5-2017

Estimates of Corn Residue Quality

Tasha M. King
University of Nebraska-Lincoln, tasha.king@huskers.unl.edu

ESTIMATES OF CORN RESIDUE QUALITY

by

Tasha M. King

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Animal Science

Under the Supervision of Professor

James C. MacDonald

Lincoln, Nebraska

May, 2017

ESTIMATES OF CORN RESIDUE QUALITY

Tasha M. King, M. S.

University of Nebraska, 2017

Advisor: James C. MacDonald

Two experiments were conducted to determine the effect of corn residue harvest method on animal performance and diet digestibility. Corn residue harvest methods used in these experiments were low-stem, high-stem, and conventional. Steers had greater ADG when fed low-stem in a growing diet compared to high-stem and conventional residues. Addition of supplemental RUP to corn-residue based diets resulted in greater ADG and G:F in steers. Digestibility of DM, OM, and NDF were greatest in lambs fed diets containing low-stem residue. Low-stem residue had greater digestible energy (DE) compared to high-stem and conventional, which did not differ.

Lastly, a study was conducted to compare the drying method of fecal samples and its effect on subsequent lab analysis. Fecal samples were dried utilizing 1 of 3 methods: 1) 60°C forced air oven for 72 h; 2) 100°C forced-air oven for 72 h; or 3) freeze dried. No effect on OM content was observed. Fecal samples dried at 100°C had greatest fiber content. No effects on digestibility of OM or fiber were observed among drying methods.

Acknowledgements

I have been blessed to continue my education surrounded by an excellent group of people. Here at Nebraska I have been surrounded by positive individuals who are willing to help and without them, I would not be where I am today.

First, to Jim, Terry, Galen, and Andrea, thank you for challenging my way of thinking and allowing me to grow both as a student and as an individual. Jim, thank you for always having an open door and providing me with opportunities to explore and find my passion. Having you right down the hall, Andrea, was incredibly helpful. Thank you for always assuring me, stopping to talk, and answering all my questions no matter how simple they were.

To my office mates, y'all have been wonderful. Thanks for the crossword breaks, laughter, and letting me be the nervous person that I am. Ashley, I appreciate that you understand how I learn and are always willing to study and create acronyms. Hannah, I don't know how I would have survived this last semester without you. Thanks for answering all my questions for the lab, teaching me new lab techniques, and helping me. Especially when I asked the same question the day before.

Jamie, Tasha, Lauren, and Brad- where would I be without you all? Thanks for reminding me to stop and have some fun. From making me laugh during long days in the lab to attempting to explain statistics to me, your support has been appreciated. I can't wait to enjoy pizza rolls and make more memories in the years to come.

Dan, you have been a friend and support person and for that I love you. Thanks for keeping me company and reminding me to stop for supper. Also, thanks for taking care of Moby when I pulled late nights of studying or lab work.

To my amazing family, thank you for the words of encouragement and warm meals. Thanks for believing me every step of the way, reminding me how proud my dad would be, and answering all my stressed out phone calls (you're the best mom!).

Table of Contents

List of Tables

Chapter I. Review of Literature

Introduction

A recent demand for biofuels has caused a shift in agricultural land use across America leading to an increase in corn and soybean production. Roughly 3 million hectares were converted to crop production between 2008 and 2012 across the nation (Lark et al., 2015). Of these converted lands, 77% of them were from hectares that had previously been grasslands. The conversion of grasslands led to a decrease in forage that was traditionally used by the livestock industry for grazing and stockpiling. Of these newly converted acres, corn was planted on 26% of the acres, providing an increase in grain and residue available. In 2016, approximately 37.9 million ha were planted in corn providing an abundant source of alternative forage in the form of residue (USDA-NASS, 2016). Corn residue can be utilized as a forage for ruminants in many systems and stages of development. Animals can directly remove the residue from the field through grazing or the residue can be harvested, baled, and stored for use.

Specifically in the western Corn Belt (North Dakota, South Dakota, Nebraska, Minnesota, and Iowa) an estimated 0.526 million ha, were converted from pasture or native grassland into row crop production between 2006 and 2011 (Wright and Wimberly, 2013). This change in land use has led to reduced hectares of traditional forage sources causing an increase in the costs of these forages. With increased prices and decreased supply of traditional forages, alternative forages from integrated cropping-livestock systems need to be considered for utilization in animal production systems. In

Nebraska, livestock producers have added corn residue into their grazing systems and forage resources.

Ruminant animals have a unique digestive system that allows for greater utilization of forages than other animals. The microbial population found in the rumen allows for microbial fermentation of forages resulting in the production of microbial protein and volatile fatty acids (VFAs). Microbes use proteins and digestible fiber for growth and development while the VFAs are absorbed across the rumen wall to be used as an energy source by the animal. Benefits of the ruminant microbes include digestion of low quality forage, like corn residue, and convert into a high quality protein through muscle deposition. The microbes' ability to utilize the low quality corn residue provides producers with increased opportunity to extend the grazing season through the winter or to utilize corn residue in diets for animals fed in dry lots.

The increase in production of biofuels and corn production, also results in an increase in milling byproducts available for livestock producers. In 2016, the United States produced 42,786 metric tons of ethanol (RFA, 2017). Dry milling (ethanol production) and wet milling (products for human consumption), produced 39.34 and 6.91 million metric tons of byproducts, respectively (NASS, 2017). Byproducts have the starch removed allowing producers to use them to help in adaptation diets in the feedlot and aid in decreasing the amount of forage being used (Nebraska Corn Board, 2010). After the milling process, these products also have a greater or equal feeding value relative to corn and are high in protein, providing a quality feedstuff available for producers.

Integrating corn residue in a livestock system can allow producers to utilize the corn residue for winter grazing. Baling capabilities also allows the corn residue to be removed and stockpiled, similar to hay. Even with the capabilities of ruminants to convert low quality forages to higher quality proteins and energy sources, depending on the status of the animal (i.e. growing, lactating, gestation, etc.), supplement may be needed to ensure nutrient requirements are met. Byproducts from the biofuels industry can be economical for use as supplementation of protein and energy in diets. Determining the nutrient content of residue, selectivity by cattle, and the different digestibility of plant components can help producers determine proper stocking rates for grazing systems. When stockpiling the forage, new technologies could potentially allow producers to stockpile a higher quality by specifying what plant parts are included in the bale.

Corn Residue Components

The corn plant is composed of the following components: stem, leaf, leaf sheath, husk, shank, grain, and cob. Corn residue is utilized after removal of the grain. When grain was harvested at 30% moisture, Pordesimo et al. (2004) found the grain to account for 45.9% of the DM content of the corn plant leaving 54.1% of its DM available in the form of residue. Upon removal of the grain, the residue can be used to provide ground cover for the field or used as a forage source. Excluding grain, McGee et al. (2012) found the percent of plant DM was 45.4, 18.7, 12.6, 7.5, 1.1, and 14.7% for stem, leaf, leaf sheath, husk, shank, and cob; respectively. This distribution is similar to results from previous research that found distribution after removal of grain to be 50.9, 21.0, 15.2, and

12.9% for stem, leaf, cob, and husk; respectively (Pordesimo et al., 2004). Jones et al. (2015b) found similar proportions of DM for corn residue which remained almost constant in time points collected after grain harvest. Any losses in residue DM were accounted to weathering. The stem and cob are lowest in digestibility and palatability, therefore they are the last plant parts to be consumed. The more digestible and palatable components, primarily leaf and husk, ranged from 34% to 39% of the residue and are readily available and consumed by cattle (McGee et al., 2012; Wilson et al., 2004; Pordesimo et al., 2004).

As the corn plant matures, the proportional distribution of grain to residue changes. Hunt et al. (1989) harvested corn plants at 3 maturities based on milkline: A. one-third down from the top of the kernel; B. two-thirds down from top of the kernel; and C. at black layer formation, or 100% milkline. Overall DM of the whole corn plant increased as maturation occurred. The plant part composition shifted from 40.9% ear (grain and cob) at harvest point A to 54.3% ear at harvest point C, leading to a decrease in the proportion of plant composed of stover (husk, leaves, and stalk). Dry matter yield and TDN yield both were similar from harvest point B to C at 25.3 and 17.3 metric ton / ha, respectively. Maturation led to a decrease in carbohydrates as the plant converted sugars to starch. Maturity has the greatest effect on the stover component of the plant leading to decrease in TDN (calculated using the following equation: TDN= (NE_1 x 90.1) + 2.898) from 55.4 to 50.4 to 46.8% for harvest points A, B, and C, respectively (Hunt et al., 1989).

Digestibility of Corn Residue

Forages can vary in digestibility depending on the part of the plant consumed and the state of maturation of the plant. Corn residue utilized as a forage source after maturation leads to an increase in the DM of the residue and a decrease in the digestibility.

