What is the digestibility and caloric value of different botanical parts in corn residue to cattle?¹

Emily A. Petzel,^{*,†} Evan C. Titgemeyer,[‡] Alexander J. Smart,^{||} Kristin E. Hales,[§]
Andrew P. Foote,^{§,¶} Subash Acharya,^{*,†} Eric A. Bailey,[†] Jeffrey E. Held,^{*} and Derek W. Brake^{*,†,2}

*Department of Animal Science, South Dakota State University, Brookings, SD, 57007; [†]Division of Animal Sciences, University of Missouri, Columbia, MO, 65211; [‡]Department of Animal Science and Industry, Kansas State University, Manhattan, KS, 66502; ^{||}Department of Natural Resource Management, South Dakota State University, Brookings, SD, 57007; [§]USDA, ARS, U.S. Meat Animal Research Center, Clay Center, NE, 68933; and [¶]Department of Animal and Food Sciences, Oklahoma State University, Stillwater, OK, 74078

ABSTRACT: Two experiments were conducted to measure rates of ruminal disappearance, and energy and nutrient availability and N balance among cows fed corn husks, leaves, or stalks. Ruminal disappearance was estimated after incubation of polyester bags containing husks, leaves or stalks in 2 separate ruminally cannulated cows in a completely randomized design. Organic matter (OM) that initially disappeared was greatest for stalks and least for husks and leaves ($P < 0.01$), but amounts of NDF that initially disappeared was greatest for husks, intermediate for stalks, and least for leaves ($P < 0.01$). Amounts of DM and OM that slowly disappeared were greatest in husks, intermediate in leaves, and least in stalks ($P < 0.01$). However, amounts of NDF that slowly disappeared were greatest in leaves, intermediate in husks, and least in stalks ($P < 0.01$). Rate of DM and OM disappearance was greater for leaves, intermediate for husks and least for stalks, but rate of NDF disappearance was greatest for stalks, intermediate for leaves, and least for husks ($P < 0.01$). Energy and nutrient availability in husks, leaves, or stalks were measured by feeding ruminally cannulated cows husk-, leaf-, or stalk-based diets in a replicated Latin square. Digestible energy lost

as methane was less ($P = 0.02$) when cows were fed leaves in comparison to husks or stalks, and metabolizable energy (Mcal/kg DM) was greater ($P = 0.03$) when cows were fed husks and leaves compared with stalks. Heat production (Mcal/d) was not different ($P = 0.74$) between husks, leaves, or stalks; however, amounts of heat produced as a proportion of digestible energy intake were less ($P = 0.05$) among cows fed leaves in comparison to stalks or husks. Subsequently, there was a tendency ($P = 0.06$) for net energy available for maintenance from leaves (1.42 Mcal/kg DM) to be greater than stalks (0.91 Mcal/kg DM), and husks (1.30 Mcal/kg DM) were intermediate. Nitrogen balance was greater when cows were fed leaves, intermediate for husks, and least for stalks ($P = 0.01$). Total tract digestion of NDF was greater ($P < 0.01$) for husks and leaves compared with stalks. Husks had greater ($P = 0.04$) OM digestibility in comparison to stalks, and leaves were intermediate. Apparently, greater production of methane from husks in comparison to leaves limited amounts of energy available for maintenance from husks even though total-tract nutrient digestion was greatest when cows were fed husks or leaves.

Key words: cow, corn residue, digestibility, energy, methane

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²Corresponding author: braked@missouri.edu

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INTRODUCTION

Annual production of corn plants in the United States contain an equivalent of nearly 3 trillion megacalories (Mcal) of energy, but almost one-half of the energy contained in corn plants remains in corn residues after grain harvest (Pordesimo et al., 2005; Cantrell et al., 2014; USDA-NASS, 2018). A preponderance of energy in corn residues are contained in β -linked carbohydrates, which are poorly digested by mammalian enzymes found in the gastrointestinal tract. Thus, most mammals are largely unable to use energy from corn residues for physiologically productive processes (e.g., maintenance, growth, reproduction, lactation). However, ruminal microbes produce enzymes that allow fermentation of β -linked carbohydrates, and ruminal fermentation allows ruminants to utilize energy in β -linked carbohydrates from forages through the production of organic acids and microbial protein.

Generally, production of organic acids and microbial protein from ruminal microbes is influenced by substrates available to be fermented. Thus, nutrients and energy available to support productive physiological processes are a function of the botanical parts selected by cattle. Unfortunately, a priori predictions of nutrients and energy available to cattle grazing forages are often difficult. Cattle grazing corn residues usually select diets with greater nutritive value than the total available biomass (Fernandez-Rivera and Klopfenstein, 1989; Stalker et al., 2015; Petzel et al., 2018). Also, diets selected by cattle grazing forages are often impacted by changes in forage quality, forage mass, and competition for feed.

Corn residues selected by cattle are largely comprised of husks, leaves, and stalks (Fernandez-Rivera and Klopfenstein, 1989; Stalker et al., 2015; Petzel et al., 2018). Several authors have evaluated the overall nutritive value of corn residues via measures of live weight gain (Klopfenstein et al., 1987; Folmer et al., 2002; Warner et al., 2011), and others have estimated the relative nutritive value of husks, leaves, or stalks with measures of *in vitro* DM (Klopfenstein et al., 1987; Gutierrez-Ornelas and Klopfenstein, 1991) or OM disappearance (Gutierrez-Ornelas and Klopfenstein, 1991; Stalker et al., 2015). However, measures of net energy available for maintenance from corn husks, leaves, and stalks remain limited.

Currently, estimates of nutrients available to cattle from corn residues are reflective of the average of all corn residues remaining after harvest of corn grain (NASEM, 2016), and predictions of

net energy are derived from calculated amounts of TDN (NASEM, 2016). An improved understanding of energy available from different botanical parts of corn residue could be used together with measures of diet selection to more accurately predict cattle performance and nutrient availability; however, we are unaware of any direct measures of energy available from different botanical parts of corn residues to cattle. Therefore, the objective of these experiments was to directly measure energy content and nutrient availability of corn husks, leaves and stalks to cattle. Previous reports have indicated that *in vitro* OM disappearance was greatest for husks, intermediate for leaves, and least for stalks (Gutierrez-Ornelas and Klopfenstein, 1991; Stalker et al., 2015). Therefore, we hypothesized that husks would contain the greatest net energy available for maintenance, stalks would contain the least and leaves would be intermediate.

MATERIALS AND METHODS

All procedures that involved the use of animals in this project were approved by the South Dakota State University Institutional Animal Care and Use Committee (protocol approval No. 17-092A).

