Effect of corn residue harvest method with ruminally undegradable protein supplementation on performance of growing calves and fiber digestibility¹

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ABSTRACT: Two experiments evaluated the effects of corn residue harvest method on animal performance and diet digestibility. Experiment 1 was designed as a $2 \times 2 + 1$ factorial arrangement of treatments using 60 individually fed crossbred steers (280 kg [SD 32] initial BW; $n = 12$). Factors were the corn residue harvest method (high-stem and conventional) and supplemental RUP at 2 concentrations (0 and 3.3% diet DM). A third harvest method (low-stem) was also evaluated, but only in diets containing supplemental RUP at 3.3% diet DM because of limitations in the amount of available low-stem residue. Therefore, the 3 harvest methods were compared only in diets containing supplemental RUP. In Exp. 2, 9 crossbred wethers were blocked by BW (42.4 kg [SD 7] initial BW) and randomly assigned to diets containing corn residue harvested 1 of 3 ways (low-stem, high-stem, and conventional). In Exp. 1, steers fed the low-stem residue diet had greater ADG compared with the steers fed conventionally harvested corn residue ($P = 0.03$; 0.78 vs. 0.63 kg), whereas steers fed high-stem residue were intermediate ($P > 0.17$; 0.69 kg), not differing from either conventional or low-stem residues. Results from in vitro OM digestibility suggest that low-stem residue had the greatest ($P < 0.01$)

amount of digestible OM compared with the other 2 residue harvest methods, which did not differ ($P = 0.32$; 55.0, 47.8, and 47.1% for low-stem, high-stem, and conventional residues, respectively). There were no differences in RUP content (40% of CP) and RUP digestibility (60%) among the 3 residues ($P \geq 0.35$). No interactions were observed between harvest method and the addition of RUP ($P \geq 0.12$). The addition of RUP tended to result in improved ADG (0.66 ± 0.07 vs. 0.58 ± 0.07 for supplemental RUP and no RUP, respectively; $P = 0.08$) and G:F (0.116 ± 0.006 vs. 0.095 ± 0.020 for supplemental RUP and no RUP, respectively; $P = 0.02$) compared with similar diets without the additional RUP. In Exp. 2, low-stem residue had greater DM and OM digestibility and DE ($P < 0.01$) than high-stem and conventional residues, which did not differ ($P \geq 0.63$). Low-stem residue also had the greatest NDF digestibility (NDFD; $P < 0.01$), whereas high-stem residue had greater NDFD than conventional residue ($P < 0.01$). Digestible energy was greatest for low-stem residue ($P < 0.05$) and did not differ between high-stem and conventional residues ($P = 0.50$). Reducing the proportion of stem in the bale through changes in the harvest method increased the nutritive quality of corn residue.

Key words: corn residue, digestibility, growing steers, harvest method, rumen undegradable protein

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INTRODUCTION

Increased demand for biofuels has shifted land use to crop production, leading to an increase in the number of hectares of corn planted annually. From 2008 to 2012, 77% of land converted to crop production was from grasslands (Lark et al., 2015). The conversion of grasslands to cropland increased the availability of corn residue, which has historically been used as an economical forage source for beef producers. Grazing

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is the most economical method of using corn residue as feedstuff, but residue can also be baled and removed from the field (Ward, 1978). Baling residue inhibits animal selectivity and reduces residue quality because both highly digestible and less digestible components are harvested. Advancements in harvest technologies have the potential to improve the feeding quality of baled corn residue. The New Holland Cornrower Corn Head (Straeter, 2011; Manufacturer information: Craig Welding, Mentone, IN) allows producers to adjust the number of rows of stem, the least digestible plant part, being cut and baled. Reducing the proportion of stem in the bale potentially increases the quality of the bale. Although many studies have evaluated how changing the proportion of corn residue components affects the performance of grazing animals, new information is needed to determine the effect of changing the leaf:stem ratio in the bale on growing steer performance.

Due to the low level of CP in corn residue, growing calves consuming residue require supplemental protein to achieve desirable gains. Studies have found a response in supplemental RUP that is dependent on what residue components are available for grazing, as well as the digestibility of the grazed residue (Fernandez-Rivera and Klopfenstein, 1989). The hypothesis of this research is that reducing the proportion of stem relative to husk and leaf in harvested corn residue and supplementing harvested corn residue-based diets with RUP will improve performance of growing steers. Therefore, the objectives of these experiments were to determine 1) the effect of harvest method on residue quality and steer performance in growing diets, 2) the effect of supplemental RUP on steer performance in residue-based growing diets, and 3) the effect of harvest method on digestibility and quality of corn residue.

MATERIALS AND METHODS

All animal care and management procedures used were reviewed and approved by the University of Nebraska Institutional Care and Animal Use Committee (IACUC number 902).

Residue Harvest

Residues for this study were harvested using 1 of 3 methods from the same field near Ithaca, NE. Low-stem and high-stem corn residues were obtained using a New Holland Cornrower Corn Head (Straeter, 2011). The Cornrower head allows the producer to choose between 0, 2, 4, 6, and 8 rows of stem to be harvested when harvesting with an 8-row corn head. The stems are cut, chopped behind the corn head, and laid in a row between the combine tires to create a windrow.

