Effect of harvest method and ammoniation of baled corn residue on intake and digestibility in lambs

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ABSTRACT: To determine the effect of harvest method and ammoniation on both in vivo and in vitro digestibility of corn residue, six corn residue treatments consisting of three different harvest methods either with or without anhydrous ammonia chemical treatment (5.5% of dry matter [DM]) were evaluated. The harvest methods included conventional rake-and-bale (CONV) and New Holland Cornrower with eight rows (8ROW) or two rows (2ROW) of corn stalks chopped into the windrow containing the tailings (leaf, husk, and upper stem) from eight rows of harvested corn (ammoniated bales of each harvest method resulted in treatments COVAM, 8RAM, and 2RAM). Nine crossbred wether lambs (49.2 ± 0.5 kg BW) were fed 64.2% corn residue, 29.8% wet corn gluten feed, 3.3% smooth-bromegrass hay, and 2.8% mineral mix (DM basis) in a 9 × 6 Latin rectangle metabolism study with a 3 × 2 factorial treatment to measure total tract disappearance. Six 21-d periods consisted of 14-d adaptation and 7-d total fecal collection, and lambs were fed ad libitum (110% of the previous day's DM intake [DMI]) during days 1 to 12 and reduced to 95% of ad libitum intake for days 13 to 21. There was a harvest method by ammoniation interaction ($P < 0.01$) for ad libitum DMI (days 7 to 11). Ammoniation increased ($P < 0.01$) intake across all harvest methods, where 2RAM DMI was 4.1%, COVAM was 3.6%, and 8RAM was 3.1%, which were all different ($P < 0.01$) from each other, but all untreated residues were consumed at 2.6% of BW ($P \geq 0.92$) regardless of harvest method. There were no interactions ($P > 0.34$) between harvest method and ammoniation for any total tract or in vitro digestibility estimate. Harvest method affected ($P < 0.04$) DM, neutral detergent fiber (NDF), and acid detergent fiber (ADF) digestibility, where 2ROW was greater than both CONV and 8ROW, which did not differ. The organic matter (OM) digestibility ($P = 0.12$) and digestible energy (DE; $P = 0.30$) followed the same numerical trend. Both in vitro DM digestibility (IVDMD) and in vitro OM digestibility (IVOMD) of the residue were affected ($P < 0.01$) by harvest method, with 2ROW being greater ($P < 0.01$) than both CONV and 8ROW. For IVDMD, 8ROW was not ($P = 0.77$) different from CONV, but 8ROW IVOMD was lower ($P = 0.03$) than CONV. Ammoniation improved ($P < 0.01$) DM, OM, NDF, and ADF digestibility of all harvest methods, resulting in a 26% increase ($P < 0.01$) in DE due to ammoniation. Similar digestibility improvements were observed in vitro with ammoniation improving IVDMD and IVOMD by 23% and 20%, respectively. Both selective harvest methods and ammoniation can improve the feeding value of baled corn residue.

Key words: corn residue, ammonia, selective harvest

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INTRODUCTION

Corn residue has been a valuable low-cost feed resource for cattle for many decades (Ward et al., 1979; Klopfenstein et al., 1987). More recently, the U.S. ethanol industry expansion from 2000 to 2009 resulted in the conversion of perennial pasture and hay acres to more high-value corn acres, which lead to reduced perennial forage resources but increased availability of corn residue in the Midwestern region of the United States (Wallander et al., 2011). In addition, demand for substrate for the cellulosic ethanol industry resulted in a robust market for baled corn residue (Wilhelm et al., 2007). Survey data indicate that 0.81 million ha in the United States were baled in 2010 (Schmer et al., 2017), and usage of baled corn residue in combination with ethanol byproducts has increased in growing and finishing diets in the Midwest (Klopfenstein et al., 2013).