Experiment 1: In Situ Disappearance

Animal husbandry and sample collection. Two ruminally cannulated Simmental $\times$ Angus cows (562 ± 3 kg BW) were used to estimate rates of ruminal digestion of each botanical part of corn residue and corn steep liquor. Corn husks, leaves, and stalks were harvested from November 10, 2017 to January 16, 2018 from a 2.7 ha field located 2.5 km north of Brookings, SD ($44^{\circ}20'51.10''\text{N}$, $96^{\circ}47'21.67''\text{W}$). The field contained a uniform mixture of 4 cultivars of corn (DKC 46-20, DKC 45-65, DKC 58-06, and DKC 54-38, Bayer Corporation, Creve Coeur, MO) planted at a rate of 12,950 seeds per ha. Standing corn plants were harvested 3 times weekly with a sickle mower (Ford 501, Ford Motor Company, Troy, MI) after DM concentration in grain had reached 84%. Whole corn plants were immediately collected after harvest and separated by hand into husks, leaves, and stalks. Measures of *in situ* disappearance were conducted on an aliquot of composited samples of husks, leaves, stalks, or steep liquor after samples were partially dried (55°C) and ground to pass a 2-mm screen in a Wiley Mill (Thomas Wiley Mill Model 4; Thomas Scientific USA, Swedesboro, NJ). Four grams of ground sample (DM basis) were placed in

a polyester bag (Dacron, 10 × 20 cm, 50 ± 10 µm pore size; R1020, Ankom Technology, Macedon, NY). Within each cow, triplicate sets of polyester bags containing husks, leaves, stalks, or corn steep liquor were placed in large mesh bags (38.1 × 45.7 × 2.5 cm, Mainstays Lingerie Mesh Laundry Bag, Wal-Mart Stores, INC, Bentonville, AR) that were weighted and suspended in the rumen for either 4, 8, 12, 24, 36, 48, 72, or 96 h. Cows were fed ad libitum amounts of long-stem corn residue (84.2% DM, 3.6% CP, 72.3% NDF, 47.2% ADF) for 14 d prior to measures of in situ disappearance. During in situ incubations, cows were allowed ad libitum access to long-stem corn residue and provided corn steep liquor (1 kg) twice daily at 0700 h and 1900 h. After ruminal incubation, bags were mechanically rinsed 5 times in a commercial washer (Fabric-Matic, Model A511S, Maytag, Newton, IA); each rinse consisted of a 1-min rinse followed by a 2-min spin cycle (Vanzant et al., 1998). Estimates of 0-h disappearance were achieved by rinsing polyester bags identically to bags previously ruminally incubated. After mechanical rinsing, all samples were dried at 55 °C for 24 h, and analyzed for DM, OM, and NDF.

Calculations and statistical analyses Nearly all corn steep liquor was removed from bags used to estimate 0 h disappearance (89.8 ± 3.2% DM) and no corn steep liquor remained in polyester bags after 4 h of incubation. Thus, corn steep liquor was considered to rapidly disappear in the rumen and estimates of rates of disappearance from a slowly degradable fraction of corn steep liquor were not calculated because it was unlikely that time points used in this trial would accurately characterize rates of disappearance from the relatively small amount of corn steep liquor that did not immediately disappear. Rates of ruminal DM, OM, and NDF disappearance from husks, leaves, and stalks were calculated following the model described by Ørskov and McDonald (1979):

$$\text{Disappearance (\%)} = \text{ID} + \text{SD} * (1 - e^{-k_d * t})$$

where ID is the proportion of a chemical component that immediately disappeared, SD is the proportion of a chemical component that slowly disappeared, k_d is the rate of disappearance (h^{-1}), and t is time (h). The equation was fitted using the Marquardt method (Marquardt, 1963) for iterative, nonlinear, least squares estimation in SAS (SAS 9.4, SAS Inst. Inc., Cary, NC). Pool sizes (ID, SD, and the proportion of a chemical component that did not

disappear) and k_d were analyzed as a completely randomized design using the MIXED procedures of SAS. The model contained effects of botanical part (i.e., husks, leaves, and stalks) and effect of cow was random. Treatment means were calculated using the LSMEANS option. Differences between botanical parts were detected with the F-statistic (Fisher, 1935). When the F-statistic was significant ($P \leq 0.05$) means were separated with the PDIFF option of SAS.

Experiment 2: Nutrient and Energy Balance

Animal husbandry and sample collection. Beginning 7 d prior to experimentation, 6 ruminally cannulated cows (3 Angus, 563 ± 72 kg initial BW, 175 ± 25 d pregnant; 3 Simmental × Angus, 576 ± 59 kg initial BW, 193 ± 35 d pregnant) were housed in a common drylot pen (0.4 ha) and offered ad libitum access to long-stem corn residue (84.2% DM, 3.6% CP, 72.3% NDF, 47.2% ADF). Subsequently, cattle were moved to a temperature (23 °C) and light-controlled (16 h of light daily) room 1 d prior to experimentation and placed in stanchions (1.2 × 1.5 m). Cows were then allocated to 1 of 2 replicated 3 × 3 Latin squares with 19 d periods (7 d adaptation, 8 d for measure of nutrient and energy balance, and 4 d of rest) to determine the energy and nutrient availability from corn husks, leaves, or stalks. Cows were fed diets in individual forage feeders each 12 h at 0700 and 1900h daily that were predominately comprised of either husks, leaves, or stalks (Table 1). Cows had ad libitum access to water and a pressed mineral block (Trace Mineralized Salt, American Stockman, Overland Park, KS; 96.5% NaCl, 4,000 mg/kg Zn, 1,600 mg/kg Fe, 1,200 mg/kg Mn, 260 mg/kg Cu, 100 mg/kg I, and 40 mg/kg Co). A priori estimates of net energy for maintenance (NEm) in husks, leaves, and stalks were calculated from predictions of TDN based on concentration of ash, CP (calculated as 6.25 × N), fatty acids, lignin, and N-free NDF (Weiss, 1993). Corn steep liquor (Table 1) was added to diets in amounts designed to slightly exceed needs for ruminally available N and to provide identical amounts of energy (23 kcal NEm/kg BW^{0.75}). Cows were fed to 90% of the predicted maintenance energy requirement (NASEM, 2016) and amounts of feed offered were calculated from measures of BW collected at the beginning of each period.

Husks, leaves, and stalks fed to cows were harvested as described in Exp. 1. Stalks were ground through a hammer mill (3" Chipper Shredder, DR Power Equipment, Vergennes, VT) to allow a bulk

Table 1. Chemical composition of corn husks, leaves, stalks, and steep liquor (CSL) fed to cows

Item, % DM basis	Feedstuff			
	Husk	Leaf	Stalk	CSL
DM	81.6 ± 2.6	87.1 ± 4.9	61.2 ± 10.5	48.0 ± 0.2
OM	96.8 ± 0.1	91.9 ± 1.1	95.1 ± 0.1	88.6 ± 0.3
NDF	76.7 ± 0.9	63.1 ± 0.7	64.1 ± 3.1	3.1 ± 0.1
ADF	40.8 ± 1.1	37.8 ± 1.5	45.0 ± 0.4	2.7 ± 0.2
Hemicellulose	36.0 ± 0.8	25.3 ± 0.8	19.1 ± 3.4	0.4 ± 0.1
Acid detergent lignin	6.1 ± 0.7	4.5 ± 0.1	10.8 ± 0.2	ND ¹
Acid detergent insoluble ash	1.7 ± 0.2	5.7 ± 0.5	2.3 ± 0.4	0.1 ± 0.0
CP	2.4 ± 0.1	7.7 ± 0.9	3.0 ± 0.2	33.5 ± 0.5

¹ND = not detected.

density nearer to that of husks and leaves and allow for the same frequency of feed delivery to cows during the experiment. Measures of DM content in husks, leaves, and stalks were conducted every 3 d, and amounts of feed provided to cows were adjusted every 3 d for DM content. Daily samples (200 g) of husks, leaves and stalks were composited within period and botanical part for analysis of chemical composition. A single lot of corn steep liquor was obtained from a commercial manufacturer (Archer Daniel Midland, Marshall, MN), sampled every 3 d (20g), and composited for analysis of chemical composition. Diets were mixed by hand immediately prior to feeding.

