	Early harvest		Late hrvest		SEM	*P* value
Item	Mean	SD	Mean	SD		
Silage DM[b], %	37.3	1.2	42.7	1.7		
Silage yield, DM Mg/ha[c]	21.41	0.52	22.58	0.13	0.19	<0.01

[a]Early harvest corn silage harvested at whole-plant DM = 37.3% DM and kernel milk = ¾ harvested on September, 4, 2014. Late harvest corn silage harvested at whole-plant DM = 42.7% DM and kernel black layer formation harvested on September 16, 2014.

[b]DM was calculated using weekly ($n = 19$) samples and oven dried for 48 h at 60 °C. Coefficient of variation was 3.2 for early harvest and 3.9 for late harvest based on weekly DM samples.

[c]Silage yield = total DM Mg/ha at 100% DM.

Table 6. The effects of delayed corn silage harvest and increased concentrations of corn silage on feedlot performance and carcass characteristics of cross bred yearling steers (experiment 1)

	Treatments[a]							
	15% Corn silage		45% Corn silage			*P* value		
Variable	37% DM	43% DM	37% DM	43% DM	sem	Int.[b]	Concentration[c]	DM[d]
Feedlot performance								
Initial BW, kg	426	427	426	427	0.5	0.77	0.87	<0.01
Final BW[e], kg	621	626	608	608	7.0	0.71	0.04	0.68
Live final BW, kg	638	649	635	640	9.7	0.76	0.54	0.44
DMI, kg/d	13.0	13.2	13.3	13.5	0.2	0.82	0.15	0.30
ADG, kg	1.85	1.87	1.72	1.71	0.07	0.79	0.04	0.90
G:F	0.142	0.142	0.129	0.126	0.003	0.79	<0.01	0.64
NE_m, Mcal/kg DM[f]	1.81	1.80	1.68	1.66	0.03	0.88	<0.01	0.62
NE_g, Mcal/kg DM[f]	1.17	1.16	1.06	1.04	0.02	0.83	<0.01	0.53
Carcass characteristics								
Hot carcass weight, kg	391	394	383	383	4.4	0.71	0.04	0.68
Dressing percentage, %	61.1	60.8	60.2	59.8	0.56	0.93	0.05	0.68
Longissimus area, cm^2	84.38	82.63	84.78	83.36	0.89	0.85	0.52	0.08
12th-rib fat, cm	1.28	1.40	1.26	1.28	0.08	0.47	0.26	0.27
Marbling score[g]	514	498	489	493	14.0	0.48	0.29	0.67

[a]Treatments: 15% silage 37% DM = 15% concentration of 37% DM silage, 15% silage 43% DM = 15% concentration of 43% DM silage, 45% silage 37% DM = 45 % concentration of 37% DM silage, 45% silage 43% DM = 45 % concentration of 43% DM silage; all diets contained 40% MDGS.

[b]Silage concentration × silage DM interaction.

[c]Fixed effect of silage concentration.

[d]Fixed effect of silage DM.

[e]Final BW, were calculated based on HCW/common dressing percent of 63%.

[f]NE_m and NE_g were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009) assuming a 625 kg target endpoint.

[g]Marbling score 400 = small00, 500 = modest00.

finishing diet increased from 15% to 45%, ADG decreased ($P = 0.04$) whereas DMI did not differ ($P = 0.15$), and this, in turn, led to a decrease in G:F ($P < 0.01$). Goodrich et al. (1974) reported linear decreases in ADG and G:F as corn silage was increased in the finishing diet. Similarly, Gill et al. (1976) observed decreased G:F as corn silage was increased in the finishing diet. Brennan et al. (1987) reported no difference in DMI, ADG, or G:F between cattle fed 41% and 23% corn silage in finishing diets. Erickson (2001) evaluated corn silage in finishing diets at 15%, 30%, or 45% of diet on a DM basis. In two trials with yearling cattle, DMI was not affected by treatment, but ADG and G:F decreased as corn silage concentration increased from 15% to 45% of the diet. In a trial with calf feds, Erickson (2001) reported that DMI increased as corn silage concentration increased; however, ADG and G:F both linearly decreased with increased corn silage. At present, Burken et al. (2017a) fed increased concentrations of corn silage at 15%, 30%, 45%, and 55% with modified distillers grains plus solubles (MDGS) concentration of 40% (DM basis) and an additional diet of 45% corn silage and no distillers in finishing diets to evaluate animal performance. As corn silage concentration increased from 15% to 45%, DMI, ADG, and G:F decreased linearly, but when comparing diets with 45% corn silage, the diet with 40% MDGS had greater ADG and G:F compared to 45% silage with 0% MDGS. Although performance was reduced when feeding greater concentrations of corn silage and distillers grains plus solubles (DGS), the decrease in performance is less with DGS in the diet compared to in previous studies without DGS.