Differences in corn plant part digestibility have been observed, with several studies showing greater digestibility of husk and leaf compared to stem, with cob being more similar to leaf in some cases and stem in others (Weaver et al., 1978; Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991; Stalker et al., 2015). As such, corn harvesting and baling technologies that alter the proportions of plant parts in the baled residue can potentially improve the feeding value of corn residue by increasing the proportion of more digestible parts (husk) compared with less digestible parts (stem). The New Holland Cornrower Corn Head (Straeter, 2011; Craig Welding, Mentone, IN) can vary the proportion of stem to leaf, husk, and cob (tailings) in the baled windrow by chopping and including either 2, 4, 6, or 8 rows of stem in the windrow for baling. Previous work has shown that a low-stem bale produced with the Cornrower (two rows chopped and added to the windrow) produces a more digestible bale when compared with conventionally harvested rake-and-bale (King et al., 2017).

In addition, ammoniation improves both digestibility and intake of low-quality forages, including corn residue (Horton and Steacy, 1979; Morris and Mowat, 1980; Saenger et al., 1982; Grotheer et al., 1986; Mason et al., 1988). However, the magnitude of improvement in the digestibility of forages has been observed to be greater for forages that have greater lignin content (less digestible forages) as the proposed mechanism of action for ammoniation is the hydrolyzing of the lignohemicellulose bonds (Knapp et al., 1975; Sewalt et al., 1996). Selective harvest technologies are hypothesized to change the proportion of more digestible corn plant parts to result in a more digestible bale. Although the utility of ammoniation has been shown for corn residue, effects of combining ammoniation with selective harvest methods are unknown. The hypothesis was that increasing the digestibility of the corn residue bales through harvest method would result in reduced effects of ammoniation. Thus, the objective of this study was to determine the effect of harvest method in conjunction with ammoniation on the in vivo and in vitro digestibility and intake of baled corn residue in lambs.

MATERIALS AND METHODS

Animal care and management procedures used were reviewed and approved by the University of Nebraska Institutional Care and Animal Use Committee (IACUC protocol #1282).

Corn Residue Harvest and Ammoniation

All corn residue was harvested in November from the same nonirrigated field and hybrid, cut at approximately 20 to 25 cm above the soil surface. The control residue was harvested using conventional rake-and-bale methods (CONV), which consisted of corn tailings (husk and cob) and stem and leaf material being gathered with a hay rake after harvest to create windrows of material, which was baled. A New Holland Cornrower Corn Head attachment (Straeter, 2011) was used to harvest the rest of the field, which resulted in two different treatments. The Cornrower attachment has eight individual chopping units underneath the corn head, which can be turned on or off in pairs, and the corn stem and leaf that is harvested is chopped and dropped directly into the resulting windrow without raking. In this study, the corn was harvested with either all eight rows or only two rows of stem and leaf chopped and added to the windrow (8ROW and 2ROW). Total yield of residue removed from the field for each of the baling methods was, 4.97 t DM/ha for CONV, 5.04 t DM/ha for 8ROW, and 0.94 t DM/ha for 2ROW. A random selection of 12 bales (90% DM) from each of the harvest methods were stacked in a pyramid arrangement on top of 6-mm black plastic, with treatments randomly distributed throughout the stack. Bales were covered using 6-mm black plastic, and composted soil was piled around the base of the stack to seal the edges. Anhydrous ammonia was applied via one injection point at 5.5% of DM in July of 2015, and the cover remained in place for 33 d. Average daily ambient temperature recorded for Wahoo, NE, for the month of July ranged between 17.2 and 28.9 °C, with average temperature recorded at 23.9 °C. This resulted in three additional residue treatments: conventional ammoniated (COVAM), 8-Row ammoniated (8RAM), and 2-Row ammoniated (2RAM).

Lamb Digestibility Trial

Nine crossbred wether lambs (49.2 ± 0.5 kg BW) were fed in a 126-d metabolism trial using a 9 × 6 Latin rectangle design with a 3 × 2 factorial treatment structure. Treatment diets consisted of corn residue harvested using the three different methods: CONV, 8ROW, or 2ROW as described previously. The chemical treatment factor entailed feeding residue from each harvest method either untreated or ammoniated (COVAM, 2RAM, and 8RAM).