Digestion collections. At 0700 and 1900 h from day 4 to 11 a 10 g bolus of Cr₂O₃ in a gelatin capsule (Size 07, Torpac, Fairfield, NJ) was orally administered to each cow to allow estimates of fecal output. Samples of feces (100 ± 3.1 g) were collected thrice daily on day 8 to 11 by manual stimulation and composited by cow within each period. Fecal samples were collected every 4 h beginning at 0700 h on day 8 and sampling time was delayed 1 h each day so that composite samples reflected each hour in a 12-h period.

Cows were fitted with a Foley catheter (24 French, 75 cc Foley catheter, C. R. Bard Inc., Covington, GA) on day 7 to allow total collections of urine from day 8 to 11. Catheters were attached (0.8 cm ID, Fisherbrand, Pittsburgh, PA) to a plastic collection vessel (20 L, RFS22, Cambro Manufacturing Company, Huntington Beach, CA) containing 900 mL of 10% (wt/wt) H₂SO₄. Total urine collections were measured daily and an aliquot (1% of daily output) was composited by cow within each period and frozen at -20 °C.

Indirect respiration calorimetry. Measures of respired gas and methane produced during the fed-state were achieved by placing each cow's head

and neck into an open-circuit respiration calorimeter (76 × 76 × 180 cm) on days 12 and 13. Air flow from each calorimeter was measured by individual mass flow meters (Dresser MicroSeries ptz+Log, GE Oil and Gas, Houston, TX) and set to a flow rate of 324 L/min. Calorimeters were run for 15 min. (4.7 volumes of each calorimeter) prior to collection of samples of respired air to ensure that sampled air was reflective of gas production from cows. Continuous sampling of inflowing and outflowing air was diverted to collection bags (61 × 61 cm Laminar, PMC, Oak Park, IL) using glass rotameters (SHO-RATE, Brooks Instrument, Hatfield, PA). Measures of air flow from each calorimeter were corrected for temperature, relative humidity (TRH-100, Pace Scientific, Mooresville, NC) and barometric pressure (P350-D-0inch, Pace Scientific) which was measured every min (XR5-SE Data logger, Pace Scientific). Ethanol recoveries were 99.08 ± 3.75% for oxygen (O₂) and 90.25 ± 2.32% for carbon dioxide (CO₂). Measures of respired air and methane were collected each 12 h for a total of 48 h. Concentrations of CO₂ and methane were measured using near infra-red reflectance spectroscopy and O₂ was measured via paramagnetic detection (Emerson X-Stream XE, Emerson Process Management, Solon, OH) after calibration to a standard gas containing 19.68% O₂, 1.01% CO₂, and 0.10% methane.

After measures of gas exchange during the fed-state, cattle were fasted using the washed rumen technique (Kim et al., 2013). Briefly, at 0900 h on day 14, reticulorumen contents were evacuated (Reid, 1965) and maintained at 29 °C. Immediately after removal of ruminal contents, the reticulorumen was rinsed with 10 L of tap water (39 °C) that was then removed through suction (10 gallon 4-Peak-HP Shop Vacuum, Shop-Vac, Williamsport, PA), and the rinsing procedure was subsequently repeated for a total of 4 rinses. Subsequently, measures of

respired gas and methane produced were collected from 1900 h on day 14 to 1900 h on day 15. After measures of gas exchange, 10 kg of pooled rumen contents from 2 Angus steers fed mechanically harvested corn residue was placed in the rumen together with each cows' original rumen contents, and cows were provided a 4-d period of rest before beginning the next experimental period.

Sample analyses. Feces, feed, and ort samples were partially dried for 48 h at 55 °C in a forced-air oven, and ground to pass a 1-mm screen using a Wiley Mill (Thomas Wiley Mill Model 4; Thomas Scientific USA). Feed, feces, and orts were analyzed for DM, OM, NDF, ADF, N, and GE; feed was also analyzed for acid detergent lignin. Dry matter was measured by drying at 105 °C for 16 h (method no. 930.15, AOAC, 2016), and OM was determined by combustion (500 °C for 16 h, method no. 942.05, AOAC, 2016). Neutral detergent fiber was measured as described by Van Soest et al. (1991) and included additions of α -amylase and sodium sulfite; ADF was measured nonsequential to NDF (Van Soest et al., 1991). Acid detergent lignin was measured after soaking ADF residue in 72% (wt/wt) sulfuric acid for 3 h (Van Soest and Robertson, 1980). Measures of NDF, ADF and acid detergent lignin were corrected for ash content which was measured by combustion (500 °C for 8 h). Nitrogen content was analyzed via the Dumas procedure (method no. 968.06; AOAC, 2016; Rapid Max N Exceed; Elementar, Mt. Laurel, NJ). Urine samples were analyzed for DM, N, and GE. Gross energy was determined using an automatic isoperibolic calorimeter (Parr 1261, Parr Instrument Company, Moline, IL). Urine energy was analyzed by lyophilizing 15 mL of urine in small pouches (5.0 × 7.6 cm, 1 mil polypropylene bag, Associated Bag, Milwaukee, WI) prior to combustion. Fecal concentrations of Cr₂O₃ were determined via atomic absorption spectroscopy (357.9 nm; Model 3110, PerkinElmer, Waltham, MA) after digestion in potassium bromate and acid manganese sulfate (Williams et al., 1962).

Calculations. Total O₂ consumption and production of CO₂ and methane were calculated from the difference in concentration of O₂, CO₂, and methane from air exhausted from each calorimeter and concentration of O₂, CO₂, and methane in ambient air and multiplied by amounts of air flowing from each calorimeter after standardizing for temperature, pressure, and humidity. Heat production (HP) and fasting heat production (FHP) were calculated

as described by Brouwer (1965) using O₂ consumption and production of CO₂ and methane during fed and fasted states respectively:

$$\text{HP or FHP (kcal)} = \frac{\left(\frac{16.18 \left(\text{O}_2, \frac{\text{L}}{\text{d}} \right) + 5.02 \left(\text{CO}_2, \frac{\text{L}}{\text{d}} \right) - 2.17}{\left(\text{CH}_4, \frac{\text{L}}{\text{d}} \right) - 5.99 \left(\text{Urine N}, \frac{\text{g}}{\text{d}} \right)} \right)}{4.183}$$

Dry matter was calculated as partial DM multiplied by DM measured after drying at 105 °C. Hemicellulose was calculated as the difference between NDF and ADF concentration (Van Soest, 1994) in husks, leaves, and stalks. Fecal output was calculated as the quotient of the amount of Cr bolused daily by the Cr concentration in feces. Urinary N output was calculated as the product of daily urine output and urine N concentration. The correlation coefficient of the regression between urinary N output and N intake was calculated using the MIXED procedures of SAS as one minus the quotient of the sum of the squared error in the full model and the sum of the squared error in the reduced model (Kuehl, 2000). Intake of DM, OM, NDF, ADF, and N was measured by multiplying DMI and concentration of DM, OM, NDF, ADF, and N in the diet. Output of DM, OM, NDF, and ADF was estimated by multiplying fecal DM output and fecal nutrient concentration. Total tract digestion (%) of DM, OM, NDF, and ADF of corn residue were calculated as the complement of the quotient of nutrient output and nutrient intake multiplied by 100 and corrected for nutrient intake from corn steep liquor (Merchen, 1988). Nitrogen output was calculated as fecal N output plus urine N output. Digestible and metabolizable energy of corn residue were calculated as described by Lofgreen and Garrett (1968) and corrected for energy provided from corn steep liquor (NASEM, 2016):

$$\text{DE}_{\text{corn residue}} \left(\frac{\text{Mcal}}{\text{d}} \right) = \text{GE} - \text{Fecal Energy} - \text{DE}_{\text{Corn Steep}}$$

$$\text{ME}_{\text{corn residue}} \left(\frac{\text{Mcal}}{\text{d}} \right) = \text{GE} - \text{Fecal Energy} - \text{Urine Energy} - \text{CH}_4 \text{ Energy} - \text{ME}_{\text{Corn Steep}}$$