Calculated net energy for maintenance (NE_m) and net energy for gain (NE_g) values were decreased ($P < 0.01$) as corn silage concentration increased from 15% to 45% of the diet DM. Preston (1975) summarized experiments where corn silage replaced corn grain up to 64% of the diet and reported linear decreases in NE_m and NE_g values as concentration of corn silage increased. Similarly, Burken et al. (2017a) reported linear decreases in NE_m by 4% (2.00 to 1.92) and NE_g by 4.5% (1.34 to 1.28) values as corn silage concentration increased from 15% to 55% of the diet DM. Although performance was reduced when feeding high levels of corn silage and DGS, the decrease in performance is less with DGS in the diet compared to previous studies without

DGS. Burken et al. (2017a) fed 40% MDGS in the diet and increased the amount of corn silage in the diet from 15% to 45%, which resulted in a 5% reduction in G:F. However, without DGS in the diet, both Goodrich et al. (1974) and Erickson (2001) reported a 15% reduction in G:F when increasing silage concentration from 15% to 45%. As corn silage concentration increased from 15% to 45%, ADG and G:F decreased due to the decrease in dietary energy content as corn silage is lower in net energy compared to the corn gain it replaced in the finishing diet.

Carcass-adjusted final BW and HCW were reduced ($P \leq 0.04$) for steers fed 45% corn silage compared to 15%. Burken et al. (2017a) reported a linear decrease in final BW and HCW as corn silage was increased in finishing diets. In two additional studies by Burken et al. (2017b), they reported that final BW and HCW tended to decrease in the first experiment and significantly decreased in final BW and HCW in the second experiment as concentration of corn silage increased from 15% to 45% of the diet. Dressing percentage decreased ($P = 0.05$) as concentration of corn silage was increased from 15% to 45% in the finishing diet. When cattle are fed elevated concentrations of corn silage, dressing percentage decreases due to increased gut fill. Peterson et al. (1973) reported that as corn silage concentration increased, dressing percentage linearly decreased. Similarly, Brennan et al. (1987) reported cattle fed increased concentrations of corn silage had decreased dressing percentages. Burken et al. (2017a) reported a linear decrease in dressing percentage as corn silage concentration increased. There were no differences ($P \geq 0.31$) in LM area, 12th rib fat, and marbling score as concentration of corn silage concentration increased. Burken et al. (2017b) also reported no differences in carcass characteristics when silage was fed at 15% or 45% of the diet.

As DM of corn silage increased from 37% to 43% due to delaying harvest, there were no differences ($P \geq 0.30$) in DMI, ADG, or G:F. In addition, there were no differences ($P = 0.68$) in carcass-adjusted final BW or HCW as corn silage DM was increased. Chamberlain et al. (1971) compared corn silage in finishing diets (27% of diet DM) harvested from 25% to 44% whole-plant DM, and as harvest maturity increased, there were no differences in final BW, DMI, ADG, or G:F in the finishing period across all corn silages. Buchanan-Smith (1982) compared corn silage harvested at 28% or 42% whole-plant DM in finishing steers and reported that steers fed 42% DM silage had a 5% increase in DMI. There was no difference in ADG between steers fed 28% and 42% DM silage; however, there was a numerical increase in ADG and G:F for steers fed 42% DM silage. Browne et al. (2004) compared silages harvested at 29.1%, 33.9%, and 39.3% whole-plant DM in European style finishing systems with 89% corn silage included in the finishing diet. The authors found that as harvest was delayed, DMI increased and G:F decreased; however, final BW, HCW, and ADG were not different. These data tend to support a lack of difference in finishing diets with 15% to 45% silage, or relatively low inclusions when corn silage is harvested between 25% and 44% DM. It is unclear if the lack of differences due to harvest DM is due to low inclusions and masking any difference in silage or if just no difference exists between harvest DM of silage when fed in finishing diets. Similar to ADG and G:F in this study, no differences ($P \geq 0.27$) in dressing percent, 12th rib fat, or marbling scores were observed as DM of corn silage was increased.