Diets consisted of 64.2% corn residue, 29.8% wet corn gluten feed (Sweet Bran, Cargill Wet Milling, Blair, NE), 3.3% smooth-bromegrass hay, 0.75% limestone, and 2.0% trace mineral supplement on a DM basis (Table 1). The nutrient composition of the diets and the individual residues is reported in Table 2. Diets were fed over six 21-d periods, which consisted of 14-d adaptation and 7-d total fecal collection. Lambs were fed ad libitum (110% of the previous day's DM intake [DMI]) during days 1 to 12 and reduced to 95% of ad libitum intake for days 13 to 21. Feeding occurred twice daily at approximately 0800 and 1500, and feed refusals were collected, weighed, and fed back during the adaptation period. Intakes were recorded daily, and values from days 7 to 11 were used for analysis of total diet intake. During the adaptation period, lambs were housed in individual pens with grate floors, individual feed bunks and automatic spout waterers, with each pen measuring approximately 1.5 m × 1 m.

Table 1. Composition of six treatment diets fed to lambs consisting of three differently harvested corn residues with and without ammoniation. Corn residue utilized was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower[1] header with all eight rows of corn plant added to the windrow (8ROW), or with only two rows added to the windrow (2ROW)

	% of diet DM[2]
Corn residue[3]	64.18
Wet corn gluten feed[4]	29.76
Brome grass hay	3.31
Supplement[5]	2.75

[1]New Holland, Craig Welding, Mentone, IN.

[2]DM = dry matter.

[3]Ammoniated diets were formulated using portions of the same residue that was ammoniated at 5.5% DM (COVAM, 8RAM, and 2RAM).

[4]Sweet Bran, Cargill Wet Milling, Blair, NE.

[5]Supplement consisted of 0.75% limestone and 2.0% commercial sheep trace mineral.

At the end of the diet adaption period, lambs were moved to individual metabolism crates and fitted with harnesses and fecal collection bags. Prior to the beginning of the study, the lambs were trained and adapted to the metabolism crates and fecal bags. Total fecal output was collected twice daily beginning on day 14 at approximately 0800 and 1500, weighed and retained in a 2.7 °C cooler for the duration of the collection period. Feed refusals were collected at feeding, weighed to determine feed allocation for the day, fed back, and any orts remaining at the end of the collection period were retained for analysis. Both fecal material and refusals were composited by lamb at the end of the collection period, and three subsamples were taken for analysis. Samples were dried in a 60 °C forced air oven (orts for 48 h and feces for 72 h) and then ground through a 1-mm screen in a Wiley mill.

Diet and fecal samples were analyzed for dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), and digestible energy (DE). Ground feed and fecal samples were dried in a 100 °C oven for 24 h to determine lab-adjusted DM and then incinerated in a muffle furnace at 600 °C for 6 h to determine the ash content to calculate OM. Both NDF and ADF were determined by refluxing 0.5000 to 0.5040 g of sample in beakers for 1 h with 0.5 g of sodium sulfite and then filtered and rinsed with acetone (Van Soest et al., 1991). Energy was measured using bomb calorimetry (6400 Automatic Isoperibol Calorimeter, Parr Instrument Co., Moline, IL). Total tract apparent digestibility was calculated using DM, OM, NDF and ADF disappearance, and DE was calculated using gross energy values.