Retained energy (RE) was calculated without correction for RE from corn steep liquor. Net energy for maintenance in husks, leaves or stalks was calculated similarly to digestible and metabolizable

energy of residue by correcting for NEm provided from corn steep liquor (NASEM, 2016) and GE of the gravid uterus (Ferrell et al., 1976).

$$\text{Retained Energy} \left(\frac{\text{Mcal}}{\text{d}} \right) = \text{GE} - \text{Fecal Energy} \\ - \text{Urine Energy} \\ - \text{CH}_4 \text{ Energy} - \text{HP}$$

$$\text{NEm}_{\text{corn residue}} \left(\frac{\text{Mcal}}{\text{d}} \right) = \text{RE} + \text{FHP} \\ - \text{Gravid Uterus Energy} \\ - \text{NEm}_{\text{Corn steep}}$$

Statistical analyses. Data from a cow in period 2 fed stalks was excluded due to small intakes (less than 50% of DM offered) that did not appear to be reflective of a normal population (studentized residual = 3.7). Additionally, another cow designed to be fed stalks was removed from the study immediately prior to the final period because it had no intake of offered forages during the recovery period.

Data were analyzed for a Latin square using the MIXED procedure of SAS with fixed effects of botanical part, period and square and random effect of cow. Denominator degrees of freedom were calculated by the Kenward and Roger adjustment (Kenward and Roger, 1997). Treatment means were calculated using the LSMEANS option. Differences in corn husks, leaves, and stalks were detected with the F-statistic, and differences between N balance and 0 were analyzed with the TTEST procedure of SAS. Significance was declared when $P \leq 0.05$, and means were separated with the PDIF option of SAS.

RESULTS AND DISCUSSION

Experiment 1

In situ disappearance. In situ disappearance of husks, leaves, and stalks are reported in Table 2. Amounts of DM that immediately disappeared ($P < 0.01$) were greatest for stalks, intermediate for husks, and least for leaves. Proportions of OM that immediately disappeared from stalks were 40% greater ($P < 0.01$) than amounts of OM that immediately disappeared from leaves and husks. Amounts of DM and OM available to slowly disappear ($P < 0.01$) were greatest for husks, least for stalks, and leaves were intermediate. Rates of DM disappearance ($P < 0.01$) were greatest for

Table 2. In situ disappearance of corn husks, leaves, and stalks fed to cows

Item, %	Botanical part			SEM	P-value
	Husk	Leaf	Stalk		
DM					
ID ¹	16.6 ^b	12.5 ^a	29.3 ^c	0.13	<0.01
SD ²	69.9 ^c	64.7 ^b	37.4 ^a	0.27	<0.01
ND ³	13.8 ^a	22.8 ^b	33.3 ^c	0.19	<0.01
Kd ⁴ , %/h	2.84 ^b	3.98 ^c	2.18 ^a	0.03	<0.01
OM					
ID ¹	20.0 ^a	20.2 ^a	28.2 ^b	0.11	<0.01
SD ²	73.9 ^c	59.6 ^b	38.5 ^a	1.91	<0.01
ND ³	6.1 ^a	20.2 ^b	33.3 ^c	2.02	<0.01
Kd ⁴ , %/h	2.48 ^a	4.10 ^b	2.22 ^a	0.11	<0.01
Neutral detergent fiber					
ID ¹	11.9 ^c	2.4 ^a	9.4 ^b	0.18	<0.01
SD ²	69.7 ^b	71.7 ^c	44.1 ^a	0.13	<0.01
ND ³	18.4 ^a	25.9 ^b	46.5 ^c	0.05	<0.01
Kd ⁴ , %/h	4.25 ^a	4.82 ^b	4.97 ^c	0.04	<0.01

a,b,c Means in rows without common superscripts differ at $P \leq 0.05$.

¹ID: Immediately disappeared.

²SD: Slowly disappeared.

³ND: Residue that did not disappear.

⁴Kd: Rate of disappearance.

leaves, intermediate for husks, and least for stalks. Similarly, rates of OM disappearance were 74% greater ($P < 0.01$) for leaves compared with husks and stalks, but rate of OM disappearance from husks and stalks were not different ($P = 0.14$). Amounts of NDF that immediately disappeared ($P < 0.01$) were greatest for husks (12%), least for leaves (2%), and intermediate for stalks (9%). Yet, amounts of NDF able to slowly disappear ($P < 0.01$) were greatest for leaves, intermediate for husks, and least for stalks, and stalks had nearly 38% less ($P < 0.01$) NDF available for fermentation compared with husks and leaves. However, rates of NDF disappearance ($P < 0.01$) were greatest for stalks, intermediate for leaves and husks were least. Amounts of DM, OM, and NDF that did not disappear ($P < 0.01$) were greatest for stalks, least for husks, and intermediate for leaves.

Water soluble nutrients make up between 14 and 27% (DM basis) of corn residues (Chen et al., 2007). Proportions of DM that immediately disappeared from stalks were greater ($P < 0.01$) than from husks and leaves; however, it is unclear if small differences in amounts of DM or OM that immediately disappeared between husks, leaves, or stalks would contribute to differences in ruminal fermentation. Stalks in many warm-season grasses have various anatomical features (e.g., primary wall lignification, cell wall middle lamellas, crystalline

regions of cellulose; Kerley et al., 1988; Jung and Deetz, 1993) that can limit digestion of soluble nutrients in corn residues (Wilson and Mertens, 1995). Grinding disrupts physical organization of cells in stalks and can increase fiber digestion when mean ruminal retention time remains the same (Wilson and Mertens, 1995). Our data seem to indicate that stalks contained greater amounts of rapidly soluble extracellular or intracellular materials in comparison to husks and leaves; although we did not directly measure the extra- or intracellular materials. It is likely that physical disruption (e.g., mechanical grinding, chewing) of cells allows access of soluble nutrients in corn residues to ruminal microbes for fermentation.

Fiber is largely comprised of the insoluble cell wall matrix and consists predominately of cellulose, hemicellulose, and lignin (Van Soest, 1994). Hemicellulose is more soluble than cellulose and greater concentrations of hemicellulose in plant fiber have been related to greater amounts of potentially fermentable fiber in feeds (Van Soest, 1994). Husks had greater amounts of hemicellulose (36.0% DM basis; Table 1) than leaves (25.3% DM basis) which had greater amounts of hemicellulose than stalks (19.1% DM basis). Lignin can limit amounts of fiber available to be slowly fermented via cross-linking with hemicellulose (Jung and Deetz, 1993). Stalks had greater amounts of lignin (10.8% DM basis; Table 1) than husks (6.1% DM basis) and leaves (4.5% DM basis). Thus, fiber in stalks is often less accessible to ruminal fermentation. Indeed, greater amounts of NDF were

available to be fermented (i.e., the complement of the nondisappeared fraction) from husks and leaves compared with stalks. Even though lignin can limit amounts of fiber available to ruminal fermentation, lignin content often has little impact on rate of NDF digestion (Smith et al., 1972).