In finishing diets, increasing silage inclusion from 15% to 45% of diet DM decreases ADG and G:F that agrees with previous work, but the decreases are less than some previous studies, particularly those without distillers grains. Whether silage was harvested at a DM of 37% or 43% DM did not affect ADG or G:F in finishing cattle.

Experiment 2—Cattle Growing Experiment

There were no linear ($P \geq 0.33$) or quadratic ($P \geq 0.36$) interactions between corn silage DM and level of RUP supplementation for growing performance. As DM of corn silage increased from 37% to 43%, there was a significant decrease ($P = 0.04$) in ending BW (Table 7). There was no difference ($P = 0.93$) in DMI between 37% and 43% DM corn silage, and ADG was reduced ($P = 0.01$) as DM of silage increased, which led to a significant decrease ($P < 0.01$) in G:F. Worley et al. (1986) fed silage harvested at 31% or 44% whole-plant DM to growing heifers. The authors reported decreased ADG and G:F in the first 28 DOF when feeding drier silage, similar to this study. Although overall performance from d 0 to d 70 was not statistically different, the 44% DM silage had numerically lower ADG and G:F. Chamberlain et al. (1971) compared corn silage in growing diets (70% of diet DM) harvested from 25% to 44% whole-plant DM. There were no differences in ADG between the first three stages of maturity harvested at 25%, 30%, and 36.5% DM, but the latest maturity harvested at 44% DM had the lowest ADG. Intake was lowest for latest harvested corn silage and G:F decreased as harvest was delayed. When evaluating corn silage harvested at ½ milk line (28.4% DM) or black layer (42.5% DM), Andrae et al. (2001) reported decreases in total tract starch, NDF digestibility (NDFD), and ADF digestibility (ADFD) by 6.5, 5.9, and 7.5 percentage units, respectively. The authors concluded that NDFD and ADFD decreased due to increased lignification, and also the increased starch content from the more mature corn silage caused an unfavorable rumen environment with lower pH that hindered fiber digestion. Calculated NE_m and NE_g values were significantly lower ($P = 0.03$) for 43% DM compared to 37% DM corn silage. These studies suggest some consensus that dryer silage fed to growing steers reduces ADG and G:F and is likely due to either decreases in fiber digestion due to more mature plants or more starch concentration that decreases fiber digestion in the rumen.

As supplemental RUP in the growing diet increased from 0.5% to 4.2% of total diet, ending BW increased linearly ($P < 0.01$) with steers receiving 4.2% RUP as a % of total diet having the heaviest ending BW and steers receiving 0.5% supplemental RUP having the lowest ending BW (Table 8). There was a linear increase ($P = 0.05$) in DMI as RUP concentration increased in the growing diet. Daily gain improved as RUP concentration increased in the growing diet, with ADG increasing ($P < 0.01$) linearly from 0.5% to 4.2% RUP concentration. With a greater increase in ADG compared to the increase in DMI, G:F increased ($P < 0.01$) linearly as RUP concentration increased. Steers fed the 4.2% supplemental RUP treatment were 19.9%, 14.5%, 5.9%, and 2.7% more efficient than steers supplemented with 0.5%, 1.4%, 2.4%, or 3.3% RUP, respectively.