To calculate the digestibility and DE of the corn residues, lambs were fed the nonresidue portion of the diet in a separate 17-d period prior to the beginning of the study (86.2% wet corn gluten feed [Sweet Bran, Cargill Wet Milling, Blair, NE], 9.6% brome grass hay, 2.2% limestone, 2.0% trace mineral supplement). Digestibility and energy values for the nonresidue components of the diet were calculated for each individual lamb from this period and applied to the same animal's corresponding values obtained during the subsequent trial. The mean digestibility of the nonresidue diet

Table 2. Nutrient composition of total diet and corn residue based on laboratory analysis. Corn residue utilized was harvested using harvest methods of either conventionally harvested rake-and-bale (CONV), New Holland Cornrower[1] header with all eight rows of corn plant added to the windrow (8ROW), or with only two rows added to the windrow (2ROW). Ammoniated diets were formulated using portions of the same residue that was ammoniated at 5.5% DM (COVAM, 8RAM, and 2RAM)

	Unammoniated			Ammoniated		
	CONV	8ROW	2ROW	COVAM	8ROW	2ROW
Total diet nutrient composition[2]						
DM, %	77.4	76.6	76.7	71.2	75.1	74.4
OM, %	91.3	91.8	94.5	92.0	92.7	94.2
NDF, %	65.4	68.6	70.8	60.2	61.5	63.9
ADF, %	38.7	37.7	37.4	36.4	36.3	38.0
CP, %	10.5	10.1	8.9	15.8	14.8	14.4
Residue nutrient composition						
OM, %	91.4	91.9	96.8	91.8	94.1	97.0
Ash, %	8.6	8.1	3.2	8.2	5.9	3.0
NDF, %	78.4	78.4	83.3	72.3	74.0	77.2
ADF, %	52.3	51.5	49.9	51.1	52.3	51.8
CP, %	4.6	5.0	4.0	12.6	11.1	11.5

[1]New Holland, Craig Welding, Mentone, IN.

[2]DM = dry matter, OM = organic matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, CP = crude protein.

was 75.7%, 79.2%, 76.4%, and 65.6% for DM, OM, NDF, and ADF, respectively. The mean DE of the nonresidue proportion of the diet was 3.64 Mcal/kg.

In Vitro Digestibility

To estimate the ruminal digestibility of the residue component of the diet, in vitro analyses were conducted in a water bath using methods described by Tilley and Terry (1963), McDougall (1948), and Mertens (1993). Rumen fluid was collected from two donor steers consuming a diet of 50% brome grass hay and 50% wet corn gluten feed (Sweet Bran, Cargill Wet Milling, Blair, NE). Corn residue samples taken during periods 1, 3, and 6 of the lamb trial were incubated for 48 h in triplicate, and the incubation was repeated to account for run-to-run variation. Corn residue standards were incubated simultaneously, and values were adjusted according to known in vivo values (Stalker et al., 2013). Samples were filtered and dried to obtain in vitro DM digestibility (IVDMD), and then filters were incinerated in a 600 °C muffle furnace for 6 h to obtain in vitro OM digestibility (IVOMD).

Statistics

Data were analyzed using the MIXED procedure in SAS 9.2, and significance was declared at $\alpha = 0.05$, with tendencies declared at $P < 0.10$. Period, harvest method, and bale treatment (ammoniation) were tested as fixed effects, and lamb was the experimental unit. Harvest method and treatment interactions were tested and removed from the model if not significant, and in such cases, only main effects were assessed. Response variables included DM, OM, NDF, and ADF total tract digestibility, DE, and DMI as a percent of BW. The in vitro digestibility data were analyzed using the GLIMMIX procedure. The mean used in the statistical analysis was the average of each sample across the two runs. Treatment and harvest method were analyzed at fixed effects. The interaction between harvest method and treatment was initially included in the model but was removed as it was not significant.

RESULTS

There was a harvest method by ammoniation interaction ($P < 0.01$) for ad libitum DMI (days 7 to 11) of lambs. Ammoniation increased intake for all harvest methods compared with unammoniated residue intake, but the amount of response varied among harvest method. The intake of diets containing nonammoniated residue did not differ ($P \geq 0.92$) among harvest methods at 2.6% BW (Figure 1), but ammoniated residue intake was greatest for 2RAM at 4.1% BW, intermediate for COVAM at 3.6% BW and 3.1% BW for 8RAM, which were all different ($P = 0.03$) from each other as well as the nonammoniated diets.