Nonetheless, ruminal fermentation plays a critical role in total tract digestion of fiber, and ruminants can derive a majority of energy from feeds via ruminal fermentation (Ørskov, 1980). Overall, these data seem to support that corn husks provide slightly greater proportional amounts of fermentable substrates to cattle than leaves, but both husks and leaves provide much greater amounts of ruminally fermentable substrates than stalks. However, husks often comprise less than 15% of the overall biomass in corn residues whereas leaves comprise at least 30% of the overall biomass (Gutierrez-Ornelas and Klopfenstein 1991; Pordesimo et al., 2004; Stalker et al., 2015). Thus, it seems that a preponderance of fermentable energy intake among cows grazing corn residues is more likely to be derived from leaves even though husks are apparently more fermentable than leaves or stalks.

Experiment 2

Digestibility. Measures of nutrient intake and total tract digestion are reported in Table 3. Dry matter intake of corn husks, leaves, and stalks were limited to 90% of predicted maintenance energy requirements (NASEM, 2016) in this study to allow determination of NEm (Brody, 1945; Blaxter, 1962;

Table 3. Total tract digestibility among cows fed different botanical parts of corn residue at 90% of maintenance energy requirements

Item	Botanical part			SEM	P-value
	Husk	Leaf	Stalk		
Intake, g/d					
DM	4,755 ^c	6,547 ^a	5,167 ^b	0.2	<0.01
OM	4,604 ^b	6,018 ^a	4,916 ^b	203.2	<0.01
NDF	3,649 ^b	4,127 ^a	3,317 ^c	133.4	<0.01
ADF	1,936 ^b	2,467 ^a	2,395 ^a	81.4	<0.01
Feces, g/d					
DM	2,203 ^c	3,391 ^a	2,969 ^b	151.5	<0.01
OM	1,863 ^a	2,732 ^b	2,623 ^b	156.6	<0.01
NDF	990 ^a	1,325 ^b	1,726 ^c	93.2	<0.01
ADF	634 ^a	944 ^b	1,237 ^c	62.1	<0.01
Digestibility, % of intake					
DM	53.23 ^a	48.14 ^{ab}	43.14 ^b	3.20	0.03
OM	59.03 ^a	54.54 ^{ab}	47.45 ^b	3.40	0.04
NDF	72.42 ^a	67.84 ^a	49.40 ^b	2.82	<0.01
ADF	66.85 ^a	61.73 ^a	48.11 ^b	3.18	<0.01

^{a,b,c}Means in rows without common superscripts differ at $P \leq 0.05$.

Kleiber, 1975). Thus, intake of DM and OM differed ($P < 0.01$) between husks, leaves, and stalks because intake was limited based on a priori estimates for NEm (NASEM, 2016) from predictions of TDN (Weiss, 1993). Intake of DM was greatest among cows fed leaves, intermediate among cows fed stalks, and least for husks ($P < 0.01$). Similarly, intake of OM was greatest among cows fed leaves, but least among cows fed husks or stalks ($P < 0.01$). Intake of NDF and ADF ($P < 0.01$) appeared to follow differences in DMI but were also reflective of differences in NDF and ADF concentration between husks, leaves, and stalks. Intake of NDF was greatest for cows fed leaves but was least for stalks and intermediate for husks ($P < 0.01$). Husks contained nearly 42 and 88% more hemicellulose (36.0%; Table 1) than leaves (25.3%) or stalks (19.8%), respectively. Thus, it is perhaps unsurprising that intake of ADF was less ($P < 0.01$) when cows were fed husks in comparison to when cows were fed leaves or stalks.

Similar to differences in DMI, fecal DM output ($P < 0.01$) was greatest when cows were fed leaves, intermediate for stalks, and least for husks. Similarly, fecal excretion of OM ($P < 0.01$) was least when cows were fed husks but was not different ($P = 0.54$) between leaves or stalks. However, fecal excretion of NDF and ADF ($P < 0.01$) was greatest when cows were fed stalks, intermediate for leaves, and least for cows fed husks.

Estimates of apparent total-tract DM digestion ($P = 0.03$) were greatest when cows were fed husks, least when cows were fed stalks, and intermediate when cows were fed leaves even though DMI and DM flow to feces was greatest when cows were fed leaves, intermediate for stalks, and least for husks. Similarly, total-tract OM digestion was greatest ($P = 0.04$) when cows were fed husks, least for stalks, and intermediate for leaves. Further, apparent total-tract digestion of NDF and ADF were greater ($P < 0.01$) when cows were fed husks or leaves in comparison to when cows were fed stalks.

Currently, we are not aware of any published reports of measures of total-tract digestibility of corn husks, leaves, or stalks in ruminants; however, there are some reports of in vitro estimates of DM or OM total-tract digestion in husks, leaves, or stalks. Several authors (Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991) reported that in vitro DM disappearance from husks were nearly 50% greater than in vitro DM disappearance from leaves or stalks. Similarly, previous measures (Gutierrez-Ornelas and Klopfenstein, 1991; Stalker et al. 2015)

of in vitro OM disappearance between corn husks, leaves, and stalks suggest that in vitro OM disappearance from husks is nearly 50% greater than OM disappearance from stalks, but that OM disappearance from husks is only 29% greater than estimates of OM disappearance from leaves. Similar to in vitro estimates of DM and OM disappearance, total-tract DM, and OM digestibility in this study were greatest when cows were fed husks in comparison to leaves or stalks. Further, several authors reported that DM disappearance of leaves and stalks were 46 ± 1.8 and $47 \pm 2.7\%$, respectively (Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991) and that OM disappearance was 52 ± 1.2 and $44 \pm 0.5\%$, respectively (Gutierrez-Ornelas and Klopfenstein, 1991; Stalker et al. 2015) after 48 h of in vitro incubation. Amounts of DM and OM apparently digested from leaves and stalks in this study were similar to measures of in vitro DM and OM disappearance (Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991; Stalker et al. 2015); however, amounts of DM apparently digested from husks (53%, DM basis) in the present study were nearly 20% less than previous measures of in vitro DM disappearance ($66 \pm 5.2\%$, Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991).

If pregastric fermentation of plant fibers accounts for nearly all total-tract nutrient disappearance from corn residues, then estimates of total-tract digestion should be similar to estimates of ruminal digestibility. Indeed, measures of total-tract NDF digestibility (Table 3) in the current experiment were similar to ruminal disappearance in Exp. 1, but measures of total-tract DM and OM digestibility were less than amounts of DM and OM that disappeared after 96 h of ruminal incubation. Husks, leaves, and stalks were ruminally incubated for a maximum of 96 h; however, previous authors demonstrated that the total mean retention time of low-quality forages is often less than 48 h (Judkins et al., 1990; Damiran et al., 2008). Differences between measures of total-tract DM digestibility and amounts of DM not able to be ruminally fermented seem to suggest that total mean retention time of husks, leaves, and stalks in Exp. 2 were less than 96 h. Indeed, if amounts of DM digested from the total-tract of cows in Exp. 2 occurred completely by ruminal fermentation then the total mean retention time of husks, leaves and stalks were equal to 17, 12, and 30 h, respectively.