Ingredients can vary in RUP content as well as RUP digestibility. Corn grain is the most commonly fed grain in the United States, and dry corn grain has a RUP value of approximately 65.3% (NASEM, 2016). Corn processing method impacts RUP %. Work by Benton et al. (2005) showed that when grain is harvested as HMC, the RUP content of corn grain decreases, and it becomes more rumen degradable as the moisture content and length of ensiling period increases. The corn grain in silage is harvested earlier than HMC and wetter, suggesting a further increase in RDP content of the corn grain in corn silage. The NASEM (2016) lists the

Table 7. Effects of delayed corn silage harvest on growing steer performance (experiment 2)

	Treatments[a]			
Item	37% DM	43% DM	SEM	*P* value
Initial BW, kg	271	271	1.8	0.92
Ending BW, kg	384	375	3.0	0.04
DMI, kg/d	8.2	8.1	0.1	0.93
ADG, kg	1.45	1.33	0.03	0.01
G:F	0.177	0.164	0.001	<0.01
NE_m, Mcal/kg DM[b]	1.73	1.65	0.02	<0.01
NE_g, Mcal/kg DM[b]	1.11	1.04	0.02	<0.01

[a]Treatments: steers were fed 88% of either 37% or 43% DM corn silage.

[b]NE_m and NE_g were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009) assuming a 625 kg target endpoint.

Table 8. The effects of increased concentration of RUP in silage based growing diets on performance of cross bred steers (experiment 2)

	Treatments[a]							
Variable	0.5%	1.4%	2.4%	3.3%	4.2%	SEM	Lin.	Quad.
Initial BW, kg	270	271	271	270	272	2.4	0.98	0.60
Ending BW, kg	359	374	388	382	394	4.1	<0.01	0.88
DMI, kg/d	7.7	8.3	8.6	7.9	8.3	0.2	0.05	0.84
ADG, kg	1.14	1.32	1.50	1.43	1.56	0.04	<0.01	0.82
G:F	0.149	0.159	0.175	0.181	0.186	0.002	<0.01	0.57
NE_m, Mcal/kg DM[b]	1.58	1.63	1.71	1.77	1.79	0.04	<0.01	0.57
NE_g, Mcal/kg DM[b]	0.97	1.02	1.09	1.14	1.16	0.03	<0.01	0.57

[a]Treatments: Diets contained 88% of either 37% or 43% DM corn silage and formulated to contain 0.5%, 1.4%, 2.4%, 3.3%, or 4.2% RUP % of total diet.

[b]NE_m and NE_g were calculated using methodology of NRC (1996) using a tool developed by Galyean (2009) assuming a 625 kg target endpoint.

RUP content for corn silage as 25.38% (% of CP). When evaluating the RUP value of forages, work by Kononoff et al. (2007) found that the digestibility of forage RUP is much lower than the 80% suggested by the NRC (1996). Specifically looking at corn silage, Kononoff et al. (2007) estimated RUP (% of CP) to be 19.25%, but with an intestinal RUP digestibility of only 19.9%. Much of the protein in silage is fermented to soluble protein in the bunker and to ammonia in the rumen. Such degradation reduces the amount of intact protein and amino acids available in the small intestine as RUP (Owens et al., 2018). The level and degradability in the rumen of protein can have a large impact on growing steer performance. Byers and Moxon (1980) fed corn silage-based growing diets (55% of diet DM) and three levels of protein, 11.6%, 14.1%, or 16.5%, to growing steers (average initial BW = 233 kg). The additional CP in these supplements came from increased soybean meal (44% RUP; NASEM, 2016) and linseed meal (32% RUP; NASEM, 2016). As CP increased from 11.6 to 16.5, DMI, ADG, and G:F significantly increased. This indicated that calves fed 11.6% CP were not meeting their MP requirements, therefore limiting growth. Perry et al. (1983) fed corn silage (92% of diet DM) to growing steers (average initial BW = 213 kg) with supplemental soybean meal to achieve CP levels of 9%, 11%, or 13% of DM. Increasing the level of CP in the diet increased DMI, ADG, and G:F of these growing calves. Although Byers and Moxon (1980) and Perry et al. (1983) concluded that increased dietary protein in silage based growing diets improves performance, it is actually RUP of supplemental CP that had a significant impact on performance because the addition of urea (100% RDP) does not have the same magnitude of increase as the RUP supplements that were used in those trials. Felix et al. (2014) compared corn silage-based (90% of DM) diets with increased levels of CP at 11%, 12%, and 13%, and only urea was used to increase CP. When increasing the CP through increased urea in silage diets fed to growing calves (initial BW = 198 kg), the authors reported a linear decrease in ending BW, ADG, and G:F and increasing the amount of RDP did not increase the microbial crude protein supply enough to maximize growth. Felix et al. (2014) compared silage-based (79% on DM basis) growing diets with sources of supplemental protein on animal performance. The authors compared silage growing diets and formulated diets to be iso-nitrogenous with a CP of 10.8%; however, the source of supplemental protein, urea, DDGS, or soybean meal (SBM), was different. The DDGS and SBM supplemented treatments had greater final BW, DMI, ADG, and G:F. As corn silage is lacking in the protein necessary to meet MP requirements in growing calves, supplementing with protein such as DDGS or SBM that has more RUP than urea benefited these growing calves compared to increased RDP in the urea treatment. All these studies, along with results from experiment 2, suggest the MP requirement is larger than previously thought or corn silage is providing less digestible RUP than previously thought. More research is needed on RUP concentration and digestibility to accurately model MP supply compared to requirements for the growing calves in experiment 2.