The spreader of the combine is disengaged, causing the tailings to fall behind the combine onto the windrow. The spreader of the combine is disengaged, causing the tailings to fall behind the combine onto the windrow, which is collected to produce a bale of residue. For this study, 2 rows of stem were harvested to create a low-stem corn residue bale and all 8 rows of stem were harvested to create a high-stem corn residue. A conventional baled residue was also harvested to provide a comparison. The conventional baled residue was produced using the traditional rake and bale system of harvesting residue. Corn was traditionally harvested and tailings were expelled through the spreader at the back of the combine. The stems and tailings were raked to create a windrow and then baled. The yield of residue removed from the field using each harvest method was calculated by multiplying the number of bales by the average weight of a bale within an area for each harvest method. Eleven bales of the same harvest method were placed on a trailer and weighed on a scale. The weight of the trailer was then subtracted from the weight of the trailer plus the bales, and the remaining weight was divided by 11 to get the average bale weight (as-is basis).

Experiment 1

An 84-d growing trial was conducted at the University of Nebraska beef research facility located at the Eastern Nebraska Research and Extension Center near Mead, NE, using 60 crossbred steers (200 kg [SD 32] initial BW) that were individually fed with a Calan gate system (American Calan, Inc., Northwood, NH). Steers were limit-fed a diet of 50% alfalfa and 50% Sweet Bran (Cargill Wet Milling, Blair, NE) at 2% of BW for 5 d prior to the start of the trial to reduce variation in gut fill (Watson et al., 2013), and 3 consecutive day weights were collected (Stock et al., 1983) and the average was used as the initial BW for the experiment. Steers were blocked by initial BW and randomly assigned to 1 of 5 treatments with 12 steers per treatment in a randomized complete block design. Steers were implanted with 36 mg of zeranol (Ralgro; Merck Animal Health, Madison, NJ) on Day 1 of the trial.

The study consisted of 5 treatments: 1) conventionally baled residue without supplemental RUP, 2) conventionally baled residue with supplemental RUP, 3) high-stem residue without supplemental RUP, 4) high-stem residue with supplemental RUP, and 5) low-stem residue with supplemental RUP (Table 1). The effect of supplemental RUP was analyzed as a 2×2 factorial using contrasts to compare high-stem and conventional corn residues with and without supplemental RUP. Due to the limited availability of low-stem corn residue bales, only a diet containing additional RUP

Table 1. Composition of diets (DM basis) fed to growing steers (Exp. 1)

Ingredient, % of DM	Treatment ¹				
	Low-stem + RUP	High-stem	High-stem + RUP	Conventional	Conventional + RUP
Low-stem residue ²	64.5	—	—	—	—
High-stem residue ³	—	64.5	64.5	—	—
Conventional residue ⁴	—	—	—	64.5	64.5
Distiller's solubles	30	30	30	30	30
Supplement	5.5	5.5	5.5	5.5	5.5
Supplement composition, %					
SoyPass ⁵	1.98	—	1.98	—	1.98
Empyreal 75 ⁶	1.32	—	1.32	—	1.32
Soyhulls	—	3.3	—	3.3	—
Limestone	1.82	1.82	1.82	1.82	1.82
Tallow	0.14	0.14	0.14	0.14	0.14
Salt	0.15	0.15	0.15	0.15	0.15
Trace minerals	0.06	0.06	0.06	0.06	0.06
Vitamins A, D, and E	0.02	0.02	0.02	0.02	0.02
Rumensin ⁷	0.01	0.01	0.01	0.01	0.01

¹Treatments include 1 of 3 residues with +RUP diets containing 3.3% of diet DM of supplemental RUP. The comparison diets contain 0% supplemental RUP.

²Low-stem residue is corn residue harvested with 2 rows of stem.

³High-stem residue is corn residue harvested with 8 rows of stem.

⁴Conventional residue is corn residue harvested with the traditional rake and bale system.

⁵SoyPass (LignoTech USA, Inc., Rothschild, WI) is a branded soybean meal source high in RUP; 75% RUP as a % of CP (49.0% CP).

⁶Empyreal 75 (Cargill Wet Milling, Blair, NE) is a branded corn gluten meal source high in protein; 65.0% RUP as a % of CP (80.0% CP).

⁷Diets were formulated to provide 200 mg/steer daily of Rumensin (Elanco Animal Health, Indianapolis, IN) at 7.26 kg DM consumption.

was included to ensure the MP requirements of the steers was met. Therefore, the effects of the 3 harvest methods on steer performance used only the 3 diets with additional RUP. Supplemental RUP was added to treatment diets through the addition of a 50:50 blend of SoyPass (LignoTech USA, Inc., Rothschild, WI) and Empyreal 75 (Cargill Wet Milling; Table 1) providing 0 or 3.3% supplemental RUP as a percent of diet DM. The 50:50 blend provided RUP in a blend of AA from soybean meal and corn gluten meal. All diets were formulated to provide 200 mg/steer daily of monensin (Rumensin; Elanco Animal Health, Indianapolis, IN).

Feed samples were collected weekly, weighed, and then dried in a 60°C forced-air oven for 48 h to determine DM content (AOAC, 1999; method 934.01). Dried feed samples were ground with a Wiley mill (Thomas Scientific, Swedesboro, NJ) through a 1-mm screen. Ash and OM were measured by placing crucibles containing 0.5 g of each feed sample in a muffle oven for 6 h at 600°C (AOAC, 1999; method 942.05). Crude protein was also analyzed using a combustion-type N analyzer (Leco FP 528 Nitrogen Analyzer; LECO Corp., St. Joseph, MI). These samples were used to calculate diet nutrient composition (Table 2).

Feed refusals were removed from the bunk weekly and analyzed for DM. Refusals were subtracted from the total DM offered for each individual animal to determine actual DMI. At the conclusion of the trial, steers were limit-fed the same diet (50% alfalfa and

50% Sweet Bran) as in the beginning limit-fed period for 5 d. Steers were weighed for 3 consecutive days, and the average was used to determine ending BW.