Different plant parts of the corn residue have differing digestibilities, McGee et al (2012) found the range to be from 33.9 to 59.0% digestibility of dry matter. The husk contained the highest *in vitro* dry matter digestibility (IVDMD) at 59.0% followed by the shank (49.8%). Due to its low percentage of total plant DM, the shank is often grouped in with other parts. The leaf and leaf sheath are intermediate between husk and stem with leaf being more digestible (45.7%) than leaf sheath (38.6%). The stem was least digestible (33.9%), but increased in digestibility at the top third of the stem (37.6%). When looking at the digestible parts consumed by cattle (Gardine et al., 2016), husk had the greatest digestible organic matter (DOM; 55.6%), leaf blade was intermediate (40.7%), and leaf sheath had lowest DOM (38.6%). The estimate of TDN would be 45% when cattle are consuming leaf and husk in the proportion produced by the plant. The TDN estimate is calculated by multiplying DOM x 1.05.

Lamm and Ward (1981) found *in vitro* organic matter digestibility (IVOMD) of all corn residue components decreased throughout the grazing period (October 23 to January 17). Residue was harvested from exclosures constructed within the grazing area a day before grazing (fall harvest) and March 22 (spring harvest). An area measuring 2.44 m x 3.05 m was used to collect residue inside the exclosure (4.57 m x 9.75 m) for each sampling. Husks, leaves, cobs, grain, and stalks cut at ground level were collected by hand to provide the sample of available residue. Fall harvested residue had greater IVOMD (72.0%) than spring (59.2%), showing a decrease in digestibility as the grazing period continued. Husks and leaves lost IVOMD value dropping from 66.2% for the fall to 47.9% in the spring for a decrease of 38% in IVOMD.

An experiment evaluated the change in corn residue plant components on various days following black layer: 51, 93, and 108 d (Jones et al., 2015b). No difference in neutral detergent fiber digestibility (NDFD) following black layer formation with stem having least NDFD (0.7%) and husk/shank having greatest NDFD (32.5%). True digestibility for the various components of corn residue maintained similar values over time. Twelve esophageally fistulated steers grazed corn residue providing extrusa samples at various points during the grazing period (Fernandez-Rivera and Klopfenstein, 1989b). The IVDMD of the esophageal extrusa samples decreased from 72% at the beginning of the grazing study to 50% near the end of the grazing period. The decline in IVDMD during the grazing season demonstrates the decrease in digestibility due to early consumption of grain and selectivity of the cattle.

Animal Selectivity

Grazing allows for the most economical utilization of corn residue (Ward, 1978). Animal selectivity is an important factor in residue grazing systems as all residue is available on day 1 of the grazing period, allowing for selection of highly digestible plant components for consumption. Cattle will utilize the leaf plus husk to a greater extent due to increased digestibility, better palatability, and availability (Fernandez-Rivera and

Klopfenstein, 1989a; McGee et al., 2012). Fernandez-Rivera and Klopfenstein (1989a) conducted an experiment evaluating the residue utilization on both dryland and irrigated fields. The dryland fields had two stocking rates applied at 1.54 and 2.47 calves / ha and the irrigated field had a stocking rate of 2.47 calves / ha leading to utilization of 32, 47 and 18% of total residue DM, respectively. Of the total residue removed, leaf plus husk accounted for 37, 53 and 32%, respectively. Selectivity creates a change in the quality of the residue throughout the grazing period leading to decreases in digestibility and protein as the grazing season progresses (Wilson et al., 2004; Ward, 1978).

Lamm and Ward (1981) compared the pre-grazing quantities of plant components to the post-grazing to evaluate selectivity by cattle. Before grazing, the residue distribution was 11.2, 9.1, 40.7, and 39.0% DM for grain, cobs, stalks and leaves + husks; respectively. Cows grazed the field for 86 d changing the distribution to 1.4, 13.1, 54.8, and 30.6% of the DM, respectively. These data suggest that the cattle graze the components with the highest nutritional value first selectively grazing in the following order: grain, leaves + husks, stalks, and cobs. Similar research evaluated extrusa samples throughout the grazing period to examine the change in diet composition. During the last half of the grazing period, animals consumed large amounts of cob due to the lack of grain, leaf and husk remaining on the field (Fernandez-Rivera and Klopfenstein, 1989b).

Stocking rate affects the quality of the residue the animal is consuming. By applying a heavy grazing stocking rate, the high quality components of the plant will be consumed more quickly due to animal selectivity compared to a light stocking rate. Cattle stocked using a light grazing treatment of 1 AUM / acre or a heavy grazing treatment of 2 AUM / acre, had a different body condition score (BCS) at the end of the grazing period (van Donk et al., 2012). While both treatments had an initial BCS of 5.5, the lightly stocked treatment maintained while the heavy stocked treatment lost 0.4 to have a final BCS of 5.1. Cattle that are not lactating or in gestation lost BCS when heavy stocked due to the selectivity of cattle choosing the nutrient dense parts of the plant to consume first. Cattle placed on the lightly stocked treatment maintained their BCS supporting the importance of proper stocking rates.

Nutritive Value of Corn Residue

Corn residue is low in protein, containing 4.25% CP when the residue being consumed is 1/3 husk and 2/3 leaves (Gardine et al, 2016). Leask and Daynard (1973) found similar findings with the average protein content being 4.5% across 22 hybrids. The hybrids did not differ in the protein content of the residue but did have an effect on dry matter yield due to a linear correlation of grain yield and residue yield. Updike et al. (2016) found the CP of husk to be 5.74% and by using alternative methods to harvest corn residue were able to get improved CP of 5.95 and 5.48% for husklage and stalklage, respectively. The husklage was produced with corn residue harvested from a single pass system (a baler attached behind the combine) with the addition of water to reach a targeted DM of 35% and bagged in an agricultural bag for at least 30 days. The stalklage was produced with corn residue harvested with a New Holland Cornrower Corn Head (Straeter Innovations, Inc.) cutting all 8 rows of stem, mixed with water to reach a targeted DM of 35% and bagged in an agricultural bag for at least 30 days.

An *in situ* experiment evaluated the RUP content of corn grain, husks, and leaf blades (Gutierrez-Ornelas and Klopfenstein, 1991a). Corn residue samples were collected at 3 times during the early-grazing trials (October to December), and 3 times during the late-grazing trials (December to March). Early-grazing samples were collected 7 d prior to grazing and 36 and 54 d after grazing. Late-grazing samples were collected on d 0, 44, and 93 of the grazing trial. The field was divided into six equal-sized areas and randomly chosen for sampling. All plant parts within the area were collected by hand except single grain kernels which remained in the field. Throughout the trials grain, husks, leaf blades, stems, cobs, and sheaths averaged 10.2, 4.4, 6.6, 5.2, 2.6, and 4.8% CP, % of DM, respectively.

Residue harvested prior to grazing in the fall was found to have an average of 8.8% CP for all residue components (Lamm and Ward, 1981). When ungrazed exclosures were harvested in the spring, the average CP had dropped to 8.2%. Individual plant components harvested in the fall contained 12.6, 6.8, and 6.6 % CP as % of OM for grain, cobs, and stalks, respectively. These three components had a drop in CP as % of OM throughout the grazing period falling to 12.2, 5.6, and 5.8%, for grain, cobs, and stalks, respectively. Lamm and Ward (1981) observed a slight increase in CP (%OM) from to fall to spring for husks and leaves increasing from 7.3 to 7.6% for fall to spring, respectively.

Each component of corn residue was analyzed with near infrared (NIR) spectroscopy starting 104 d after planting until d 213 (Pordesimo et al., 2005). The residue components varied in composition of cell soluble solids (calculated as total glucan minus structural glucan) over time of plant maturation. Stalks and husks had similar composition but varied in concentrations of xylan with husk having a greater xylan concentration of 26.8% vs. 19.4% for stalks. Leaves had the greatest levels of overall soluble solids around 35%, when analyzed at grain physiological maturity. When examined upon harvest of grain (at 15.5% moisture), stalks, husks, and leaves all contained roughly 5% soluble solids. Pordesimo et al., (2005) also utilized an adiabatic bomb calorimeter to determine gross energy content. Throughout plant maturation, gross energy of the plant components varied but tended to fall in the range of 16.7 to 20.9 kJ / g (4000-5000 cal g^{-1}).

Corn Residue Yield

Wilson et al. (2004), found a relationship between bushel corn yield and leaf and husk to be: ([bu/ acre corn yield x 38.2] +429) x 0.39 to produce one lb of leaf and husk. In grazing situations, utilization of husk and leaf is estimated to be 50% due to losses of residue caused by trampling and weather. An experiment harvesting 10 plants per replication, found that the average residue was 7.2 kg DM / bu of corn when grain was at 15.5% moisture (Gardine et al., 2016). With the estimation of 50% grazing efficiency, it can be estimated that roughly 3.6 kg residue DM is utilized per bushel of corn yield.