Experiment 3—Lamb Digestion Experiment

There was no interaction between corn silage DM and intake level for DM and OM intake and digestibility, and the main effects will be presented. Owing to intake restriction between ad libitum and lambs held at 1.5% of BW, there was a significant ($P < 0.01$) decrease in DMI and OM intake for restricted lambs as designed (Table 9). There were no differences ($P = 0.56$) in DM digestibility and OM digestibility between silage harvest and intake level. Worley et al. (1986) fed silage harvested at 31% or 44% whole-plant DM either ad libitum or restricted to growing lambs. The authors reported greater DMI for 44% DM corn silage when fed ad libitum, but there were no differences in DM digestibility between silage DM when fed ad libitum or restricted. Johnson and McClure (1968) reported greater DMI as whole-plant DM increased to 33.9% DM and remained constant up to 46% when fed to growing lambs. The authors reported DM digestibility and OM digestibility were significantly affected by harvest DM over a broad range of harvest DM. Between 33.9% and 42.6% DM, DM digestibility changes were minimal: 68.2% vs. 68.9% for 33.9 and 42.6% DM silages, respectively. When feeding beef steers, Joanning et al. (1981) reported no difference in DM digestibility between corn silage harvested at 22% or 35% DM. Similarly, McGeough et al. (2010) reported no differences in DMI or DM digestibility between silage harvested at four different maturities.

There was an intake × harvest time interaction for NDF intake and therefore the simple effects will be discussed. Concentration of NDF was lower in 43% DM silage so lambs restricted to 1.5% BW for intake had lower NDF intake than 37% DM. The interaction was observed because the magnitude of

Table 9. Effect of delayed corn silage harvest and intake restriction on digestibility in lambs (experiment 3)

	Treatments[a]							
	Ad libitum		Limited			*P* value		
Item	37% DM	43% DM	37% DM	43% DM	SEM	Int.[b]	Intake[c]	DM[d]
DM								
Intake, kg/d	2.14	1.99	1.16	1.15	0.08	0.28	<0.01	0.23
Digestibility, %	70.8	71.5	71.9	71.1	1.3	0.56	0.76	0.97
OM								
Intake, kg/d	2.01	1.89	1.09	1.09	0.08	0.33	<0.01	0.39
Digestibility, %	72.6	73.3	73.7	73.1	1.3	0.56	0.67	0.99
NDF								
Intake, kg/d	1.07	0.77	0.58	0.45	0.03	<0.01	<0.01	<0.01
Digestibility, %	63.4	53.3	65.4	53.5	0.02	0.67	0.60	<0.01

[a]Treatments: Diets contained 92.14% of either 37% or 43% DM corn silage and fed at ad libitum or restricted at 1.5% of BW.