Measures of NDF and ADF digestion were greater ($P < 0.01$; Table 3) when cows were fed

husks and leaves compared with stalks. Differences in total tract digestibility could be influenced by limitations in ruminal fermentation of fiber as a result of differences in lignin content between husks, leaves, and stalks. Typically, stalks have greater amounts of lignin in comparison to corn leaves and husks (Barten, 2013). Additionally, stalks also contain relatively large amounts of guaiacyl lignin that allows for more extensive cross-linking with fiber (Van Soest, 1994) and can reduce fiber digestibility to a greater extent than syringyl lignin (Jung and Casler, 2006), which often comprises a greater proportion of lignin found in husks and leaves. It is also possible that ruminal disappearance of nutrients from corn residues can be limited by inadequate amounts of ruminally available N to support optimal fermentation.

In this study, cows were provided isocaloric amounts of corn steep liquor designed to exceed needs of ruminally available N; however, previous in vitro estimates of total-tract nutrient disappearance (Tilley and Terry, 1963) in corn residues (Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991) did not provide supplemental sources of available N. It remains unclear if in vitro estimates of total-tract nutrient disappearance (Tilley and Terry, 1963) are strongly correlated with total-tract nutrient digestion among cattle fed corn residues. Nonetheless, it is important to note that cattle in this study were fed to amounts below ad libitum intake to allow for similar caloric intakes and to estimate energy available for maintenance. It is possible that limited intakes may have increased total mean retention

time of feed and allowed for increased amounts of total tract nutrient disappearance in comparison to cattle fed to ad libitum.

Nitrogen balance Nitrogen intake (Table 4) was greatest ($P < 0.01$) when cows were fed leaves, least among cows fed stalks, and husks were intermediate. Similarly, urine N and fecal N (g/d) were greatest ($P < 0.01$) among cows fed leaves compared with cows fed husks and stalks. Amounts of N excreted in urine as a proportion of N intake were less ($P = 0.02$) in cows fed husks and leaves compared with cows fed stalks, and urine N excretion as a proportion of total N output was less ($P = 0.04$) when cows were fed husks in comparison to leaves or stalks. Furthermore, fecal N excretion as a percent of total N output was greater ($P = 0.04$) when cows were fed husks in comparison to leaves or stalks. Castillo et al. (2000) calculated that urine N output was more closely related to N intake ($R^2 = 0.76$) than N excreted in feces ($R^2 = 0.48$), which is often more reflective of large intestinal fermentation and undigested proteins in feed (Van Soest, 1994). Indeed, Castillo et al. (2000) reported that urine N output increased exponentially with greater N intake but that fecal N output increased linearly with greater amounts of N intake. Urine N output seemed to be related to N intake (pseudo $r^2 = 0.54$) in this study and N excreted in urine decreased at a greater rate in response to differences in N intake. Kebreab et al. (2002) noted that increased fermentable energy increased amounts of N excreted in feces and decreased amounts of N excreted in urine. Amounts of OM available for

Table 4. Nitrogen balance of cows fed corn residue and steep liquor to 90% of maintenance energy requirements

Item	Botanical part			SEM	P-value
	Husk	Leaf	Stalk		
N ¹ intake, g/d	73.6 ^a	134.9 ^b	60.4 ^c	4.79	<0.01
N excreted, g/d					
Urine	33.1 ^a	61.8 ^b	42.4 ^a	5.56	<0.01
Feces	42.9 ^a	60.5 ^b	38.6 ^a	2.84	<0.01
Total	76.0 ^a	122.3 ^b	81.9 ^a	6.38	<0.01
N excretion, % of total N excretion					
Urine	42.9 ^a	50.1 ^b	52.0 ^b	3.46	0.04
Feces	57.1 ^a	49.9 ^b	48.0 ^b	3.46	0.04
N excretion, % of N intake					
Urine	44.9 ^a	46.3 ^a	69.6 ^b	6.92	0.02
Feces	58.4 ^a	45.0 ^b	63.6 ^a	4.03	<0.01
N balance					
g/d	-2.4 ^{ab}	12.6 ^a	-19.5 ^b	7.14	0.01

^{a,b,c}Means in rows without common superscripts differ at $P \leq 0.05$.

¹Nitrogen.

fermentation were apparently greatest from husks, intermediate for leaves, and least for stalks. Thus, our data seem to be in agreement with the calculations of [Kebreab et al. \(2002\)](#). A greater amount of N intake was excreted in feces of cows fed husks and stalks ($P < 0.01$), which may indicate that a greater proportion of fiber from husks and stalks is fermented in the hind-gut in comparison to leaves.

Overall, N balance ($P = 0.01$) was greatest when cows were fed leaves, least for stalks, and husks were intermediate. [Hemphill et al. \(2018\)](#) limit-fed corn residue based diets to gestating heifers and observed similar amounts of N retained in comparison to our observations. Typically, when cattle are fed diets with amounts of NEm equal to or less than the maintenance energy requirement then N balance is equal to 0 or reflective of tissue mobilization (i.e., negative N balance). Measures of N balance among cows fed husks and leaves were small and did not differ from 0 ($P \geq 0.20$); however, measures of N balance were least when cows were fed stalks and tended to be less than 0 ($P = 0.07$).

Gas exchange and energy balance There were no differences ([Table 5](#)) in production of CO₂ or consumption of O₂ when cows were fed husks, leaves, or stalks or when cows were fasted. However, the

respiratory quotient was greater ($P < 0.01$) among cows fed husks compared with leaves or stalks. In general, the respiratory quotient is inadequate as an indicator of intermediary metabolism but can be used as a general indicator of metabolic state (e.g., fasting vs. fed; [Kleiber, 1975](#)). Typically, a fasting metabolic state is indicated by a respiratory quotient of less than 0.70 ([Brody, 1945](#); [Blaxter, 1962](#); [Kleiber, 1975](#)). The fasting respiratory quotient was not affected ($P = 0.60$) by prior feeding of husks, leaves, or stalks and averaged 0.69 which seems to suggest that the washed rumen approach used in this study was successful at achieving a postabsorptive state in cows. Conversion of feed DM to methane ($P < 0.01$) was greatest when cows were fed husks and least when cows were fed leaves or stalks. The nearly 46% increase in conversion of feed DM to methane when cows were fed husks compared with leaves or stalks also tended ($P = 0.07$) to increase daily methane production (L methane/cow) by nearly 29%. This difference could be attributed to the total mean retention time or differences in chemical composition of the botanical parts. Additionally, husks had greater ruminal disappearance indicating a greater amount of fermentation which could provide increases in methane production. Overall, methane production during fasting

Table 5. Consumption of oxygen (O₂) and production of carbon dioxide (CO₂) and methane (CH₄) among cows fed different botanical parts of corn residue at 90% of maintenance energy requirements and at fast¹