Another way to determine the production of corn residue is by using the harvest index. The harvest index is the proportion of corn grain of the total above ground dry biomass. Harvest index is dependent on grain yield, rising as the yield increases, and on average ranges from 0.45 to 0.55 (Gallagher and Baumes, 2012). Watson et al. (2015) determined for every 1 kg of corn grain (DM basis) produced, 0.8 kg of corn residue will be produced at a harvest index of 0.55. Commonly a ratio of 1:1 is used for grain mass to stover mass resulting in a harvest index of 0.5 (Gupta et al., 1979; Graham et al., 2007). Producers can use the harvest index to determine the amount of residue on a field available for grazing or baling by multiplying the dry weight of corn grain produced by the HI. The method used to harvest the residue affects the amount of residue removed from the field. In a grazing situation, an estimated 25 to 30% of total residue would be removed (Mayer, 2012; Fernandez-Rivera and Klopfenstein, 1989a). In a chop, rake, and bale system, up to 80% of residue can be removed, while windrowing behind the combine will remove around 50% of the residue (Mayer, 2012). Removing corn residue from the field removes nutrients that are important to soil health. In a grazing situation some of these nutrients, a majority of the N, P, and K and some carbon, are applied directly back to the soil through the feces of the animal (Drewnoski et al., 2016). A baling system can then replenish nutrients by hauling manure from dry lots to distribute onto the field after the residue bales have been removed.

With a field harvested for grain at 27% moisture, Lamm and Ward (1981) found 694.3, 567.6, 2,536.4, and 2,423.3 kg of DM / ha for grain, cobs, stalks, and husks-leaves, respectively. This provided a total of 6,221.6 kg of DM / ha for grazing. After grazing for 86 d, the field contained 44.9, 406.2, 1,698.1, and 949.5 kg of DM / ha, respectively. Each grazed plot contained an exclosure allowing an ungrazed plot to be collected in the spring to identify losses due to weathering. The ungrazed plots contained 365.6, 613.8, 1,560.7, and 1,382.2 kg of DM / ha, respectively. Losses due to weathering in the ungrazed plots caused disappearance of half of the grain and husks-leaves and one third of the stalks.

Baling of Corn Residue

Baling the residue decreases losses caused by weathering and trampling. However, baling leads to a decrease in quality compared to grazing due to the amount of stalk that is harvested with the bale, and is normally left ungrazed by cattle. Various techniques have been developed for harvesting and storing corn residue for future use in livestock feeding operations. By baling corn residues, it can be stored for year round use as well as hauled to the site where cattle are being fed. Allowing residue to sit on the field before baling did not affect energy content of the residue but did cause a decrease in soluble solids (Pordesimo et al., 2005). Delayed collection provides the opportunity for the producer to complete grain harvest of their entire crop system before baling the residue with a decrease in yield, due to decreases in soluble DM and weathering, but no effects on energy value.

The traditional method used to harvest corn residue is the conventional rake and bale system. The combine is used to harvest the grain and all excess material is expelled out the back. After grain harvest is complete, the producer rakes the residue from the field into windrows and bales the windrows. The raking pulls a larger quantity of the stem into the bale than what would be consumed by cattle that are allowed to graze. The various operations required in the conventional method of harvesting corn residue can cause soil contamination into the product (Shinners and Binversie, 2007). The rake and bale system typically requires the residue to remain on the field for a minimum of three days before baling to allow for average moisture of the residue to fall below 30%, with 20% moisture being optimal (Atchison and Hettenhaus, 2004). Allowing the residue to dry prevents damage from occurring during the storage period. By allowing the residue to field dry to a moisture content of 30% or less, keeps dry matter losses to 12% or less in the conventional rake and bale system (Wendt et al., 2014). The cost of harvesting and collecting bales was an estimated $33.24 / ton based on 2011 prices with dry matter losses costing an additional $4.79 / ton when stored under a tarp.

Alternative Baling Methods

In order to create a product that would have similar quality to residue that is grazed, selectivity of the components that are baled needs to occur. Harvesting a bale with a high leaf plus husk: stem ratio would mimic animal selectivity that occurs when grazing increasing the quality of the residue (Fernandez-Rivera and Klopfenstein, 1989).

Single-pass harvesting scenarios collect cobs, husk, and leaf components of the plant resulting in 37 to 40% of potential residue being harvested. The moisture content of corn residue harvested with this system ranges from 32 to 48% resulting in a product that is too dry to allow preservation through fermentation (Shinners and Binversie, 2007). A John Deere 568 round baler can be modified with the Hillco single pass system (an accumulator consisting of a hopper, a conveyor, and a metering system) to produce round bales of husklage (Keene et al., 2013). Addition of the Hillco single pass system allows the round baler to produce bales without stopping grain harvest. Husklage contains the husk and cob resulting in a product that can contain 60 to 70% cobs (Klopfenstein et al., 1987). Updike et al. (2015a) conducted a study with individually fed growing steers in which husklage had improved G: F and ADG ($P < 0.05$) compared to conventional rake and bale cornstalks resulting from the lack of stalk that is collected. However, feed refusals need to be considered as refusals ranged from 5-8% of daily feed offering when consuming husklage compared to an average 2% for cornstalks. Klopfenstein et al. (1987) reported similar findings with 500 calves fed husklage over a five yr period had gains ranging from 0.40 to 0.77 kg/d.

Another method of collecting corn residue in a single pass system, can be to attach a forage blower to the back of the combine (Hoskinson et al., 2007). The forage blower collects residue discharged from the rear of the combine and blows it into a forage wagon. Using this method Hoskinson et al. (2007), harvested 5.1 Mg/ha of residue DM, leaving a sufficient amount of residue on the field. With a normal cut of about 40 cm up the stalk, residue was left to provide soil cover to help with moisture retention and to minimize erosion. Single pass systems can present challenges in storage of the residue due to the higher moisture content at harvest. Four methods of storing residue harvested with the single pass system at 45% moisture were evaluated for cost and DM losses (Wendt et al., 2014). High moisture bales of corn residue harvested using a single-pass system were stacked 4 x 4 and stored under a tarp or stacked 1 x 3 and bale wrapped, 7 layers of bale wrap were used to limit oxygen exchange. Two bulk storage methods were also evaluated, storing the chopped residue in an Ag-Bag versus chopped residue in a drive-over pile covered with plastic tarps. Wendt et al. (2014) found high moisture bales stored and bale wrapped to be most economical at $32.64/ton for harvest, collection, and storage for 6 months with only 5% DM loss. Both bulk methods had similar dry matter losses assumed at 5% but were more costly at $45.92/ton and $35.69/ton, respectively. High moisture bales stored under a tarp was more economical than the bulk method at $34.45/ton but suffered DM losses of 25%.

Another technique was developed by Straeter Innovation, Inc. and manufactured by New Holland, the system incldes a chopping corn head with a system for collecting residue and windrowing under the combine head. Cobs and husks then fall from the back of the combine onto the windrow (Barten, 2013). The windrow is then directly baled decreasing soil contamination which prevents adding ash to the product (Straeter, 2011). The chopping mechanism decreases the size of residue particles resulting in a bale with higher density. Straeter (2011) found a 15% improvement in bale density over conventionally raked and baled residue, resulting in an increased amount of residue being transported per semi load. The Cornrower head also allows a producer to choose the number of stalks that are cut and chopped for the windrow ranging from 0 to 8. By decreasing the number of stalks, the leaf + husk: stem ratio can be increased allowing for a producer to mimic animal selectivity that occurs during grazing. By decreasing the stem which is least digestible, the quality of the bale is increased.

Quality of Corn Residues Harvested with Alternative Methods

An *in vitro* experiment was conducted comparing conventionally baled cornstalks with just husk, and bales harvested with the Cornrower Head containing 2, 4, 6, and 8 rows of stem (Updike et al., 2015b). Husk had the greatest *in vitro* OM digestibility (IVOMD) of 72.4%. The IVOMD value agrees with previous research with husk having an IVDMD value of 60.9% (Gutierrez-Ornelas, 1991). Lamm and Ward (1981) found a slightly lesser value (66.2%) when evaluating IVOMD for both husk and leaf together. The bales harvested with the Cornrower head had greatest at IVOMD with 66.4% for 2-row, 8-row was the least at 47.0%, with 4-row and 6-row being intermediate at 54.3 and 53.3%, respectively. All harvest methods had greater IVOMD compared to conventional cornstalks (43.0%). These data suggest that as the number of rows with cut stems is decreased, the proportion of leaf and husk to stem increases, thereby increasing the quality of residue.