An in vitro procedure was performed for 48 h to obtain in vitro OM digestibility (**IVOMD**) on the corn residues using the Tilley and Terry (1963) method with the modification of adding 1 g urea/L buffer (Weiss, 1994). One in vitro run was conducted with residues weighed in triplicate into 100-mL in vitro tubes. Rumen fluid from 2 cannulated steers, housed in the digestion area of the Animal Science building (University of Nebraska, Lincoln), consuming a diet of 70% grass hay and 30% concentrate was collected and strained through 4 layers of cheesecloth. Rumen fluid was then added to separatory funnels, flushed with CO₂, stoppered, and placed in a warm water bath (39°C) to allow particulates to float to the top. Fluid with particulates removed was mixed with McDougall's buffer in a 1:1 ratio and then added to tubes. Standards for hay and corn residue with known in vivo values were included to provide a comparison of between-run values (Geisert, 2007). In vitro tubes were placed in a 39°C water bath for 48 h. Tubes were swirled every 12 h to mimic contraction and mixing of rumen contents. Upon completion of the 48-h fermentation period, hydrochloric acid and pepsin were added to each tube and the tubes were kept in the water bath for an additional 24 h to stimulate abomasal digestion. Tubes contents were filtered through Whatman 541 ashless filters and placed in a 100°C forced-air oven for 12 h to

Table 2. Nutrient composition of diets fed to growing steers (Exp. 1)

Item	Low-stem + RUP ¹	High-stem ²	High-stem + RUP ³	Conventional ⁴	Conventional + RUP ⁵
DM, %	55.90	54.97	54.97	56.15	56.15
OM, %	93.87	92.57	92.42	92.05	91.90
NDF, %	55.83	55.68	54.27	51.76	50.36
Fat, %	5.55	5.59	5.55	5.70	5.67
CP, %	12.71	11.72	13.03	11.79	13.10

¹Diet contained corn residue harvested with 2 rows of stem and supplemental RUP at 3.3% of diet DM.

²Diet contained corn residue harvested with 8 rows of stem.

³Diet contained corn residue harvested with 8 rows of stem and supplemental RUP at 3.3% of diet DM.

⁴Diet contained corn residue harvested with traditional rake and bale method.

⁵Diet contained corn residue harvested with traditional rake and bale method and supplemental RUP at 3.3% of diet DM.

determine DM weight. Filtered samples were placed in a crucible and ashed in a muffle furnace for 6 h at 600°C for determination of ash and OM content.

The proportion of RUP in the 3 residue types and the RUP digestibility in the small intestine were determined using a mobile bag procedure (Haugen et al., 2006; Kononoff et al., 2007; Cherry et al., 2010; Pagan Riestra et al., 2010). Dacron bags (ANKOM Technology Corp., Fairport, NY) with a 50- μ m pore size (5 by 10 cm) were filled with 1.25 g of dried corn residue ground through a 2-mm screen of a Wiley mill (Thomas Scientific) and heat-sealed. Four bags per residue were placed in mesh bags in the ventral rumen of 2 ruminally fistulated steers fed a diet of 70% grass hay and 30% concentrate. Bags were incubated for 30 h and then removed and evenly divided, with half being stored at -20°C.

The remaining in situ bags (2 per residue per steer) were preincubated in a pepsin and HCL solution (1 g of pepsin/L and 0.01 *N* HCl) for 3 h at 37°C and agitated every 15 min to simulate abomasal digestion (Haugen et al., 2006). Two dairy cows with duodenal cannulations were then used to determine protein digestion in the small intestine in place of the steers, which had only ruminal cannulas. Bags were rolled along the width axis and inserted directly in the duodenum of 2 dairy cows at the rate of 1 bag every 5 min for a total of 6 bags per cow daily, with each cow receiving all 6 bags from 1 steer. Upon excretion, bags were removed from the feces and stored at -20°C until collection of all bags.

All bags were machine washed for 15 min using 5 rinse cycles consisting of 1 min of agitation and a 2-min spin. Bags were then refluxed in NDF solution using the ANKOM Fiber Analyzer (ANKOM Technology Corp.) and dried in a forced-air oven for 48 h at 60°C, air equilibrated for 3 h, and weighed, allowing for calculation of the intestinal disappearance of RUP.

Statistical Analysis

Data for the performance trial were analyzed using MIXED procedures of SAS (SAS Inst. Inc., Cary, NC).

All 60 steers were blocked by BW and randomized to treatment, resulting in 12 steers per treatment. Data were analyzed as a randomized complete block design with 3 harvest methods and 2 inclusion levels of supplemental RUP. Effects of steer, block, harvest method (low-stem, high-stem, and conventional corn residues), and supplemental RUP inclusion (0 or 3.3%) were included in the model, with steer serving as the experimental unit. Treatments (harvest method and supplemental RUP) were included as fixed effects, and block was included as a random effect. Single degree of freedom contrasts were used to compare low-stem, high-stem, and conventional corn residues with animal performance from steers fed 1 of the 3 corn residue diets with the inclusion of supplemental RUP at 3.3% diet DM. A 2 $\times$ 2 factorial was used to analyze the interaction of supplemental RUP and harvest method with 0 and 3.3% supplemental RUP and high-stem and conventional harvest methods.

In situ data were analyzed as completely randomized designs using the MIXED procedure of SAS. Residue harvest method was the treatment and steer (in situ) was the experimental unit. Significance level was set at a *P*-value of 0.05.