[b]Silage intake × silage DM interaction.

[c]Fixed effect of silage intake.

[d]Fixed effect of silage DM.

difference in NDF intake was even greater when lambs were fed ad libitum, which was due to lower NDF concentration and numerically lower DMI for 43% DM silage compared to 37% DM silage. In general, intake of NDF was reduced ($P < 0.01$) when intake was restricted as expected but also reduced ($P < 0.01$) for lambs fed 43% DM corn silage compared to 37% DM corn silage. The NDF concentration of the silage was decreased and starch concentration increased as corn silage harvest was delayed. As silage harvest was delayed from 37% to 43% DM, there was a significant decrease ($P < 0.01$) in NDFD from 64.39% to 53.41%. Worley et al. (1986) reported greater NDF intake in 44% DM corn silage compared to 31% DM but reported no difference in NDFD when lambs were fed ab libitum or had intake restricted. The corn silage used by Worley et al. (1986) increased in NDF concentration as corn silage harvest was delayed, this is not in agreement with previous work that shows NDF concentration decreases as corn silage harvest is delayed, and could explain why these authors reported increased NDF intake. Jensen et al. (2005) reported NDF intake decreased as whole-plant DM increased from 35% to 40% DM. As corn silage is harvested later in the harvest season with advanced maturity, whole-plant NDF decreases (Bal et al., 1997; Di Marco et al., 2002; Ferraretto and Shaver, 2012). Andrae et al. (2001) reported that as the corn plant matures, the NDF content of the corn plant decreased from 43.67% to 38.43% NDF when harvested at 28.4% and 42.4% DM, respectively. These authors also reported digestibility of the NDF decreased from 39.11% to 33.21% when corn silage harvest was delayed. Fiber digestibility significantly decreased as corn silage harvest was delayed in growing lambs (Johnson and McClure, 1968). Joanning et al. (1981) reported that as silage DM increased from 22% to 35% DM, there was a decrease in NDFD of 14.6 percentage units in a 90% silage diet. Jensen et al. (2005) reported decreased NDFD as harvest DM increased from 35% to 40% DM. Similar to decreased NDF digestion by lambs in experiment 3, all studies show decreased fiber digestibility as silage harvest is delayed (i.e., DM increased in silage). Delaying silage harvest allows for increased grain yield as a percentage of whole-plant yield, with no impact on OM digestion, but delaying silage harvest decreases NDF content in this study and many others.

Delaying corn silage harvest increased corn silage yield and maximized grain yield. Although increasing corn silage concentration from 15% to 45% in place of corn in finishing diets reduced ADG and G:F, there were no differences in performance when corn silage harvest was delayed from 37% to 43% DM in these finishing diets. However, delayed corn silage harvest in growing diets indicates that 37% DM silage would result in greater ADG and G:F compared to feeding 43% corn silage. As corn silage harvest is delayed, plant NDF decreases at the expense of corn grain being maximized and NDF intake and digestibility decrease. Increasing the amount of RUP in silage growing diets resulted in linear increases in DMI, ADG, and G:F. These results indicate that the addition of RUP into silage growing diets will improve performance by supplying more MP.

Although increasing the concentration of corn silage in the finishing diet resulted in decreased performance compared to lower concentrations, the potential for increasing net farm income may be increased. Economic analysis was not performed, but by reducing cost of gain during the finishing period and recycling of nutrients from feedlot manure to farm fields, an opportunity may exist to increase farm profits.

Conflict of interest statement. None declared.

LITERATURE CITED

Allen, M.S., J.G. Coors, and G.W. Roth. 2003. Corn silage. In: Buxton, D.R., R.E. Muck, and J.H. Harrison, editors, Silage science and technology. agronomy monograph Vol. 42. Madison (WI): ASA, CSSA, SSSA. p. 574–608.

Andrae, J.G., C.W. Hunt, G.T. Pritchard, L.R. Kennington, J.H. Harrison, W. Kezar, and W. Mahanna. 2001. Effect of hybrid, maturity, and mechanical processing of corn silage on intake and digestibility by beef cattle. J. Anim. Sci. 79:2268–2275. doi:/10.2527/2001.7992268x.