Lambs were used to gather *in vivo* digestibility estimates for various harvest methods of corn residue (Updike et al., 2016). Husk had the greatest DM, OM and NDF digestibility at 68.11, 70.49, and 75.28%, respectively. Husklage and stalklage, two feed products harvested using alternative methods, saw improved total tract digestibilities but not to the extent of improvement when feeding just husk over traditional brome. A similar *in vivo* experiment using lambs saw improvement in total tract digestibility of just husk over corn residue that contained leaf, husk, and stem (McPhillips et al., 2016). Corn residues harvested using the Cornrower head, containing either 4 or 8 rows of stem, had significantly reduced total tract digestibilities compared to husk. No differences in DM, OM, or NDF total tract digestibilities were observed suggesting that the rows of stem harvested needs to be less than 4 to find significant improvement in digestibility.

Protein Supplementation for Corn Residue Diets

Protein for ruminants is classified into two categories: ruminal degradable protein and ruminal undegradable protein. Rumen degradable protein (RDP) is readily degraded in the rumen and provides a nitrogen source for the microbial population. Rumen undegradable protein (RUP) is not degraded in the rumen, and passes into the small intestine. Once in the small intestine the RUP can then be digested and absorbed providing a supply of amino acids for the ruminant. The other source of amino acids comes from the microbial cells that have flowed out of the rumen into the small intestine (Merchen et al., 1986). The supply of protein being absorbed in the small intestine from microbial crude protein (MCP) and RUP are needed to meet the needs of the animal, as defined in the metabolizable protein (MP) system (NASEM, 2016). The MP system separates the protein needs into requirements of animal and requirements of microbes. When providing a supplement, it is important to consider the protein provided to the animal from the diet (RDP and RUP profiles of feedstuff), as well as the predicted microbial protein yield. This would help meet the MP requirements of the animal which provides amino acids to the animal.

Supplementation while on low quality forages provide the microbes with substrate which leads to growth of the microbial population (Ferrell et al., 1999). The growth of microbes allows further breakdown and utilization of forages in the rumen. The increased microbial population also provides an increased source of microbial crude protein absorbed through the small intestine providing MP. The results from Ferrell et al. (1999) suggest increases in ruminal ammonia N can be observed when supplemental protein is provided. This increased concentration can lead to enhanced microbial growth. Therefore, providing microbes with supplemental substrate can lead to increased forage degradation (DelCurto et al., 1990).

Intake is a factor that needs to be considered when determining supplementation levels. Limited intake or full feed can affect how the supplementation is utilized. Schadt et al. (1999) found that restricting intake of forage led to a greater ruminal retention time, providing the ruminal microbes a longer opportunity to degrade protein and fiber. Increased ruminal retention time can lead to greater degradation of the RUP supplement within the rumen. Similar results were observed when feeding a 75% forage diet compared to a 25% forage diet, with retention time for feed particles not affected by intake but increasing when wethers were on the diet containing 75% forage (Merchen et al., 1986). Degrading the RUP supplement in the rumen provides nutrients for the microbes which could lead to greater ruminal degradation of the fiber. When forage intake was restricted, degradability of protein that would normally escape the rumen was increased (Scholljegerdes et al., 2005a).

Due to the low level of CP in corn residue, a majority of which is RDP, growing calves consuming residue require supplemental protein to achieve desirable gains. A 62 d growing study looked at extrusa samples throughout the grazing period examining the plant parts consumed and the nutrients (Gutierrez-Ornelas and Klopfenstein, 1991b). The beginning of the grazing period had no deficiencies in RUP possibly due to RUP not being the first limiting nutrient or high variations among treatments. There was no difference in gain among steers being fed varying levels of RUP supplementation. Steers supplemented with a higher level of RUP had increased gains from d 20 to 34. The last half of the grazing period showed decreasing quality of plant parts consumed potentially causing the diet to be energy deficient preventing RUP from being the first limiting nutrient. Examining extrusa samples, Gutierrez-Ornelas and Klopfenstein (1991b) observed consumption of partially husks and grain with the cobs in the first 30 d of grazing. The last half of the grazing period, cattle consumed mainly leaf blades and husks. Stem, cob, and sheath components were only consumed when more desirable components were no longer available, or covered in snow. Supplemental RUP showed to be effective between wk 4 and wk 6 and was maintained to the end of the trial. Previous research found similar results with cattle supplemented with protein had responses up to 163 g of supplemental RUP daily to reach the maximum gain of 0.308 kg/d (Fernandez-Rivera and Klopfenstein, 1989b). Responses to protein supplementation were observed in the first half of the study when energy availability was high, but began to decrease when intakes and digestibility decreased, thereby limiting energy intake.

The response to supplemental protein was evaluated in steer calves grazing corn residue from an irrigated field in an experiment conducted by Tibbitts et al. (2016). Steers grazed the same field and were supplemented individually once daily. Five treatments were applied, with all supplements formulated to meet 1.42 kg of TDN equivalent to the TDN provided from 1.36 kg of DM of distillers grains plus solubles (DGS). Supplementation of DGS has previously been shown to increase ADG with increasing rates of dried DGS supplementation providing RUP and energy to cattle grazing corn residue (Jones et al., 2015a). Distillers grains are high in protein (30% CP) and energy (104% TDN), DGS and also a good source of RUP. Of the 5 treatments applied, 2 treatments high in RDP and RUP (60:40 blend of SoyPass: soybean meal and

DGS), resulted in maximum daily gains of 0.7 and 0.6 kg, respectively (Tibbitts et al., 2016).

A study was conducted feeding corn residue with various supplements to evaluate the effect of protein supplementation when cattle were fed low quality residue diets (Collins and Pritchard, 1992). Ground corn residue was fed to 120 growing steers for 52 d, with soybean meal (SBM) and corn gluten meal (CGM) supplemented daily or on alternate days with or without monensin. Steers supplemented with CGM had improved ADG and gain:feed (G:F) compared to SBM. Alternate day supplementation was efficient if the supplement was a good source of RUP. Experiment 4 fed 24 wethers corn residue with varying levels of CP supplementation from SBM or CGM. Residue had a CP content of 3.19% with supplementation providing 70% of dietary CP. Collins and Pritchard (1992) found dry matter disappearance (DMD) to decrease as CP levels increased dropping from an average DMD of 63% to 60% for 8% to 10% protein supplementation level likely due to increased DMI of diets containing greater protein supplementation inclusion. With increased DMI observed at more frequent supplementation and increased protein levels suggests that supplementation leads to effects on intake when consuming low quality forages.

Essential Amino Acids

To make grazing systems as economical as possible, many producers try to ensure that intake meets the requirements of cattle through supplementation of protein or energy. Metabolizable protein requirements are met through the supply of microbial protein and dietary protein that is rumen protected and digested in the small intestine. Therefore, it is important to take into account increased ruminal degradation when intake is limited. Scholljegerdes (2005b) reported that as intake became more restricted, organic matter (OM) digested in the rumen decreased, but postruminally OM was highly digestible due to the availability of the undegradable protein from the RUP supplement. This led to an increased overall OM digestibility of the diet. Fluid passage rate linearly decreased as the intake of forage decreased allowing the RUP supplement to be retained in the rumen longer and providing a longer opportunity for the microbes to work on degrading the supplement. This greater degradation of protein supplement in the rumen could be due to the decrease in passage rate and supply of nutrients to microbes from the degraded RUP supplement, which then increases the microbes activity when forage intake is limited (Merchen, et al., 1986; Scholljegerdes, et al., 2005a). A cubic effect was observed showing that as the intake became more severely restricted the quantity of essential amino acids (g / d) being provided from the RUP supplement increased (Scholljegerdes, 2004). Understanding the decreased passage rate and increased rumen degradability of RUP supplement is important in ensuring that a balance of essential amino acids is provided when forage intake may be limited.

The amino acid profiles of duodenal digesta samples tended to be similar across diets containing alfalfa hay at 75% or 25% of diet DM and soybean meal included in the diet containing 25% DM alfalfa hay used by Merchen et al. (1986). The flow of amino acids tended to be greater when consuming a 25% forage diet compared to a 75% forage diet. The intake level had a significant effect of total amino acid flow into the small intestine with wethers on high intake being twice that of low intake. Scholljegerdes

(2004) also saw an increase in essential amino acid flow into the small intestine as forage intake increased from 30% to 120% that of maintenance. These results conclude that a simple linear regression equation can be used to estimate the amount of essential amino acids flowing to the small intestine due to MCP flow from forage OM intake.