There were no harvest method by ammoniation interactions ($P \geq 0.82$) for OM, DM, NDF, ADF digestibility, or DE; thus, main effect means are presented (Table 3). Harvest method affected DM digestibility ($P = 0.04$), and OM digestibility followed the same numerical trends but was not statistically different ($P = 0.12$) among treatments. Compared with conventional, harvesting with the New Holland Cornrower with two rows increased DM digestibility by 15% (7 percentage units; $P = 0.01$), but harvesting with eight rows resulted no difference (6%; 2.6 percentage units; $P = 0.34$) in DM digestibility. The effect was more pronounced in NDF digestibility, as the 2ROW harvest increased NDF digestibility by 46% (19.9 percentage units; $P < 0.01$) and the 8ROW harvest increased by 27% (11.9 percentage units; $P = 0.01$) over conventionally harvested residue. The ADF digestibility of the residue was affected ($P < 0.01$) by harvest method. There was a numerical increase in ADFD of 4.6% (2.3 percentage units; $P = 0.40$) from CONV to 8ROW, but a 23.6% (11.7 percentage units; $P < 0.01$) increase from CONV to 2ROW. There was no effect ($P = 0.30$) of harvest method on DE.

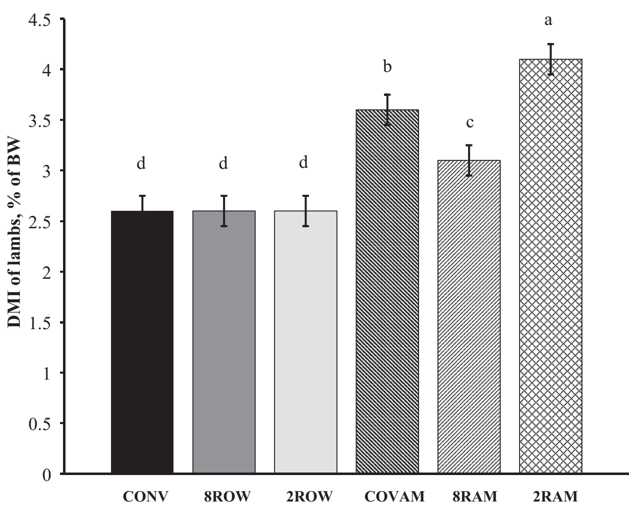

Figure 1. Dry matter intake (ad libitum) of total diet for lambs when fed diets containing corn residue at 64% of diet dry matter (DM) that was harvested using either rake-and-bale (CONV), New Holland Cornrower header (Craig Welding, Mentone, IN) with all eight rows of corn plant added to the windrow (8ROW), or New Holland Cornrower header with only two rows added to the windrow (2ROW). Ammoniated diets (COVAM, 8RAM, or 2RAM) utilized corn residue from the same harvest methods, but were treated with anhydrous ammonia at 5.5% of DM. There was a harvest method by ammoniation interaction ($P < 0.01$). Bars lacking common superscripts are significantly different from each other ($P < 0.05$).

Ammoniation improved ($P < 0.01$) DM, OM, NDF, and ADF digestibility of all harvest methods, resulting in a 24%, 21%, 37%, and 19.6% increase, respectively (Table 3). Similarly, there was a 26% ($P < 0.01$) improvement in DE due to ammoniation.

There was no interaction ($P > 0.34$) between harvest method and ammoniation for IVDMD or IVOMD (Table 4). Both harvest method and ammoniation affected ($P < 0.01$) IVDMD and IVOMD of the corn residue. For IVDMD, there was no difference ($P = 0.69$) between CONV and 8ROW, but 2ROW was 14% more ($P < 0.01$) digestible than the other harvest methods. The IVDMD of the ammoniated residue increased ($P < 0.01$) by 20% when compared with the unammoniated residue. This pattern was similar to IVOMD, where the 2ROW residue was greater ($P < 0.01$) than both

Table 3. Effect of harvest method (HM) and ammoniation (AM) on total tract DM, OM, NDF, and ADF digestibility[1], and DE content of the corn residue component of the diet fed to lambs