AOAC. 1999. Official methods of analysis. 16th ed. Arlington (VA): Association of Official Analytical Chemists.

Bal, M.A., J.G. Coors, and R.D. Shaver. 1997. Impact of the maturity of corn for use as silage in the diets of dairy cows on intake, digestion, and milk production. J. Dairy Sci. 80:2497–2503. doi:10.3168/jds.S0022-0302(97)76202-7.

Benton, J.R. 2005. High moisture corn processing and degradable intake protein in diets for finishing cattle. M.S. Thesis. Lincoln (NE): University of Nebraska.

Buchanan-Smith, J.G. 1982. Preservation and feeding value for yearling steers of whole plant corn ensiled at 28 and 42% dry matter with and without cold flow ammonia treatment. Can. J. Anim. Sci. 62:173–180. doi:10.4141/cjas82-018. doi:10.4141/cjas82-018.

Brennan, R.W., M.P. Hoffman, F.C. Parrish, F. Epplin, S. Bhide, and E.O. Heady. 1987. Effects of differing ratios of corn silage and corn grain on feedlot performance, carcass characteristics, and projected economic returns. J. Anim. Sci. 64:23–31. doi:10.2527/jas1987.64123x.

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.

Browne, E.M., D.T. Juniper, M.J. Bryant, D.E. Beever, and A.V. Fisher. 2004. Intake, live-weight gain and carcass characteristics of beef cattle given diets based on forage maize silage harvested at different stages of maturity. Anim. Sci. 79:405–413. doi:10.1017/S1357729800090275.

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. 2017a. 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. 1:367–381. doi:10.2527/tas2017.0045.

Burken, D.B., B.L. Nuttelman, M.J. Jolly-Briethaupt, J.L. Gramkow, S.E. Gardine, T.J. Klopfenstein, J.C. MacDonald, and G.E. Erickson. 2017b. Digestibility and performance of steers fed varying inclusions of corn silage and modified distillers grains with solubles to partially replace corn in finishing diets. Transl. Anim. Sci. 1:382–396. doi:10.2527/tas2017.0046.

Byers, F.M., and A.L. Moxon. 1980. Protein and selenium levels for growing and finishing beef cattle. J. Anim. Sci. 50:1136–1144. doi:10.2527/jas1980.5061136x.

Chamberlain, C.C., H.A. Fribourg, K.M. Barth, J.H. Felts, and J.M. Anderson. 1971. Effect of maturity of corn silage at harvest on the performance of feeder heifers. J. Anim. Sci. 33:161–166. doi:10.2527/jas1971.331161x.

Darby, H.M. and J.G. Lauer. 2002. Harvest date and hybrid influence on corn forage yield, quality, and preservation. Agron. J. 94:559–566. doi:10.2134/agronj2002.5590.

Di Marco, O.N., M.S. Aello, M. Nomdedeu, and S. Van Houtte. 2002. Effect of maize crop maturity on silage chemical composition and digestibility (in vivo, in situ and in vitro). Anim. Food Sci. Tech. 99:37–43. doi:10.1016/S0377-8401(02)00077-9.

Erickson, G.E. 2001. Designing beef feedlot nutrition programs to solve environmental challenges related to nitrogen and phosphorus. Ph.D. Diss. Lincoln (NE): University. of Nebraska.

Felix, T.L., S.C. Loerch, and F.L. Fluharty. 2014. Protein supplementation for growing cattle fed a corn silage-based diet. Prof. Anim. Sci. 30:327–332. doi:10.15232/S1080-7446(15)30124-8.

Ferraretto, L.F. and R.D. Shaver. 2012. Meta-analysis: effect of corn silage harvest practices on intake, digestion, and milk production by dairy cows. Prof. Anim. Sci. 28:141–149. doi:10.15232/S1080-7446(15)30334-X.