Young growing calves need an adequate supply of RUP in their diet. Not providing this adequate supply could lead to protein deficiencies, thereby limiting growth. When supplying RUP in a diet to growing calves, it is important that the source and amount is considered. The first limiting amino acids are lysine and methionine (Richardson and Hatfield, 1978). However in a finishing trial by Oney et al.(2016), providing supplemental bypass lysine and methionine had no effects on live performance and only slight improvements on marbling score and twelfth rib fat, suggesting the diet being fed met the amino acid and RUP requirements of the calves. Hilscher et al. (2016) evaluated the effects of providing RUP in a blend of corn and soybean supplementation on growing calves fed a high corn silage diet. Five levels of RUP were provided from 0 to 10%. As the RUP supplementation level increased, linear increases in final BW, DMI, and ADG were observed leading to an improvement in feed efficiency.

Amino acid profile is dependent on the source of the supplement. Plant protein sources can be beneficial when animals are consuming a low protein forage (Collins and Pritchard, 1992). Corn gluten meal, which has a poor amino acid profile due to its low concentration of lysine, may still be a beneficial protein source due to its high RUP characteristics. Fernandez-Rivera and Klopfenstein (1989b) supplemented calves grazing cornstalks with 200 g of CP from either soybean meal or corn-urea. The soybean meal supplement provided 68 g of RUP / d compared to the corn-urea supplement which provided 33 g of RUP / d resulting in faster gains (184 g / d) but not significantly different gains from the corn-urea supplement (124 g / d).

Protein Found in Forages

The majority of protein contained in forages is mainly rumen degradable protein (RDP). Digestibility of RUP of forages is hypothesized to be lower than that of concentrates likely due to the low digestibility of cell wall components (Negi and Makkar, 1988). With a high rumen degradability and low RUP digestibility, young or low quality forages may not be able to meet the high nutrient requirements of growing cattle with RUP being the first limiting nutrient of growing calves in a grazing system (Creighton et al., 2003).

Haugen et al. (2006) measured indigestible dietary protein (IDP) and digestibility of RUP in smooth bromegrass and birdsfoot trefoil and found use of constant digestibility values of RUP to be too high for forages. The IDP of smooth bromegrass increased from June to July as it matured leading to decreased digestibility of RUP. Similarly, an increase in IDP was found by Buckner et al. (2013) when comparing smooth bromegrass, subirrigated meadows, and warm-season grasses over time. Birdsfoot trefoil, a legume, also showed an increase in IDP from June to July (Haugen et al., 2006). However, potentially due to the tannin levels of legumes, more CP may have been protected from degradation in the rumen allowing for greater digestibility to occur in the intestine. Due to an increase of RUP flow coming from the rumen, birdsfoot trefoil showed no difference in digestibility of RUP even with the increase of IDP from June to July compared to smooth bromegrass which saw a decrease in RUP digestibility as IDP increased. Buckner et al. (2013) observed increased CP and RUP content when cattle were grazing warm-season grass pastures which contained the legume, leadplant. Selection for leadplant led to greater consumption of RUP by cattle over time compared to cattle grazing smoothgrass, subirrigated meadow, and upland native range. As the season continued, decreases in CP were observed with maturation resulting in increased RUP as a % of CP. However, Buckner et al. (2013) determined that comparing RUP on a DM basis results in no differences in RUP content throughout time. Similar to Haugen et al. (2006), decreases in RUP digestibility were observed for smooth bromegrass, subirrigated meadow, and upland native range (Buckner et al., 2013). These findings support that as the plant matures the protein becomes less digestible. When RUP values in forages are high, this could suggest that the forage would be a good source of MP.

As the bromegrass and birdsfoot trefoil matured from June to July, the amount of lignin increased (Haugen et al., 2006). Lignin is the component of the cell wall that is recognized for limiting cell wall digestibility (Jung and Allen, 1995). A negative effect between lignin and digestibility is often observed as it can prevent enzymes from accessing cell wall polysaccharides. Digestibilities of forage are important to consider when determining the nutrient availability of forages. Having high RUP values in forage could suggest that the forage is a good source of MP (Buckner et al., 2013). However, if the RUP is indigestible, no MP is available to the animal. The range for RUP digestibility for forages observed by Buckner et al. (2013) was 25% to 60%. This range is lower than the recommended range of 60% to 75% RUP digestibility for grasses and hays by the NRC dairy (2001). These ranges are significantly lower than the recommendation from the NRC beef recommendation (1996) that previously suggested a RUP digestibility of 80% for all feedstuffs. The type of forage, maturity of the forage, and RUP digestibility is important to consider when evaluating the protein availability of forage.

Corn Milling Byproducts

Corn milling is completed through two types of processes resulting in different byproducts. Wet milling requires high-quality (No. 2 or better) corn and fresh water to produce multiple products for human use through a steeping, grinding, and separation process. Dry milling uses a starch source, primarily corn, to produce ethanol and CO_2 through a grinding and fermentation process (Klopfenstein, et al., 2007). Dry milling only produces distillers grains and solubles as feed byproducts. The DGS can either be fed wet or dried and often have solubles added to produce DGS. The separation phase of the wet milling process leads to production of a greater variety of products. Separated into corn bran, starch, corn gluten meal (CGM, protein), germ, and soluble components, wet corn gluten feed is often produced by mixing the corn bran with wet milling distillers and steep liquor (the liquid added to the fermentation vat).

With the increase in availability of byproducts from the wet and dry milling processes, many studies have been conducted to compare the energy value of these byproducts to the energy value of corn. Though typically used as a protein source, many of these products, like distillers grains (DG), can be included at a level greater than needed to meet protein requirements and also used as a source of energy in the diet. An improved performance response has been observed in growing and finishing diets where corn milling byproducts replaced corn grain (Larson et al., 1993; Ham et al., 1994; Trenkle, 1997; Corrigan et al., 2007; Bremer et al., 2011). Klopfenstein et al. (2008) found an inclusion of 30-40% DGS in the diet led to a greater energy supply and 24% greater feeding value compared to that of corn.

Loy et al. (2008) found dried distillers grains plus solubles (DDGS) to have a TDN content that is 18 to 30% greater than DRC resulting in improved BW gain and feed efficiency when supplementing DDGS compared to DRC to heifers consuming a grass hay diet. Distillers grains have higher energy values and TDN than corn while dried corn gluten feed (DCGF) has a lower dietary energy value than corn. Kampman and Loerch (1989) conducted a study feeding corn silage-based diets containing inclusion of DCGF at 0, 40, 60, and 80% to determine the effects of DCGF as a dietary energy source. The fastest gain and greatest DM intake were observed with the inclusion of 60% DCGF in the diets. The DCGF had increased apparent protein digestion as inclusion level increased as well as an NDF fraction that was highly digestible, the increased degradability of these portions provide an energy and protein source for the rumen microbes. Though the effect on cattle gain was dependent on the circumstances surrounding feeding, the DCGF led to a poor feed conversion when used in silage or HMC based diets (Kampman and Loerch, 1989). However, Ham et al. (1995) fed wet corn gluten feed (WCGF) at 49% of diet and also saw a faster gain compared to the control without WCGF but no improvement in feed efficiency. Therefore, CGF may provide slightly less energy than corn but can be substituted in diets with WCGF having a greater nutritional quality than DCGF.

Energy

Energy is important for supplementation when grazing growing animals, understanding the energy of feedstuff for diets in growing animals allows producers to target sufficient gains. Energy, the potential to do work, can be measured by nutritionists using bomb calorimetry. Bomb calorimetry measures energy in calories. A calorie is the amount of energy it takes to raise 1 gram of water 1°C from 16.5°C to 17.5°C (NASEM, 2016). Calories can also be converted from joules with 4.184 joules equivalent to 1 calorie.

Calories from bomb calorimetry are gross energy (GE) which is the energy released when a substance is oxidized leaving only water and carbon dioxide. Gross energy is the total energy of a substance but does not provide information on availability as a feedstuff (NASEM, 2016). It does not account for losses or what portion of the energy is available to the animal. Digestible energy (DE) can be collected from GE by determining the energy remaining in the feces and the energy consumed through the animal's diet.

Inclusion of DGS at a greater inclusion than would be found when using it as a protein source, meets the MP requirements. Once MP requirements have been met the excess protein recycles N back to the rumen to provide RDP. Excess MP can also be deaminated to provide energy (NASEM, 2016). When DGS is fed in the wet byproduct form it can lead to increased palatability and meet the protein and energy requirements of growing calves when consuming a diet of low-quality forage. A review was produced by the Nebraska Corn Board and the University of Nebraska that examined the nutrient composition of multiple byproducts and their use in the cattle feeding industry. It is important to note that the DM of the byproduct, whether it was fed in a wet or dried form and level of inclusion, had an effect on feeding value (Nebraska Corn Board, 2010). Wet corn gluten feed had the same NE_g as DRC depending on the amount of steep added back into the product, while DGS had greater NE_g than the DRC. Wet DGS had the highest NE_g among the DGS samples with modified (partially dried) DGS intermediate and dried DGS having the lowest NE_g.