Experiment 2

An 85-d digestion study was conducted at the University of Nebraska metabolism area in the Animal Science building, Lincoln, NE, using 9 crossbred wethers (42.4 kg [SD 7.0] initial BW) divided into 3 blocks based on initial BW. The digestion study was 4 periods (17-d periods) long with treatments randomly assigned to lambs within each period, allowing each lamb to receive each treatment at least once. The treatments consisted of 3 residue-based diets containing the corn residue harvested with 1 of 3 methods (low-stem, high-stem, and conventional corn residues) that was fed in Exp. 1. All diets contained 70% residue, 27% Sweet Bran, and 3% brome grass hay (DM basis; Table 3). Corn residues and brome grass hay were ground with a tub grinder (Mighty Giant; Jones Manufacturing Co., Beemer, NE)

through a 2.5-cm screen. Sweet Bran and brome grass hay were fed at a 9:1 ratio in a fifth period for determination of partial digestion coefficients of residues. Partial digestion coefficients used total fecal output from the Sweet Bran and brome grass that contributed to fecal output of the other 4 periods. Digestibility of the residue diets were corrected by subtracting the contribution of Sweet Bran and brome grass hay in feces.

The periods were 17 d long, allowing for 10 d of adaptation and 7 d for total fecal collection. Feed was offered twice daily, at 0800 and 1600 h, with 50% of daily DM fed at each feeding. Wethers were fed 97% ad libitum to prevent sorting of the least digestible plant parts. Ad libitum intake was established in the first 10 d of the adaptation period and averaged to set the feed offering for the collection period. If feed refusals were observed in the morning, they were collected at 0740 h and fed back to wethers with adjusted 0800 h feeding to prevent sorting.

Wethers were placed in metabolism crates with fecal bags on the evening of d 10. Feces were collected at 0800 and 1600 h daily, weighed, and placed in individual sample bags and stored at 2.8°C until the end of the period. At the end of each period, feces were individually composited and mixed. Two 100-g subsamples were taken and dried in a 60°C forced-air oven for 72 h. Dried samples were ground through a 1-mm screen of a Wiley mill.

Samples of individual feedstuffs were taken on d 10 and 14, in coordination with the mixing of the diets, and dried to correct for DM of each period. Feedstuff samples were first ground through a 2-mm screen of a Wiley mill and then composited by period, and a subset of period composites were ground through a 1-mm screen of a Wiley mill. Samples were then analyzed for DM, OM, NDF, and GE to provide nutrient composition (Table 3).

Analysis of NDF for feeds and feces was conducted using the beaker method (Van Soest et al., 1991). Each beaker contained 0.5 g of sample, 0.5 g sodium sulfite, and 100 mL NDF solution. Beakers were placed on hot plates, covered with condensers, and brought to a boil. Upon boiling, heat was reduced allowing samples to reflux for 1 h. Samples were then filtered through Whatman 541 ashless filters, rinsed with hot water, and dried with a vacuum. Filters containing sample were then dried in a 100°C forced-air oven for a minimum of 12 h and weighed. Ash content of the sample was then determined by placing the filter in a crucible in a 600°C muffle oven for 6 h, allowing calculation of ash-free NDF.

Individual fecal samples and composite feed samples for each period were analyzed for GE using a Parr 6400 calorimeter (Parr Instrument Company, Moline, IL). Caps containing 0.2 g of sample were spiked with 0.4 g of mineral oil and sat for a minimum of 12 h.

Table 3. Diet and nutrient composition (DM basis) for wethers (Exp. 2)

Ingredient, % of DM	Low-stem	High-stem	Conventional	SBB ¹
Low-stem corn residue ²	64.18			
High-stem corn residue ³		64.18		
Conventional corn residue ⁴			64.18	
Sweet Bran ⁵	29.76	29.76	29.76	86.24
Brome grass hay	3.31	3.31	3.31	9.59
Limestone	0.75	0.75	0.75	2.17
Supplement	2.00	2.00	2.00	2.00
Nutrient composition				
DM, %	77.84	77.26	77.93	64.28
OM, %	93.93	91.29	92.14	91.00
NDF, %	66.18	64.63	60.74	36.41
Fat, %	3.67	3.67	4.82	2.44
CP, %	8.80	9.38	9.44	20.29
GE, Mcal/kg	4.40	4.04	4.09	4.56

¹SBB = a 9:1 ratio diet of Sweet Bran to brome grass hay.

²Low-stem residue is corn residue harvested with 2 rows of stem.

³High-stem residue is corn residue harvested with 8 rows of stem.

⁴Conventional residue is corn residue harvested with the traditional rake and bale system.

⁵Sweet Bran is a wet corn gluten feed product produced by Cargill Wet Milling, Blair, NE.

Samples were then bombed to determine gross heat and calculate DE. Digestible energy was calculated by subtracting the energy that was lost in feces from the GE of the feed consumed (NASEM, 2016).

Fifth-period collections allowed determination of the contribution from nonresidue feedstuffs, allowing digestibilities to be adjusted to reflect only residue. The known digestibility of the nonresidue contribution can be used to determine partial digestibility from total tract digestibility, allowing residue digestibilities to be calculated and analyzed. Similar calculations were performed to determine DE of only the residue component.

Statistical Analysis

Residue nutrient composition was analyzed using MIXED procedure of SAS. The residue harvest method was the treatment and was included in the model as a fixed effect. Total tract digestibility data were analyzed using the MIXED procedure of SAS. The experiment was designed as an unbalanced row-by-column design to meet 12 observations per treatment. Lambs were blocked by weight into 3 blocks (light, medium, and heavy) with 3 lambs per block. Lamb within block within period served as the experimental unit, with treatment included in the model as a fixed effect. Period and block were included in the model as random effects. Harvest method served as the treatment. Significance level was set at a *P*-value of 0.05.