Item	Botanical part			SEM	P-value
	Husk	Leaf	Stalk		
O ₂ consumption at a maintenance level of intake					
L/cow	1,847.8	1,840.6	1,777.5	134.68	0.87
L/kg SBW ^{0.75}	16.66	16.80	16.14	0.90	0.85
CO ₂ production at a maintenance level of intake					
L/cow	1,726.9	1,559.0	1,555.2	94.24	0.12
L/kg SBW ^{0.75}	15.61	14.22	14.10	0.66	0.13
Maintenance RQ	0.94 ^a	0.85 ^b	0.88 ^b	0.02	<0.01
CH ₄ production at a maintenance level of intake					
L/cow	116.1	92.4	87.67	15.06	0.07
L/kg DMI	19.81 ^a	12.09 ^b	15.00 ^b	2.01	<0.01
O ₂ consumption at fast					
L/cow	1381.5	1443.5	1283.9	110.20	0.37
L/kg SBW ^{0.75}	12.43	13.21	11.62	0.78	0.25
CO ₂ production at fast					
L/cow	941.8	962.9	886.6	72.89	0.55
L/kg SBW ^{0.75}	8.48	8.79	8.06	0.47	0.40
Fasting RQ	0.68	0.67	0.70	0.02	0.60
CH ₄ production at fast					
L/cow	5.5	5.5	7.2	0.64	0.12
L/kg SBW ^{0.75}	0.05	0.05	0.06	0.006	0.30

^{a,b}Means in rows without common superscripts differ at $P \leq 0.05$.

¹Cows were fasted using the washed rumen technique ([Kim et al., 2013](#)).

(5.9 ± 1.5 L/d) was much less than methane production when cows were fed husks, leaves, or stalks (104 ± 33 L/d). Furthermore, overall methane production during fasting was not different ($P = 0.12$) between cows fed husks, leaves, or stalks prior to fasting.

Cows were fed amounts designed to provide similar amounts of NEm based on a priori estimates of TDN (Weiss, 1993) and predictive models of NEm content (NASEM, 2016). Thus, as expected, daily GE intake from corn residue (Mcal/d; Table 6) differed ($P < 0.01$) between cattle fed husks, leaves and stalks. Daily fecal energy losses (Table 6) were greatest ($P < 0.01$) for cows fed leaves and stalks and least for husks. However, fecal energy losses as a proportion of GE intake from corn residue (Table 7) were greatest ($P = 0.03$) when cows were fed stalks compared with leaves and husks. Digestible energy intake from corn residue (Table 6) was greatest ($P < 0.01$) for cattle consuming leaves compared with stalks and husks. Intake of DE from corn residue as a proportion of DMI (Table 7) was greatest ($P = 0.02$) when cows were fed husks, intermediate among cows fed leaves, and least when cows were fed stalks. However, DE intake from corn residue as a proportion of GE intake from corn residue (Table 7) was nearly 10% greater ($P = 0.03$) when cattle were fed husks or leaves than when cattle were fed stalks. Current tabular estimates of DE (2.32 ± 0.35 Mcal/kg DM) in corn residues (i.e., “cornstalks”) are similar to our measures of DE provided from husks (2.34 ± 0.38 Mcal/kg DM), but greater than our measures

of DE provided from leaves (2.17 ± 0.16 Mcal/kg DM) or stalks (1.96 ± 0.39 Mcal/kg DM). Stalker et al. (2015) reported that corn residue is primarily comprised of stalks (40.5%) and leaves (35.1%) and that husks (9.5%) and cobs (14.8%) contribute to a smaller proportion of the overall biomass in corn residue. If the composition of corn residues consumed by cattle is identical to the overall biomass in a field, then our data seem to indicate that DE intake would be 1.78 Mcal/kg. Nonetheless, cattle grazing corn residues often select diets different from the average of the overall biomass available (Lamm and Ward, 1981; Fernandez-Rivera et al., 1989; Gutierrez-Ornelas et al., 1991; Petzel et al., 2018). Most tabular estimates of DE are calculated from estimates of TDN by using a common linear coefficient ($DE = 4.4 \times TDN$; NASEM, 2016). Unfortunately, use of a common linear coefficient does not account for differences in digestibility of various feedstuffs. Forages are typically much lower in digestibility in comparison to concentrate feeds and typically have greater variation in digestibility. Thus, it is perhaps not surprising that current tabular estimates of DE do not reflect measures of DE in this study.

There were no differences ($P = 0.91$) in losses of overall urinary energy (Table 6) or as a proportion of GE ($P = 0.37$; Table 7) or DE ($P = 0.34$; Table 7) when cows were fed husks, leaves, or stalks. Methane lost as a percent of DE (Table 7) was less ($P = 0.02$) for cows fed leaves compared with cows fed stalks and husks, but methane lost as a percent of GE ($P < 0.01$; Table 7) was less for cows fed leaves

Table 6. Daily energy losses among cows fed different botanical parts of corn residue at 90% of maintenance energy requirements

Item	Botanical part			SEM	P-value
	Husk	Leaf	Stalk		
GE intake, Mcal	25.32 ^a	32.40 ^b	26.26 ^a	1.08	<0.01
GE intake from steep liquor	4.71 ^a	4.68 ^a	3.85 ^b	0.19	<0.01
GE intake from corn residue	20.61 ^a	27.72 ^b	22.31 ^c	0.89	<0.01
Fecal energy, Mcal	9.64 ^a	13.79 ^b	12.93 ^b	0.66	<0.01
DE intake, Mcal	15.68 ^a	18.60 ^b	13.41 ^c	1.12	<0.01
DE intake from steep liquor	4.44 ^a	4.41 ^a	3.63 ^b	0.17	<0.01
DE intake from corn residue	11.24 ^a	14.20 ^b	9.79 ^a	0.97	<0.01
Urinary energy, Mcal	1.40	1.28	1.37	0.27	0.91
Methane energy, Mcal	1.10	0.87	0.83	0.14	0.07
ME intake, Mcal	13.18 ^a	16.45 ^b	11.20 ^c	1.03	<0.01
ME intake from steep liquor	3.64 ^a	3.61 ^a	2.97 ^b	0.14	<0.01
ME intake from corn residue	9.53 ^a	12.84 ^b	8.23 ^a	0.92	<0.01
Heat production, Mcal	9.11	8.85	8.63	0.62	0.74
Retained energy, Mcal	3.25 ^a	6.79 ^b	2.18 ^a	1.00	<0.01
Fasting heat production, Mcal	6.42	6.65	5.96	0.50	0.39

^{a,b,c}Means in rows without common superscripts differ at $P \leq 0.05$.

Table 7. Daily energy values among cows fed different botanical parts of corn residue at 90% of maintenance energy requirements

Item	Botanical part			SEM	P-value
	Husk	Leaf	Stalk		
GE ¹ , Mcal/kg residue	4.33 ^a	4.23 ^b	4.34 ^a	0.02	<0.01
Fecal energy, % of GE ¹	47.24 ^a	49.81 ^a	57.25 ^b	3.15	0.03
DE ² , Mcal/kg residue	2.34 ^a	2.17 ^{ab}	1.91 ^b	0.13	0.02
DE ² , % of GE ¹	54.07 ^a	51.16 ^a	44.19 ^b	3.13	0.03
Urinary energy, % of GE ³	5.54	3.97	4.93	0.99	0.37
Urinary energy, % of DE ⁴	9.31	6.96	9.85	1.90	0.34
Methane energy, Mcal/kg residue	0.23 ^a	0.13 ^b	0.16 ^b	0.02	<0.01
Methane energy, % of GE ³	4.28 ^a	2.67 ^b	3.22 ^b	0.43	<0.01
Methane energy, % of DE ⁴	6.85 ^a	4.61 ^b	6.64 ^a	0.60	0.02
ME ⁵ , Mcal/kg residue	1.99 ^a	1.96 ^a	1.62 ^b	0.14	0.03
ME ⁵ , % of DE ²	84.48 ^a	90.43 ^b	84.19 ^a	2.04	0.03
HP ⁶ , % of DE ²	83.32 ^a	62.55 ^b	87.06 ^a	7.61	0.05
FHP ⁷ , Mcal/kg SBW ^{0.75}	0.06	0.06	0.05	0.003	0.27
NEm ⁸ , Mcal/kg residue	1.30	1.42	0.91	0.18	0.06

^{a,b,c}Means in rows without common superscripts differ at $P \leq 0.05$.