Total Digestible Nutrients

Total digestible nutrients (TDN) are the total carbohydrate, fiber, protein, and lipid components of a feedstuff (Rasby and Martin, 2016). Total digestible nutrients are similar to DE and can be used to describe the value of feed with 1 kg of TDN being equivalent to 4.4 Mcal of DE (NASEM, 2016). Digestible energy can also be calculated from DE by multiplying the % TDN content by 2. Total digestible energy can also be calculated by multiplying the % digestible organic matter (DOM) by 1.05 (Gardine, 2016).

Proximate analysis was originally used for calculation of TDN by summing the digestible crude protein (DCP), digestible crude fiber (DCF), digestible nitrogen-free extract (DNFE), and 2.25 times digestible ether extract (DEE) to account for crude fat being 2.25 times the energy of carbohydrates (Rasby and Martin, 2016). Using proximate analysis to calculate TDN often led to estimates that were low for feeding values of concentrates relative to forages. Errors occur using the summative nature of this calculation causing many people to begin using modern analytical procedures for the determination of TDN.

Supplementation of Energy vs Protein

Providing a supplement that increases energy without providing adequate protein depresses intake and digestibility (DelCurto et al., 1991). Ferrell et al. (1999) conducted an experiment to determine the effect of supplemental energy, N, and protein on feed intake and N metabolism in sheep consuming a diet of low-quality forage. They fed chopped brome hay as their low-quality forage and applied treatments through supplementation. All lambs receiving an energy supplement had greater total DMI and greater digestibility. The RUP supplement had the greatest response with values 40% greater for digested DM, OM, and energy over the control and with improvements in response of 13 to 18% greater over the energy-supplemented lambs. Providing only a supplemental source of energy with a low-quality forage diet can lead to the mobilization of body protein which can become detrimental in the long run to animals (Ferrell et al., 1999).

In 2007, MacDonald et al. compared various supplements provided to heifers grazing smoothgrass brome pasture. Corn gluten meal provided a linear increase in performance suggesting that once metabolizable protein (MP) requirements were met, excess protein was available for deamination to provide a carbon skeleton for energy. Heifers supplemented with the corn gluten meal also showed a significant effect on forage intake. The high RUP content of the corn gluten meal may have caused this decrease in forage intake.

Finding a supplementation source that provides both energy and protein would be beneficial for producers. With increased byproducts available from the ethanol industry, cereal grain byproducts have been readily available to be used as a supplementation source. Dried distillers grains (DDG) can be used to replace forage at a rate of 50% (MacDonald et al., 2007). When providing alternate RUP sources, MacDonald (2007) found the gains to be 39% as great as those achieved by DDG. This result would suggest that responses achieved from supplementing grazing animals with DDG is roughly one third due to meeting the metabolizable protein requirement of the animal.

Drying Methods

Lab analysis and standards are created to ensure that each analysis follows the same procedure at varying labs. Not only is it important to properly follow the procedure when conducting the lab assay, handling of the collected materials is important leading up to the lab assay. How the material was collected and prepared for lab analysis should be considered carefully. A study compared 3 drying methods to undried samples analyzing for DM, GE, N, C, and S concentrations (Jacobs et al., 2011). The three drying methods applied to the samples were forced air oven drying at 55°C and 100°C for 48 hrs and freeze drying. In swine fecal output, a difference of 5 and 58% was observed for GE and S, respectively, compared to feces that was undried. However, there was no difference among drying method on DM, GE, N, C, or S concentrations.

Gallup and Hobbs (1944) found a loss of N when feces were dried at 60°C or 100°C compared to undried samples. Drying at 100°C resulted in a loss of N ranging from 4.3 to 10.7 percent, while losses of N had a smaller range when dried at 60°C resulting in 4.1 to 6.4 percent loss. The addition of alcohol or acid and an alcohol-acid solution prior to drying was also examined. Addition of acid resulted in a decrease but did not eliminate losses of N. No change in N was observed for two fecal samples with addition of 25 ml of 20 percent acid-alcohol prior to drying at 100°C. This large addition of acid leads to interference with other lab assays to determine fat and crude fiber of the sample. Falvey and Woolley (1974) also saw N losses when comparing dried fecal samples to undried fecal samples. Fecal samples dried at 60°C for 48 hr led to greater N losses than those from drying for 24 hr at 75°C, 80°C, and 100°C. Effect of drying period appeared to have an effect when comparing the nitrogen losses in samples dried at 48 hr vs samples dried for 24 hr. Samples dried for 24 hr had similar nitrogen losses with a temperature effect being observed at 100°C and 80°C for fecal samples from animals consuming a high nitrogen diet.

Summary of Research

Current data suggest that the quality of corn residue varies depending on the component of the residue. Knowing the digestibility of individual corn residue components has led to the development of alternative technologies for harvesting of corn residue. Limited research has been conducted determining the digestibility and performance on animals consuming corn residue harvested with these alternative methods.

Though corn residue is an economical forage, residue is lower in CP and energy then needs of growing calves for rapid gains. With the low level of CP, and majority being RDP, providing supplemental RUP can help achieve desirable gains in calves. Previous findings have found that supplementing when calves are in a grazing situation or fed a low quality forage diet can lead to an increase in gain. Research on supplementation with alternatively harvested forages is limited.

For easy storage and handling for lab analysis, fecal matter from digestibility trials is dried. Previous research has found that the drying method (temperature, length of drying period) can cause nitrogen losses. Limited research has been conducted evaluating the effect of continuation of fermentation of fiber in the feces at various temperatures and the effect on lab assays.

The objectives of these trials were to examine the effect of alternative harvest methods of corn residue on performance and digestibility as well as the impact of supplemental RUP on performance in growing calves consuming residue diets and the effect of drying methods of fecal matter on lab assays.

Literature Cited

Atchison, J. E., and J. R. Hettenhaus. 2004. Innovative methods for corn stover collecting, handling, storing and transporting. Subcontractor report prepared for U.S. Dept. of Energy Office of Energy Efficiency and Renewable Energy. http://www.osti.gov/bridge.

Barten, T. J. 2013. Evaluation and prediction of corn stover biomass and composition from commercially available corn hybrids. PhD. Diss. Iowa State Univ., Ames.

Bremer, V. D., A. K. Watson, A. J. Liska, G. E. Erickson, K. G. Cassman, K. J. Hanford, and T. J. Klopfenstein. Effect of distillers grains moisture and inclusion level in livestock diets on greenhouse gas emissions in the corn-ethanol-livestock life cycle. Prof. Anim. Sci. 27:449-455.

Buckner, C. D., T. J. Klopfenstein, K. M. Rolfe, W. A. Griffin, M. J. Lamothe, A. K. Watson, J. C. MacDonald, W. H. Schacht, and P. Schroeder. 2013. Ruminally degradable protein content and digestibility for forages using the mobile bag in situ technique. J. Anim. Sci. 91:2812-2822.

Collins, R. M., and R. H. Pritchard. 1992. Alternate day supplementation of corn stalk diets with soybean meal or corn gluten meal fed to ruminants. J. Anim. Sci. 70:3899-3908.

Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, K. J. Vander Pol, M. A. Greenquist, M. K. Luebbe, K. Karges, and M. L. Gibson. 2007. Effect of distillers grains composition and level on steers consuming high-quality forage. Neb. Beef Cattle Rep. No. MP

Creighton, K.W., C. B. Wilson, T. J. Klopfenstein, and D. C. Adams. 2003. Undegradable intake protein supplementation of compensating spring-born steers and summer-born steers during summer grazing. J. Anim. Sci. 81:791-799.

DelCurto, T., R.C. Cochran, D.L. Harmon, A.A. Beharka, K.A. Jacques, G. Towne and E.S. Vanzant. 1990. Supplementation of dormant tallgrass-prairie forage:L I. Influence of varying supplemental protein and (or) energy levels on forage utilization characteristics of beef steers in confinement. J. Anim. Sci 68: 515-531.

Drewnoski, M. E., J. C. MacDonald, G.E. Erickson, K. J. Hanford, and T. J. Klopfenstein. 2016. Long-term corn residue grazing improves subsequent soybean yields in a corn-soybean rotation. Crop Forage Turfgrass Manage. doi:10.2134/cftm2015.0192.

Falvey, L. and Woolley, A. 1974. Losses from cattle faeces during chemical analysis. Aust. J. Exp. Agric. Anim. Husb. 14:716-719.

Fernandez-Rivera, S., and T. J. Klopfenstein. 1989a. Yield and quality components of corn crop residues and utilization of these residues by grazing cattle. J. Anim. Sci. 67:597-605.