Filya, I. 2004. Nutritive value and aerobic stability of whole crop maize silage harvested at four stages of maturity. Anim. Feed Sci. Tech. 116:141–150. doi:10.15232/S1080-7446(15)30334-X.

Galyean, M. 2009. The Home Page of Michael Galyean. NEm and NEg Calculations. [accessed April 25, 2018]. Available: http://www.depts.ttu.edu/afs/home/mgalyean/.

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. Research Report B-195. Minneapolis (MN): University of Minnesota. p. 14–19.

Hunt, C.W., W. Kezar, and R. Vinande. 1989. Yield, chemical composition and ruminal fermentability of corn whole plant, ear, and stover as affected by maturity. J. Prod. Agric. 2:357–361. doi:10.2134/jpa1989.0357.

Jensen, C., M.R. Weisbjerg, P. Nørgaard, T. Hvelplund. 2005. Effect of maize silage maturity on site of starch digestion and NDF digestion in lactating dairy cows. Anim. Feed Sci. Tech. 118:279–294. doi:10.1016/j.anifeedsci.2004.10.011.

Joanning, S.W., D.E. Johnson, and B.P. Barry. 1981. Nutrient digestibility depressions in corn silage-corn grain mixtures fed to steers. J. Anim. Sci. 53:1095–1103. doi:10.2527/jas1981.5341095x.

Johnson, R.R. and K.E. McClure. 1968. Corn plant maturity. IV. Effects on digestibility of corn silage in sheep. J. Anim. Sci. 27:535–539. doi:10.2527/jas1968.272535x.

Kononoff, P.J., S.K. Ivan, and T.J. Klopfenstein. 2007. Estimation of the proportion of feed protein digested in the small intestine of cattle consuming wet corn gluten feed. J. Dairy Sci. 90:2377–2385. doi:10.3168/jds.2006-552.

Mc Geough, E.J., P. O'Kiely, P.A. Foley, K.J. Hart, T.M. Boland,

and D.A. Kenny. 2010. Methane emissions, feed intake, and performance of finishing beef cattle offered maize silages harvested at 4 different stages of maturity. J. Anim. Sci. 88:1479–1491. doi:10.2527/jas.2009-2380.

NASEM. 2016. Nutrient requirements of beef cattle: eighth revised edition. Washington, DC: The National Academies Press.

NRC. 1996. Nutrient requirements of beef cattle. 7th ed. Washington, DC: National Academy Press.

Owens, F. 2008. Corn silage – facts, fantasies, and the future. 2008. In: Proceedings of the Florida Ruminant Nutrition Symposium. Gainesville: University of Flordia.

Owens, F., A. DiCostanzo, and T. Johnson. 2018. Efficiency of various corn cropping and feeding systems. In: Proceedings of the 2018 Plains Nutrition Council Spring Conference, San Antonio, TX. Amarillo, TX: Texas AgriLife Res. and Ext. Ctr. p. 38–82.

Perry, T.W., D.R. Shields, W.J. Dunn, and M.T. Mohler. 1983. Protein levels and monensin for growing and finishing steers. J. Anim. Sci. 57:1067–1076. doi:10.2527/jas1983.5751067x.

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 weighing procedures and variation in protein degradation rate on measured performance of growing lambs and cattle. J. Anim. Sci. 57:1276–1285. doi:10.2527/jas1983.5751276x.

Suazo, R., R.N. Sonon, L. Ptaff, J.T. Dickerson, and K.K. Bolsen. 1991. Effects of hybrid and maturity at harvest on agronomic performance of corn for silage. In: Proc. Cattlemen's Day 1991. Manhattan: Kansas State University. p. 63–65.

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. (Abstract of 1964 Amer. Dairy Sci. Assoc., Univ. of Ariz. Tucson).

Van Soest, P.J., J.B. Robertson, and B.A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2.

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.

Worley, R.R., J.A. Paterson, K.P. Coffey, D.K. Bowman, and J.E. Williams. 1986. The effects of corn silage dry matter content and sodium bicarbonate addition on nutrient digestion and growth by lambs and calves. J. Anim. Sci. 63:1728–1736. doi:10.2527/jas1986.6361728x.