	Harvest method[2]			Treatment[3]		P-values[4]		
Item[5]	CONV	8ROW	2ROW	Untreated	Ammoniated	SEM	HM	AM
DM digestibility, %	44.7^{b}	47.3^{b}	51.7^{a}	42.8^{B}	53.0^{A}	1.86	0.04	<0.01
OM digestibility, %	50.5	51.5	55.4	47.4^{B}	57.5^{A}	1.71	0.12	<0.01
NDF digestibility, %	60.0^{c}	64.8^{b}	68.9^{a}	59.8^{B}	69.4^{A}	1.36	<0.01	<0.01
ADF digestibility, %	49.6^{b}	51.9^{b}	61.3^{a}	49.4^{B}	59.1^{A}	1.89	<0.01	<0.01
DE, Mcal/kg	1.73	1.76	1.88	1.58^{B}	1.99^{A}	0.060	0.30	<0.01

[1]Total tract digestibility of the corn residue component was calculated by difference using disappearance values obtained from the same lambs fed only the nonresidue components of the diet.

[2]Corn residue utilized was harvested using harvest methods of either conventionally harvested rake-and-bale (CONV), New Holland Cornrower (Craig Welding, Mentone, IN) header with all eight rows of corn plant added to the windrow (8ROW), or with only two rows added to the windrow (2ROW).

[3]Ammoniated corn residues had anhydrous ammonia applied at 5.5% DM.

[4]Means lacking common superscripts within factor are significantly different ($P < 0.05$). All interactions between HM and AM were not significant ($P > 0.55$).

[5]DM = dry matter, OM = organic matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, DE = digestible energy.

Table 4. Effect of harvest method (HM) and ammoniation (AM) on IVDMD and IVDMD of corn residue

	Harvest method[1]			Treatment[2]		*P*-values[3]		
	CONV	8ROW	2ROW	Untreated	Ammoniated	SEM	HM	AM
IVDMD, %[4]	52.0[b]	51.8[b]	59.1[a]	49.3[B]	59.3[A]	0.53	<0.01	<0.01
IVOMD, %	56.9[b]	55.5[b]	62.8[a]	53.5[B]	63.3[A]	0.71	<0.01	<0.01

[1]Corn residue utilized was harvested using harvest methods of either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header (Craig Welding, Mentone, IN) with all eight rows of corn plant added to the windrow (8ROW), or with only two rows added to the windrow (2ROW).

[2]Ammoniated corn residues had anhydrous ammonia applied at 5.5% DM.

[3]Means lacking common superscripts within factor are significantly different from each other ($P < 0.05$). All interactions between HM and AM were not significant ($P > 0.34$).

[4]IVDMD = in vitro dry matter digestibility; IVOMD = in vitro organic matter digestibility.

8ROW and CONV, with only a tendency ($P = 0.08$) for the latter two to be different. The IVOMD of the ammoniated residue was 20% greater ($P < 0.01$) than the unammoniated residue.

DISCUSSION

New corn harvesting and baling technologies designed to improve field efficiency have emerged to meet agronomic demands for more versatile equipment. Implements such as the New Holland Cornrower, while not specifically designed with the intention of selective harvest, will produce a bale with altered proportions of various plant parts by decreasing the number of rows of chopped stem added to the windrow while forming a mat for the tailings of husk and cob. Theoretically, this decreases the proportion of less digestible part (stem) to more digestible corn plant parts in the subsequent bale (Gutierrez-Ornelas and Klopfenstein, 1991). Based on this, digestibility of the baled residue should be improved when stem is decreased and/or husk is increased, and the digestibility values presented in this study for the unammoniated residue bales are consistent with previous work investigating this selective harvest method (King et al., 2017).