Fernandez-Rivera, S., and T. J. Klopfenstein. 1989b. Growth response to escape protein and forage intake by growing cattle grazing cornstalks. J. Anim. Sci. 67:574-580.

Ferrell, C. L., K. K. Kreikemeier, and H.C. Freetly. 1999. The effect of supplemental energy, nitrogen, and protein on feed intake, digestibility, and nitrogen flux across the gut and liver in sheep fed low-quality forage. J. Anim. Sci. 77:3353-3364.

Gallagher, P. W., and H. Baumes. 2012. Biomass supply from corn residues: Estimates and critical review of procedures. USDA Agricultural Economics Report Number 847. U.S. Department of Agriculture, Washington, D.C.

Gallup, W.D. and C. S. Hobbs. 1944. The desiccation and analysis of feces in digestion experiments with steers. J. Anim. Sci. 3:326-332.

Gardine, S. E., A. K. Watson, J. L. Harding, and T. J. Klopfenstein. 2016. Accurate amounts and nutritive values of corn residues. Neb. Beef Cattle Rep. No. MP101. Univ. of Nebraska, Lincoln. p. 71-73.

Graham, R. L., R. Nelson, J. Sheehan, R. D. Perlack, and L. L. Wright. 2007. Current and potential U.S. corn stover supplies. Agron. J. 99:1-11.

Gupta, S. C., C. A. Onsted, and W. E. Larson. 1979. Predicting the effects of tillage and crop residue on soil erosion. J. Soil Water Conserv. Spec. Publ. 25:7-9.

Gutierrez-Ornelas, E., and T. J. Klopfenstein. 1991a. Changes in availability and nutritive value of different corn residue parts as affected by early and late grazing seasons. J. Anim. Sci. 69:1741-1750.

Gutierrez-Ornelas, E., and T. J. Klopfenstein. 1991b. Diet composition and gains of escape protein-supplemented growing cattle grazing corn residues. J. Anim. Sci. 69:2187-2195.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, and R. P. Huffman. 1995. Determining the net energy value of wet and dry corn gluten feed in beef growing and finishing diets. J. Anim. Sci. 73:353-359.

Haugen, H. L., S. K. Ivan, J. C. MacDonald, and T. J. Klopfenstein. 2006. Determination of undegradable intake protein digestibility of forages using the mobile nylon bag technique. J. Anim. Sci. 84:886-893.

Hilscher, F. H., R. G. Bondurant, J. L. Harding, T. J. Klopfenstein, and G. E. Erickson. 2016. Effects of protein supplementation in corn silage growing diets harvested at 37 or 43% DM on cattle growth. Neb. Beef Cattle Rep. No. MP101. Univ. of Nebraska, Lincoln. p. 49-51.

Hoskinson, R. L., D. L. Karlen, S. J. Birrell, C. W. Radtke, and W. W. Wilhelm. 2007. Engineering, nutrient removal, and feedstock conversion evaluations of four corn stover harvest scenarios. Biomass and Bioenergy. 31:126-136.

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

Jacobs, B. M., J. F. Patience, W. A. Dozier III, K. J. Stalder, and B. J. Kerr. 2011. Effects of drying methods on nitrogen and energy concentrations in pig feces and urine, and poultry excreta. J. Anim. Sci. 89:2624-2630.

Jones, M., J. C. MacDonald, G. E. Erickson, T. J. Klopfenstein, and R. Bondurant. 2015a. Dried distillers grains supplementation of calves grazing irrigated corn residue. Neb. Beef Cattle Rep. No. MP100. Univ. of Nebraska, Lincoln. p. 25-26.

Jones, M., J. C. MacDonald, T. J. Klopfenstein, G. E. Erickson, K. Glewen, and A. K. Watson. 2015b. Evaluation of changes in nutritional quality of corn residue over time. Neb. Beef Cattle Rep. No. MP100. Univ. of Nebraska, Lincoln. p.59-61.

Jung, H. G., and M. S. Allen. 1995. Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. J. Anim. Sci. 73:2774-2790.

Kampman, K. A., and S. C. Loerch. 1989. Effects of dry corn gluten feed on feedlot cattle performance and fiber digestibility. J. Anim. Sci. 67:501-512.

Keene, J. R., K. J. Shinners, L. J. Hill, A. J. Stallcop, S. J. Wemhoff, H. D. Anstey, A. J. Bruns, and J. K. Johnson. 2013. Single-pass baling of corn residue. Trans. ASABE. 56(1): 1-8.

Klopfenstein, T., L. Roth, S. Fernandez-Rivera, and M. Lewis. 1987. Corn residues in beef production systems. J. Anim. Sci. 65:1139-1148.

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2007. Feeding corn milling byproducts to feedlot cattle. Vet. Clin. Food Anim. 23:223-245.

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. Board-invited review: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223-1231.

Lamm, W. D., and J. K. Ward. 1981. Compositional changes in corn crop residues grazed by gestating beef cows. J. Anim. Sci. 52:954-958.

Lark, T. J., J. M. Salmon, and H. K. Gibbs. 2015. Cropland expansion outpaces agricultural and biofuel policies in the United States. Environ. Res. Lett. 10:044003. doi:10.1088/1748-9326/10/4/044003.

Larson, E. M., R. A. Stock, T. J. Klopfenstein, M. H. Sindt, and R. P. Huffman. 1993. Feeding value of wet distillers byproducts for finishing ruminants. J. Anim. Sci. 71:2228-2236.

Leask, W. C., and T.B. Daynard. 1973. Dry matter yield, in vitro digestibility, percent protein and moisture of corn stover following grain maturity. Can. J. Plant Sci. 53:515-522.

Loy, T. W., T. J. Klopfenstein, G. E. Erickson, C. N. Macken, and J. C. MacDonald. 2008. Effect of supplemental energy source and frequency on growing calf performance. J. Anim. Sci. 86:3504-3510. doi:10.2527/jas2008-0924.

MacDonald, J. C., T. J. Klopfenstein, G. E. Erickson, and W. A. Griffin. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or ether extract on performance and forage intake of heifers grazing smooth bromegrass pastures. J. Anim. Sci. 85:2614-2624.

Mayer, M. 2012. Placing a value on corn stover. UW-Extension. http://green.uwex.edu/files/2010/05/Placing-a-Value-on-Corn-Stover.pdf. (Accessed 24 June 2016).

McGee A. L., M. Johnson, K. M. Rolfe, J. L. Harding, and T. J. Klopfenstein. 2012. Nutritive value and amount of corn plant parts. Neb. Beef Cattle Rep. No. MP97. Univ. of Nebraska, Lincoln. p. 11-12.

McPhillips, L. J., J. J. Updike, J. C. MacDonald, T. J. Klopfenstein, J. L. Harding, and M. L. Jolly-Breithaupt. 2016. Effect of corn residue composition on digestibility by lambs. Neb. Beef Cattle Rep. No. MP101. Univ. of Nebraska, Lincoln. p. 74-75.

Merchen, N. R., J. L. Firkins, and L. L. Berger. 1986. Effect of intake and forage level on ruminal turnover rates, bacterial protein synthesis and duodenal amino acid flows in sheep. J. Anim. Sci. 62:216-225.

National Academies of Sciences, Engineering, and Medicine. 2016. *Nutrient Requirements of Beef Cattle*, *Eighth Revised Edition*. Washington, DC: The National Acadamies Press. doi: 10.17226/19104

NASS (National Agricultural Statistics Service). 2017. USDA Grain Crushings and Co-Products Production 2016 Summary. USDA National Agricultural Statistics Service. Available online at http://usda.mannlib.cornell.edu/usda/current/GrnCrushAnn/GrnCrushAnn-03-01-2017.pdf. Accessed on March 13, 2017.

Nebraska Corn Board and University of Nebraska-Lincoln. 2010. Feeding Corn Milling Co-Products to Feedlot Cattle. Available at http://www.nebraskacorn.gov/wp-content/uploads/2010/07/2010BeefCoProducts_Manual.pdf.

Negi, S.S., B. Singh, and H. P. S. Makkar. 1988. An approach to the determination of rumen degradability of nitrogen in low-grade roughages and partition of nitrogen therein. J. Agric. Sci. Camb. 111:487-493.

NRC. 1996. Nutrient Requirements in Beef Catttle. Nat. Acad. Press. Washington, D.C.

NRC. 2000. Nutrient Requirements in Beef Cattle. 7th edition. Nat. Acad. Press, Washington, D.C.

NRC. 2001. Nutrient requirements of dairy cattle. Natl. Acad. Press, Washington, DC.