Table 4. Main effects of supplemental RUP in corn residue based diets fed to growing steers¹ (Exp. 1)

Item	No RUP ²	Supplemental RUP ³	SEM	P-value
Initial BW, kg	280	281	4.9	0.91
Ending BW, kg	329	336	7.5	0.14
ADG, kg	0.58	0.66	0.07	0.08
DMI, kg/d	6.27	5.77	0.52	0.14
G:F	0.095	0.116	0.006	0.02

¹Interaction between residue harvest method and supplemental RUP was not statistically different ($P \geq 0.12$).

²No RUP diets had 0% supplemental RUP inclusion in the diet.

³Supplemental RUP diets had supplemental RUP included at 3.3% diet DM.

RESULTS

Experiment 1

No interactions between harvest method and supplemental RUP were observed ($P \geq 0.12$) for the 2×2 factorial. The addition of RUP resulted in a tendency ($P = 0.08$) for an improvement in ADG (0.66 ± 0.07 vs. 0.58 ± 0.06 kg for supplemental RUP and no RUP, respectively; Table 4) and improved G:F ($P = 0.02$; 0.116 ± 0.006 vs. 0.095 ± 0.006 for supplemental RUP and no RUP, respectively) compared with the same diets without supplemental RUP.

Steers fed the low-stem residue diet had the greatest ($P = 0.03$) ADG compared with steers fed the high-stem and conventional residues (0.78 ± 0.07 vs. 0.69 ± 0.07 and 0.63 ± 0.07 kg, respectively; Table 5). Ending BW tended ($P = 0.08$) to be heavier for the low-stem diet (345 ± 10 , 338 ± 10 , and 334 ± 6 kg for low-stem, high-stem, and conventional, respectively) compared with the conventionally harvested corn residue. Steers fed the low-stem diet consumed less than those on the high-stem diet, resulting in greater feed efficiency (0.139 ; $P < 0.01$). Steers fed the conventional diet did not differ ($P = 0.49$) in DMI from steers fed the low-stem diet but differed from steers fed the high-stem diet ($P = 0.05$). However, feed efficiencies for the high-stem and conventional diets did not differ (0.103 and 0.108 , respectively; $P = 0.11$).

Results from the IVOMD assay demonstrate that low-stem residue had numerically greater digestible OM (55.0, 47.8, and 47.1% for low-stem, high-stem, and conventional, respectively; Table 6) compared with the other 2 residue harvest methods. The high-stem residue diet resulted in values not different from the conventional corn residue diet, which is likely due to the high-stem bales containing a similar proportion of stem as the conventional bales. Assuming the TDN is equal to the digestible organic matter, the yield of TDN was calculated, with low-stem residue having the lowest yield of TDN per hectare compared with high-stem and conventional residues.

In situ results showed no difference ($P \geq 0.35$) in RUP content as a percentage of CP (40%) and RUP digestibility (60%) among the 3 residues (Table 7.). However, the CP content was less for the low-stem residue compared with the high-stem and conventional residues ($P = 0.01$).

Experiment 2

Conventional and low-stem residues had DM contents that did not differ ($P = 0.70$) and were greater than that of high-stem residue ($P < 0.01$). Residues differed in OM, NDF, and ash-free NDF, with low-stem residue having greater concentrations than high-stem and conventional residues ($P < 0.01$; Table 8.). High-stem residue had less OM content than conventional residue ($P < 0.01$) but greater NDF and ash-free NDF concentration than conventional residue ($P < 0.01$).

No differences in total diet intake were observed among treatments for DM, OM, and NDF ($P \geq 0.34$; Table 9). The DM digestibilities and OM digestibilities of the total diet were greater in low-stem residue than in the high-stem and conventional residues ($P < 0.01$). Digestibility of NDF was different among all treatments, with low-stem residue having the greatest, high-stem residue being intermediate, and conventional residue containing the least NDF digestibility (NDFD; $P < 0.01$; 64.3, 56.6, and 52.0%, respectively).

Intakes and digestibility estimates for partial digestibility estimates are reported for residue with the Sweet Bran and brome grass hay component removed (Table 10). The Sweet Bran and brome grass hay component had digestibility estimates of 76.0, 79.1, and 75.5% for DM, OM, and NDF, respectively. No differences in DMI, OM intake, or NDF intake were observed among residue types ($P \geq 0.28$). However, there was tendency for low-stem residue to have greater NDF intake than conventional residue ($P = 0.09$). No differences ($P \geq 0.28$) were observed when evaluating intakes as a percent of BW, due to the lambs being limit fed throughout the trial.

Low-stem residue had greater DM digestibility (DMD) than conventional and high-stem residues ($P < 0.01$; Table 10). There were no differences in DMD ($P = 0.63$) or OM digestibility (OMD; $P = 0.86$) between high-stem residue and conventional residue. Low-stem residue had the greatest OMD and NDFD ($P < 0.01$). High-stem residue had a greater NDFD than conventional residue ($P < 0.01$). The residues had the same ranking of digestibilities when ash-corrected NDF was considered (Table 9).