Previous work with the Cornrower observed increased IVOMD, total tract DM and OM digestibility and DE of 2ROW compared with 8ROW and CONV, which did not differ (King et al., 2017). This demonstrates that decreasing the number of rows of stem added to the windrow (8ROW vs. 2ROW) can result in improved digestibility of the baled product. The higher OM content of the 2ROW compared with the CONV and 8ROW indicates that either the Cornrower with 2ROW reduced dirt contamination or it reduced the proportion of plant parts with higher ash content, particularly the leaf (Lanning et al., 1980). The lower ash content of the 2ROW is an influencing factor in the improvement in digestibility as evidenced by the changes in differences between DM and OM digestibility of 2ROW compared with both CONV and 8ROW. For instance, the DM digestibility of 2ROW was 7% units greater than CONV, but OM digestibility was only 5% units greater.

It should be noted that in the present study and that of King et al. (2017), the in vivo values were determined using lambs as a model for total tract digestibility. Therefore, these data should only constitute comparative values for residues as they are not representative of digestibility that would be observed when fed to cattle given that sheep are less efficient at digesting low-quality forages than cattle (Prigge et al., 1984; Soto-Navarro et al., 2014). Similar to what was observed by King et al. (2017), the in vitro values were numerically greater than the in vivo values though the pattern and relative differences among treatments remained consistent.

Ammoniation will result in more digestible forage by acting specifically to increase surface area and accessibility to the structural carbohydrates, essentially "unlocking" more fermentable potential in the forage, which will increase ruminal passage rate and DMI (Berger et al., 1994). Therefore, the overall improvement in digestibility observed in this study with ammoniation of the corn residue is not unexpected. Likewise, the increase in intake due to ammoniation was not unexpected. There is abundant evidence in the literature that ammoniation will increase DMI due to the improvement in digestibility, leading to increased passage rate, and in some cases also as a result of increased nitrogen from the ammonia, leading to increased RDP and thus improved microbial efficiency (Hershberger et al., 1959; Horton and Steacy, 1979; Paterson et al., 1981; Saenger et al., 1982; Zorrilla-Rios et al., 1985; Brown et al., 1987; Krueger et al., 2008). For instance, Saenger et al. (1982) observed corn residue ammoniated at 2% DM increased DMI of steers by 31% compared with nonammoniated corn residue when fed ad libitum with a corn supplement at approximately 0.4% of BW (0.91 kg/h/d), and the DM digestibility of the residue increased from 55.4% to 62.1%. In their study, the response is likely due to both the increase in the accessibility of the structural carbohydrates and the increase in nitrogen available to the microbes.

Paterson et al. (1981) fed ad libitum corn residues that were ammoniated at either 2%, 3%, or 4% of DM with anhydrous ammonia to lambs (supplemented with blood meal at 3.3% of diet DM) and compared DMI with nonammoniated corn residue (fed with 3.3% blood meal and 1% urea). The intake increased linearly ($P < 0.05$) with level of ammoniation, with the increase from unammoniated residue to the 4% ammoniated residue being 150% (398 to 997 g/d). Given that urea was provided to lambs fed the nonammoniated residue this response is likely only due to changes in the accessibility of the structural carbohydrates as a result of the ammoniation process. Similarly, in the present study, the RDP available in the nonammoniated diets would not have been limiting, and thus the improvement in intake was due to accessibility of the structural carbohydrates when the residue was ammoniated.