¹Gross energy from corn residue.

²Digestible energy from corn residue.

³% of gross energy intake.

⁴% of digestible energy intake.

⁵Metabolizable energy from corn residue.

⁶Heat production.

⁷Fasting heat production.

⁸Net energy for maintenance corrected for energy requirements of the gravid uterus (Ferrell et al., 1976) and energy supplied from corn steep liquor (NASEM, 2016).

or stalks in comparison to husks. Energy losses from methane as a proportion of DMI (Table 7) were less ($P < 0.01$) for leaves and stalks and greater when cows were fed husks. These data indicate that diets selected by cattle grazing corn residues may have large impacts on energy lost as methane. It seems likely that differences in energy losses as methane may be related to differences in ruminal fermentation. A myriad of factors (e.g., lignin, N concentration, rates, and extent of fermentation) can apparently influence methane energy losses from ruminants (Moe and Tyrrell, 1979). Johnson and Johnson (1995) concluded that energy lost as methane is less variable when DM digestibility is improved, and DM intake is inversely correlated with methane emissions from cattle (Johnson et al., 1994). Yet, greater concentration of lignin and other cell wall fiber components contribute to greater methane emissions (Moe and Tyrrell, 1979; Beever et al., 1989). It seems plausible that greater rates of particulate passage and lesser rate and extent of ruminal fermentation of fiber could contribute to reduced energy losses of methane from cattle. Goopy et al. (2014) reported that sheep with greater ruminal particulate and liquid passage rates produced less methane. Further, greater amounts

of feed processing can reduce amounts of methane produced by cattle (Blaxter, 1989). Differences in energy losses as methane (Table 7) contributed to differences ($P = 0.03$) in ME derived from husks (1.99 Mcal/kg), leaves (1.96 Mcal/kg), and stalks (1.62 Mcal/kg). Current tabular estimates of ME (NASEM, 2016) indicate that corn residues contain 1.90 Mcal/kg DM.

Metabolizable energy as a proportion of DE from corn residue (Table 7) was greater ($P = 0.03$) for leaves compared with husks or stalks. Current estimates of conversion of DE to ME are 82% (NASEM, 2016). Cows fed husks and stalks converted DE to ME at 84.5 and 84.2%, respectively, but cows fed leaves converted DE to ME at 90.4%. The ME:DE ratio can range between 0.82 and 0.93 and is influenced by diet and level of DMI (Vermorel and Bickel, 1980; Hales et al., 2014; Galyean et al., 2016). Increases in rapidly fermentable substrates seem to increase the conversion between DE and ME (Hales et al., 2014). Our data seems to support this because rates of ruminal disappearance of OM from leaves were more than 74% greater than rates of ruminal OM disappearance from husks or stalks.

Daily amounts of HP (Table 6) did not differ ($P = 0.74$) when cows were fed husks, leaves or

stalks; however, amounts of DE from corn residue lost as HP (Table 7) were less ($P = 0.05$) when cows were fed leaves compared with husks and stalks. Fasting HP (Table 6) did not differ ($P = 0.39$) when cows were fed husks, leaves, or stalks. Heat production is typically reflective of total nutrient intake (Rubner, 1902), which in our study was designed to provide 90% of the maintenance energy requirement. Fasting HP is generally considered to be equal to the maintenance energy requirement of cattle (NASEM, 2016). Current estimates of maintenance energy requirements of cattle calculate maintenance energy (NASEM, 2016) as 77 kcal for each kg of “metabolic body weight” (i.e., shrunk $BW^{0.75}$). Measures of FHP in this study were less than current estimates of maintenance energy requirements in cattle (6.34 vs. 8.61 Mcal/d). Estimates of maintenance energy requirements (6.29 Mcal/d; Brody, 1945) based on the exponent reported by Brody (1945) were much nearer to our measures of FHP (6.34 Mcal/d). Thus, our data seem to indicate that metabolic body size among cows in this experiment were more aptly estimated by the approach of Brody (1945) in comparison to current estimates of maintenance energy requirements in cattle (NASEM, 2016).

Net energy for maintenance (Table 7) tended ($P = 0.06$) to be greatest for leaves (1.42 Mcal/kg DM) and for husks (1.30) and least for stalks (0.91). Pennington et al. (2017) fed yearling Holstein steers a corn-based diet and replaced 0, 10 and 20% corn silage with ground mechanically harvested corn residue. Average daily gain was not affected by greater inclusion of corn residue (1.6 kg/d) but DMI increased in cattle fed ground corn residue. Net energy for maintenance can be calculated from average daily gain and DMI (Vasconcelos and Galyean, 2008). Data from the study of Pennington et al. (2017) suggests that the NEm of ground mechanically harvested corn residue is 0.75 Mcal/kg DM which is less than current tabular values of NEm for corn residues (1.06 Mcal/kg DM; NASEM, 2016) and our estimate of NEm in stalks (0.91 Mcal/kg DM). Typically, stalks comprise 40% of the overall biomass in mechanically harvested corn residue (Stalker et al., 2015). It is likely that the ground corn residues fed by Pennington et al. (2017) increased intake of stalks compared with cattle fed mechanically harvest corn residues or cattle grazing corn residues. Additionally, digestion of corn residues and performance of cattle fed by Pennington et al. (2017) may have been negatively impacted by feeding in a corn-based diet (Pordomingo et al., 1991)

If intake among cattle fed corn residues is similar to the average of the overall biomass then our data suggest that the NEm content is 0.99 Mcal/kg DM, which is similar to tabular estimates of NEm available to cattle from cornstalks (1.06 Mcal/kg DM; NASEM, 2016). Even though tabular estimates of NEm are similar to the average of our measures of NEm weighted to the relative amounts of husks, leaves, and stalks in corn residue, cattle grazing corn residues select diets different from the overall biomass (Lamm and Ward, 1981; Fernandez-Rivera et al., 1989; Gutierrez-Ornelas et al., 1991; Petzel et al., 2018). Gutierrez-Ornelas and Klopfenstein (1991) reported that the diet of cattle grazing corn residues is comprised of 65% husks, 35% leaves, and negligible amounts of stalks. If cattle grazing corn residues typically select diets similar to that reported by Gutierrez-Ornelas and Klopfenstein (1991) then our data imply that the caloric density of diets typically selected by cattle grazing corn residue would be more than 25% greater than energy values of the available biomass (1.34 Mcal/kg DM).

Overall, data from these studies imply that corn residues grazed by cattle can have a greater energy value than current tabular estimates. Data from these experiments can be used together with accurate estimates of diet selection to more appropriately estimate energy intake of cattle grazing corn residues.

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