Digestible energy for the total diet was greatest for low-stem residue (2.79 Mcal/kg; Table 11) compared with high-stem and conventional residues (2.21 and 2.25 Mcal/kg, respectively; $P < 0.01$) estimates,

Table 5. Effects of corn residue harvest method on performance of growing steers (Exp. 1)

Item	Low-stem + RUP ¹	High-stem + RUP ²	Conventional + RUP ³	SEM	Contrast		
					Low-stem vs. high-stem	Conventional vs. low-stem	Conventional vs. high-stem
Initial BW, kg	280	280	281	6.6	0.97	0.90	0.93
Ending BW, kg	345	338	334	10.0	0.26	0.08	0.52
ADG, kg	0.78	0.69	0.63	0.07	0.17	0.03	0.41
DMI, kg/d	5.78	6.60	5.84	0.59	0.01	0.49	0.05
G:F	0.139	0.103	0.108	0.006	<0.01	<0.01	0.51

¹Diet contained corn residue harvested with 2 rows of stem and supplemental RUP at 3.3% of diet DM.

²Diet contained corn residue harvested with 8 rows of stem and supplemental RUP at 3.3% of diet DM.

³Diet contained corn residue harvested with traditional rake and bale method and supplemental RUP at 3.3% of diet DM.

with no difference between high-stem and conventional residues ($P = 0.64$). Partial DE estimates for only the residue resulted in low-stem residue (1.56 Mcal/kg; Table 11) having greater DE than high-stem and conventional residues (0.99 and 1.04 Mcal/kg, respectively; $P < 0.01$) and no difference observed between high-stem and conventional residues ($P = 0.50$).

DISCUSSION

Animal diet selectivity occurs when grazing corn residue, with cattle choosing to consume the most digestible components of the plant first (Wilson et al., 2004). Less digestible components are consumed only when the availability of other plant components becomes limited (Ward, 1978; Wilson et al., 2004). A grazing study evaluated esophageal samples and found a decline in IVDMD as the grazing season advanced, demonstrating the decrease in digestibility that occurs due to early consumption of grain and selectivity of cattle (Fernandez-Rivera and Klopfenstein, 1989). Although grazing is the most economical method of using corn residue for forage, residue can be baled and moved off the field to be used as a forage source (Ward, 1978). However, when the residue is baled, all components are harvested and offered to animals. Changing the harvest method of the residue can improve the quality over conventionally harvested residue by mimicking animal selectivity in harvesting the components with greater digestibility.

Low-stem residue resulted in a tendency for improved ADG and improved G:F compared with conventionally baled corn residue. Due to the limited sample size, the observed tendencies could be Type II errors and the differences in animal performance resulting from the different harvest methods may be biologically meaningful. Results of the IVOMD analysis support this finding, with low-stem residue having greater digestibility than the high-stem and conventional residues, which suggests that harvesting fewer stems in bales leads to an increase in digestibility and nutritive value of residue. The improvement in nutritive value is due to low-stem residue bales having a greater proportion of husk and leaf, which are

more digestible than stems and cobs. An in vivo experiment using lambs saw an improvement in total tract digestibility of husk compared with residue containing leaf, husk, and stem (McPhillips et al., 2016). Corn residues harvested with the New Holland Cornrower Corn Head, containing either 4 or 8 rows of stem (medium-stem and high-stem), resulted in reduced total tract digestibilities compared with husk. No differences in total tract digestibility were observed for DM, OM, and NDF between residues harvested with 4 or 8 rows of stem, perhaps suggesting that the number of rows of stem needs to be less than 4 for a detectable improvement in digestibility. In Exp. 2, high-stem and conventional residues both contained all rows of stem, resulting in similar DMD (47%) and OMD (51%) and allowing an average estimate to be used. This is likely due to the high-stem bales containing a similar proportion of plant parts as the conventional bales. It is important to note that the absolute digestibility values of the residues reported in Exp. 2 may not be appropriate for cattle. Differences have been observed when comparing digestibility coefficients of low-quality forages in wethers and cattle. Digestibility of low-quality forages has been found to be more complete in cattle than in sheep (Soto-Navarro et al., 2014). Apparent digestibility of OM and NDF was greater in cattle than in sheep consuming lovegrass hay (Soto-Navarro et al., 2014). Prigge et al. (1984) also found steers to have greater digestibility coefficients when consuming low-quality switchgrass hay compared with wethers. A greater retention time was observed in steers, suggesting that the longer rumen retention time led to a greater digestibility. When the switchgrass was fed at an ad libitum level, a 6 percentage units difference (57.3 vs. 63.2%) was observed in digestibility between wethers and steers compared with just a 1 percentage units difference (62.9 vs. 64.2%) when intake was limited. Therefore, the digestibility in cattle may be greater than the digestibility estimates calculated from wethers in Exp. 2.

The ability to decrease the amount of stem included in the bale is vital to increasing the quality of the bale. However, with the reduction in stem harvested, the yield of residue removed from the field is decreased. A har-

Table 6. Effect of harvest method on in vitro OM digestibility (IVOMD) and yield of corn residue (Exp. 1)

Item	Low-stem ¹	High-stem ²	Conventional ³
IVOMD, %	56.1	50.0	49.7
DOM, ⁴ % DM	55.0	47.8	47.1
Residue yield, ⁵ t/ha (DM)	0.94	5.04	4.97
TDN, ⁶ t/ha	0.57	2.67	2.59

¹Low-stem residue is corn residue harvested with 2 rows of stem.

²High-stem residue is corn residue harvested with 8 rows of stem.

³Conventional residue is corn residue harvested with the traditional rake and bale system.

⁴DOM = Digestible OM. Amount of digestible OM as a percent of DM. Calculated as OM content × IVOMD.

⁵Yields were calculated by multiplying the number of bales produced by the average weight of the bales within an area.