The novel aspect of this trial was to determine if harvest method and ammoniation would interact resulting in differential responses among harvest methods to ammoniation. Although the overall effect of ammoniation between the treated and untreated bales was not unexpected, the working hypothesis was that the effect would be lower in magnitude for the more digestible harvest methods. However, 2ROW appeared to have a similar response to ammoniation with a 10.5% unit increase in DM digestibility compared with 8.8% and 11.3% for CONV and 8ROW, respectively. This lead to an additive response with the 2RAM (56.9%) being 16.6% units greater in DM digestibility than the CONV (40.3%). There is no available literature on the effect of ammoniation with selective harvest methods and the data available on the potential for differential responses of the various corn plant parts to chemical treatment is inconsistent. There is some evidence to suggest that corn plant parts respond to ammoniation to different degrees. Ramírez et al. (2007) alkali treated corn residue and corn cobs with feed grade urea at 0%, 4.5%, and 6% of DM and showed that the in situ effective degradability of DM (EDDM) in lambs increased by 14.6% and 26% over the control for residue, and by 55.0% and 40.0% for cobs as treatment level increased. The corn residue responded linearly, but the corn cobs did not, with both the 4.5% and 6% levels of treatment being not different ($P > 0.05$) from each other. This suggests that not only do cobs show greater improvement in digestibility due to chemical treatment, but they also reached their maximum capacity for chemical reaction before the whole corn residue, raising the possibility that the inherent differences in the cellular structure of the different corn plant parts means that each part will respond differently to chemical treatment (Grabber, 2005). Conversely, Oji et al. (2007) treated corn husks, cobs, and stems with an aqueous ammonia and feed grade urea at 3% of DM and found that while the improvement in IVDMD was statistically greater than untreated control plant parts, there was no statistical difference between the three different plant parts. There was no interaction observed between the different plant parts, and numerical differences observed in IVDMD were 14% to 15% increase for stems, 16% to 17% increase for husks, and 14% to 15% improvement for cobs. Although there is no clear reason for the different responses in these two studies, it illustrates the need for more targeted investigation into the potential differential response of corn plant parts to chemical treatment.

In the present study, there was an interaction between harvest method and ammoniation for DMI, with ammoniation increasing DMI by 57.7% for 2RAM, 38.5% for COVAM, and 19.2% for 8RAM. This differential response again suggests an additive effect of ammoniation although the interaction was not detectible in total tract or in vitro digestibility. This could be due to the changes in plant part proportion and different response of animal intake for each of the different plant parts when ammoniated. The 2ROW would have the lowest proportion of stem relative to CONV and 8ROW, and the greatest proportion of cob. Also, it has been suggested that the 8ROW would preserve more tailings (cob, leaf, and husk) for baling and thus the proportion of stem harvested may be less. However, the intake and digestibility data suggest that there was not an advantage of the 8ROW over CONV. There was a qualitative observation that the animals ate the ammoniated residue with greater enthusiasm and less sorting when ammoniated, particularly the ammoniated cobs. This suggests that the DMI response may be due not only to changes in digestibility but also to changes in palatability; however, this was not measured. Once again, the evidence is not clear as to whether ammoniation will affect corn plant parts differentially, and this should be explored further.

Despite the increase in digestibility, the 2ROW bales yielded only about 22% of the digestible DM/ha that CONV and 8ROW harvest methods yielded. This is a direct result of reduced residue removal from the field, where the CONV and 8ROW methods removed about 50% of the corn residue compared with only 10% with the 2ROW. Although the 2ROW harvest method yielded fewer bales of higher digestibility, there was also considerably more undisturbed residue remaining on the field for soil cover. Recommended corn residue removal rates vary regionally based on yield, climate, geography, soil type, and tillage practices, and in many instances, leaving more residue in the field can have positive effects on soil organic carbon, reduced soil erosion, and increased subsequent crop yields (Wilhelm et al., 2004; Blanco-Canqui and Lal, 2009). In this regard, any changes in digestible DM yield due to harvest method would need to be evaluated in a whole system context including animal, soil, and crop impacts.

CONCLUSIONS

Harvest methods of corn residue that change the proportion of different plant parts can alter the digestibility and subsequent feeding value of baled corn residue. Compared with a conventional rake-and-bale system, a 5% improvement in DM digestibility was observed using the Cornrower attachment chopping only two rows of stem, but it had no impact on intake of nonammoniated residue. A much greater increase in DM digestibility (10% units) and an increase in intake were observed with ammoniation of the corn residue. The data presented in this study demonstrate the continued utility of ammoniation as a practical and effective method of improving digestibility of corn residue for use in ruminant diets. Most importantly, this study shows that ammoniation and selective harvest effects are additive, resulting in significant improvements in both digestibility (16% units) and intake of corn residue.

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