⁶TDN assumed equal to DOM.

vest index—the proportion of grain relative to the total aboveground biomass—can be used to determine the amount of residue produced (Watson et al., 2015). The dry weight grain mass-to-stover mass ratio is approximately 1:1, resulting in a harvest index of 0.5 (Gupta et al., 1979; Graham et al., 2007). Calculated as a kg/hectare yield × harvest index, an estimated 9.48 t/hectare of residue was produced on the field, with about 50% being harvested using high-stem and conventional methods (Table 5). As the quality of the bale increased, the yield decreased to 0.94 t DM/hectare for the low-stem bales.

Although the current experiments investigated harvesting methods to increase the quality of corn residue, chemical treatment methods have been evaluated to improve its quality after it has been conventionally harvested. Sewell et al. (2009) fed pellets made of corn residue chemically treated with CaO and saw improvements in digestibility compared with a diet of pellets made with untreated corn residue. The thermochemical treatment resulted in greater surface availability through increased hydrolysis of lingocellulosic bonds increasing NDF digestibility and ADF digestibility. Ammoniation of corn residue also has resulted in improved digestibility and greater CP compared with untreated corn residue (Saenger et al., 1982). The alkaline solution of these treatments solubilizes the lignin and increases the available soluble sugars (Chen et al., 2009). Comparing treatments, Chen et al. (2009) found sodium hydroxide to result in the highest lignin removal. These methods can improve the quality of corn residue as a roughage source.

Steers consuming the low-stem residue refused 5.0% of their daily feed compared with 1.5% refused by steers consuming conventional corn residue in Exp. 1. Low-stem residue has a decreased yield of residue, leading to an increased proportion of cob in the bale, with cob being less digestible and easily sorted compared with more digestible components, such as husk and leaf.

Table 7. Effect of harvest method on RUP of residue (Exp. 1)

Item	Low-stem ¹	High-stem ²	Conventional ³	SEM	P-value
CP, %	6.06 ^a	7.80 ^b	7.78 ^b	0.21	0.01
RUP, % of CP	35.8	40.9	44.6	0.12	0.88
RUP digestibility, %	58.0	51.8	67.4	0.06	0.35

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Low-stem residue is corn residue harvested with 2 rows of stem.

²High-stem residue is corn residue harvested with 8 rows of stem.

³Conventional residue is corn residue harvested with the traditional rake and bale system.

Accordingly, the refusals collected were primarily cobs. This differed in Exp. 2, where lambs were fed at 97% ad libitum to prevent sorting of cobs when determining digestibility. Any residual feed collected was fed back to lambs, ensuring that all components were consumed and lowering the chance of sorting. Therefore, the relative differences in the nutritive value among the residues may have been greater in Exp. 1 compared with Exp. 2 due to sorting of the cob, which is lower in digestibility. Nevertheless, the low-stem residue still resulted in greater total tract and partial digestibility compared with high-stem and conventional residues. Even with the greater proportion of cob compared with conventional bales, the decrease in the quantity of stem found in low-stem residue increased the proportion of husks, leaves, and leaf sheaths. The change in the proportion of plant parts in the bale impacted digestibility, which is supported by previous research that found husk to be the most digestible (Lamm and Ward, 1981; Watson et al., 2015). However, low-stem residue may result in more refusals due to the greater proportion of cob.

The increase in ADG and improvement in G:F of low-stem residue vs. conventional residue from Exp. 1 is supported by the DE results observed in Exp. 2. Low-stem residue had the greatest DE, and this was improved over high-stem and conventional corn residues, both of which included all 8 rows of stem in the bale. The GE for the residues from Exp. 2 appeared low compared with the observation of Pordesimo et al. (2005), who reported estimates from 16.7 to 20.9 kJ/g (4,000–5,000 cal/g) for corn stover fractions throughout plant development. Gross energy observed for the residues used in the trial ranged from 16.02 kJ/g for high-stem residue to 18.36 kJ/g for low-stem residue; conventional residue was intermediate at 16.34 kJ/g. However, Pordesimo et al. (2005) tested plants throughout maturation to develop a range, whereas the range observed in this trial was of material harvested after maturation. The high-stem and conventional residue harvest methods both fell below the average GE of 17.65 kJ/g reported for corn residue (Domalski et al., 1986) whereas the low-stem residue had a greater GE.

Table 8. Composition of residues harvested with varying methods

Item	Low-stem ¹	High-stem ²	Conventional ³	SEM	P-value
DM, %	87.0 ^a	85.8 ^b	87.6 ^a	0.22	<0.01
OM, %	96.8 ^a	92.7 ^c	94.0 ^b	0.21	<0.01
NDF, %	83.1 ^a	78.5 ^b	73.8 ^c	0.36	<0.01
NDF _{om} ⁴ , %	83.5 ^a	81.1 ^b	75.1 ^c	0.38	<0.01

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Low-stem residue is corn residue harvested with 2 rows of stem.

²High-stem residue is corn residue harvested with 8 rows of stem.

³Conventional residue is corn residue harvested with the traditional rake and bale system.

⁴NDF_{om} = ash-free NDF.

Degradation of protein from forages is rapid, meaning that a majority of the protein is RDP (NASEM, 2016). Haugen et al. (2006) used the mobile bag technique and found that the intestinal digestibility of RUP from forages is low and decreases as the maturity increases or the quality of the forage decreases. Buckner et al. (2013) also observed a linear decrease in RUP digestibility over time. Although the RUP content of the forage increased, RUP digestibilities declined, ranging from 25 to 60% for grasses (Buckner et al., 2013). The increase in RUP content as forages matures supports the findings of this study, which found that the RUP as a percentage of CP ranged from 36 to 45% for the corn residues. Digestibility of RUP for the conventional residue falls in the range recommended by the NRC (2001), which uses 60 to 75% RUP digestibility for grasses and hay, whereas the low-stem and high-stem residues had lower RUP digestibilities (58 and 52%, respectively). The RUP digestibility is important to consider because greater RUP values could suggest that the forage is a good source of MP to the animal. However, if

Table 10. Effect of harvest method of corn residue on partial intake and partial digestibility of residue fraction (Exp. 2)

Item	Low-stem ¹	High-stem ²	Conventional ³	SEM	P-value
DM					
Intake, % BW/d	1.40	1.39	1.48	0.10	0.37
Digestibility, %	53.4 ^a	44.4 ^b	44.3 ^b	1.85	<0.01
OM					
Intake, % BW/d	1.35	1.28	1.39	0.10	0.28
Digestibility, %	56.7 ^a	47.3 ^b	49.1 ^b	1.37	0.06
NDF _{om} ⁴					
Intake, % BW/d	1.16	1.09	1.09	0.08	0.39
Digestibility, %	56.1 ^a	47.0 ^b	38.7 ^c	1.79	<0.01

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Low-stem residue is corn residue harvested with 2 rows of stem.

²High-stem residue is corn residue harvested with 8 rows of stem.

³Conventional residue is corn residue harvested with the traditional rake and bale system.

⁴NDF_{om} = ash-free NDF.

Table 9. Total tract digestibilities of diets fed to wethers (Exp. 2)

Item	Low-stem ¹	High-stem ²	Conventional ³	SEM	P-value
DM					
Intake, % BW/d	2.18	2.16	2.31	0.16	0.37
Digestibility, %	61.4 ^a	55.6 ^b	55.4 ^b	0.90	<0.01
OM					
Intake, % BW/d	2.09	2.01	2.17	0.15	0.34
Digestibility, %	64.9 ^a	59.1 ^b	60.2 ^b	0.89	<0.01
NDF _{om} ⁴					
Intake, % BW/d	1.48	1.40	1.43	0.10	0.58
Digestibility, %	64.3 ^a	56.6 ^b	52.0 ^c	1.12	<0.01

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Diet containing corn residue harvested with 2 rows of stem.

²Diet containing corn residue harvested with 8 rows of stem.

³Diet containing corn residue harvest with the traditional rake and bale method.

⁴NDF_{om} = ash-free NDF.

the RUP of the forage is indigestible, it supplies no MP. Therefore, growing cattle being fed forage diets may require supplemental RUP to meet their MP requirements.

Corn residue is a low-quality forage and was observed to be low in CP (average of 7.2%; Exp. 1), supporting the requirement for supplemental protein when residue-based diets are used for growing calves. The observed improvements in digestibility and the performance of steers consuming low-stem residue was not reflected in CP, with high-stem and conventional residues having greater CP than low-stem residue. From visual assessment, there was more cob in the low-stem bale compared with the high-stem and conventional bales. Watson et al. (2015) found cob to have the least amount of CP of the corn residue components. Even though the low-stem residue has less stem, the cob being lower than stem in CP resulted in low overall CP, suggesting that all harvest methods for corn residue need supplemental protein. Supplementation of RUP with an ad libitum low-quality forage resulted in 40% greater digestibilities of DM, OM, and energy in sheep compared with those receiving no supplement and 13 to 18% greater than lambs supplemented with an energy source (Ferrell et al., 1999). Supplemental protein provided to growing

Table 11. Digestible energies for diets using corn residue harvested with alternative methods (Exp. 2)

Item	Low-stem ¹	High-stem ²	Conventional ³	SEM	P-value
Total diet DE, Mcal/kg	2.79 ^a	2.21 ^b	2.25 ^b	0.05	<0.01
Residue DE, Mcal/kg	1.56 ^a	0.99 ^b	1.04 ^b	0.05	<0.01

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Low-stem residue is corn residue harvested with 2 rows of stem.

²High-stem residue is corn residue harvested with 8 rows of stem.

³Conventional residue is corn residue harvested with the traditional rake and bale system.

calves grazing corn residue led to optimal gains when energy availability was high (Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991). Fernandez-Rivera and Klopfenstein (1989) saw a maximum gain of 0.308 kg/d when supplementing grazing calves with 163 g of supplemental RUP daily. The maximum gain was less than that in Exp. 1, with gains of 0.58 and 0.66 kg/d observed for 0 and 3.3% (0.190 kg/d) RUP diet inclusion, respectively. In Exp. 1, energy was not likely a limiting factor due to the inclusion of distiller's solubles in the diet. This differs from the decrease in energy availability when intakes and digestibility decrease at the end of a grazing period. Similar gains (0.7 and 0.6 kg/d) were observed in a corn residue grazing study when supplements high in RDP and RUP (60:40 blend of SoyPass:soybean meal and distiller's grains plus solubles) were fed (Tibbitts et al., 2016).

The quality of corn residue can be improved over conventionally harvested residue by changing the harvest method to reduce the proportion of stem. As the number of rows of stem is reduced in the bales, gain and efficiency improved. Corn residue containing low-stem residue had the greatest overall digestibility and DE, with high-stem residue being intermediate and conventional harvesting being the least digestible and having lowest DE. However, with this reduction in stems, the yield of residue removed from the field is decreased. Estimates from these experiments suggest that harvesting low-stem residue increases DE by 50% compared with conventionally harvested residue but only 20% as much residue is collected. The feasibility of using a low-stem harvesting technique depends on the relative importance of yield per hectare and nutritive value of the residue.

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