Oney, C., C. J. Bittner, F. H. Hilscher, A. K. Watson, T. J. Klopfenstein, G. E. Erickson, and W. Rounds. 2016. Rumen protected amino acids in finishing cattle diets. Neb. Beef Cattle Rep. No. MP101. Univ. of Nebraska, Lincoln. p. 115-116.

Pordesimo, L. O., W. C. Edens, and S. Sokhansanj. 2004. Distribution of aboveground biomass in corn stover. Biomass and Bioenergy. 26:337-343.

Pordesimo, L. O., B. R. Hames, S. Sokhansanj, and W. C. Edens. 2005. Variation in corn stover composition and energy content with crop maturity. Biomass and Bioenergy. 28:366-374.

Rasby, R. and J. Martin. 2016. Understanding Feed Analysis. Learning Modules. University of Nebraska. Available at http://beef.unl.edu/learningmodules.html. Accessed March 5, 2017.

RFA (Renewable Fuels Association). 2017. Industry Statistics. Available at http://ethanolrfa.org/resources/industry/statistics. Accessed March 13, 2017.

Richardson, C. R. and E. E. Hatfield. 1978. The limiting amino acids in growing cattle. J. Anim. Sci. 46:740-745.

Schadt, I., W. H. Hoover, T. K. Miller Webster, W. V. Thayne, and G. Licitra. 1999. Degradation of two protein sources at three solids retention times in continuous culture. J. Anim. Sci. 77:485-491.

Scholljegerdes, E. J., P. A. Ludden, and B. W. Hess. 2004. Site and extent of digestion and amino acid flow to the small intestine in beef cattle consuming limited amounts of forage. J. Anim. Sci. 82:1146-1156.

Scholljegerdes, E. J., P. A. Ludden, and B. W. Hess. 2005a. Effect of restricted forage intake on ruminal disappearance of bromegrass hay and a blood meal, feather meal, and fish meal supplement. J. Anim. Sci. 83:2146-2150.

Scholljegerdes, E. J., T. R. Weston, P. A. Ludden, and B. W. Hess. 2005b. Supplementing a ruminally undegradable protein supplement to maintain essential amino acid supply to the small intestine when forage intake is restricted in beef cattle. J. Anim. Sci. 83:2151-2161.

Shinners, K. J., and B. N. Binversie. 2007. Fractional yield and moisture of corn stover biomass produced in the Northern US Corn Belt. Biomass and Bioenergy. 31:576-584.

Straeter, J. E. 2011. Cornrower system of stover harvest. Presented at 2011 ASABE Annual International Meeting, Louisville, KY.

Tibbitts, B. J., J. C. MacDonald, R. N. Funston, C. A. Welchons, R. G. Bondurant, and F. H. Hilscher. 2016. Effects of supplemental energy and protein source on performance of steers grazing irrigated corn residue. Neb. Beef Cattle Rep. No. MP101. Univ. of Nebraska, Lincoln. p. 31-32.

Trenkle, A. 1997. Substituting wet distillers grains or condensed solubles for corn grain in finishing diets for yearling heifers. Beef Research Report- Iowa Stare Univ. ASRI 451.

Updike, J. J., A. C. Pesta, R. G. Bondurant, J. C. MacDonald, S. Fernando, G. E. Erickson, T. J. Klopfenstein. 2015a. Evaluation of the impact of an alternative corn residue harvest method on performance and methane emissions from growing cattle. Neb. Beef Cattle Rep. No. MP100. Univ. of Nebraska, Lincoln. p. 42-44.

Updike, J. J., J. L. Harding, T. J. Klopfenstein, and J. C. MacDonald. 2015b. Effect of harvest method on in vitro digestibility of corn residues. Neb. Beef Cattle Rep. No. MP100. Univ. of Nebraska, Lincoln. p. 62-63.

Updike, J. J., L. J. McPhillips, M. L. Jolly-Breithaupt, J. L. Harding, T. J. Klopfenstein, and J. C. MacDonald. 2016. Effect of corn residue harvest method on in vivo and in vitro digestibility. Neb. Beef Cattle Report. No. MP101. Univ. of Nebraska, Lincoln. p. 76-78.

USDA National Agricultural Statistics Service (USDA-NASS). 2016. Corn acres planted. http://nass.usda.gov/Statistics_by_Subject. (Accessed 23 June 2016).

van Donk, S., A. L. McGee, T. J. Klopfenstein, and L. A. Stalker. 2012. Effect of corn stalk grazing and baling on cattle performance and irrigation needs. Neb. Beef Cattle Rep. No. MP97. Univ. of Nebraska, Lincoln. p. 8-10.

Ward, J. K. 1978. Utilization of corn and grain sorghum residues in beef cow forage systems. J. Anim. Sci. 46:831-840.

Watson, A. K., J. C. MacDonald, G. E. Erickson, P. J. Kononoff, and T. J. Klopfenstein. 2015. Forages and pastures symposium: Optimizing the use of fibrous residues in beef and dairy diets. J. Anim. Sci. 93:2616-2625.

Wendt, L., K. Cafferty, W. Smith, I. Bonner, Q. Huang, and R. Colby. 2014. 1.2.1.1 Harvest, Collection and Storage Quarter 3 Milestone Report. Prepared for U.S. Dept. of Energy Office of Energy Efficiency and Renewable Energy. http://www.osti.gov/bridge.

Wilson, C. B., G. E. Erickson, T. J. Klopfenstein, R. J. Rasby, D. C. Adams, and I. G. Rush. 2004. A review of corn stalk grazing on animal performance and crop yield. Neb. Beef Cattle Rep. No. MP80-A. Univ. of Nebraska, Lincoln. p. 13-15.

Wright, C. K., and M. C. Wimberly. 2013. Recent land use change in the western Corn Belt threatens grasslands and wetlands. Proc. Natl. Acad. Sci. USA 110:4134-4139.

Chapter II. Effect of corn residue harvest method with RUP supplementation on performance of growing calves and fiber digestibility

T. M. King[*], M. L. Jolly-Breithaupt[*], R. G. Bondurant[*], J .L. Gramkow[*], T. J. Klopfenstein[*], and J. C. MacDonald[*]

[*]Department of Animal Science, University of Nebraska-Lincoln, Lincoln, NE 68583

Abstract

Two experiments were conducted to evaluate the effects of corn residue harvest method on animal performance and diet digestibility. Experiment 1 was designed as a 2 x 2 + 1 factorial arrangement of treatments using 60 individually fed crossbred steers (initial BW = 283; SD = 32 kg; n = 12). Factors were 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 with the inclusion of supplemental RUP at 3.3% diet DM. In Exp. 2, nine crossbred wethers were blocked by BW (initial BW = 42.4; SD = 7 kg) 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 to the conventionally harvested corn residue ($P < 0.05$), whereas high-stem was intermediate (0.78, 0.69, 0.63 ± 0.07 for low-stem, high-stem, and conventional, respectively). Results from *in vitro* OM digestibility suggest low-stem residue had greatest amount of digestible organic matter compared to the other two residue methods, which did not differ (55.0, 47.8, 47.1% for low-stem, high-stem, and conventional, respectively; $P < 0.05$). There were no differences in RUP content (40% of CP) and RUP digestibility (60%) among the three residues ($P \geq 0.35$). No interactions were observed between harvest method and addition of RUP ($P \geq 0.12$). The addition of RUP resulted in an improvement in ADG (0.66, 0.58 ± 0.06 for supplemental RUP and no RUP, respectively; $P = 0.08$), and G: F (0.116, 0.095 ± 0.020 for supplemental RUP and no RUP, respectively; $P = 0.02$) compared to the same diets without the additional RUP. In Exp. 2, low-stem had greater DM and OM digestibility and digestible energy ($P < 0.01$) than high-stem and conventional which did not differ ($P \geq 0.63$). Low-stem also had greatest NDF digestibility (NDFD, $P < 0.01$), while high-stem had greater NDFD than conventional ($P < 0.01$). Digestible energy was greatest for low stem ($P < 0.05$) and did not differ between high-stem and conventional ($P = 0.50$). Reducing the proportion of stem in the bale through changes in the harvest method increased the quality of corn residue.

Keywords: corn residue, digestibility, growing, harvest method, rumen undegradable protein

Introduction

Increased demand for biofuels has shifted land use to crop production leading to an increase in the hectares of corn planted and harvested each year. From 2008 to 2012, 77% of land converted to crop production was from grasslands (Lark et al., 2015). As availability of grassland decreased the number of additional acres planted in corn increased by roughly 785,000 hectares, increasing availability of corn residue which has historically been utilized as an economical forage source for producers. Grazing is the most economical method of utilizing residue as feedstuff, but residue can also be baled and removed from the field (Ward, 1978).

Previous research has shown that quality of the residue depends on which plant parts are harvested, with the husk having greater digestibility compared to the stem, which has the least digestibility (Watson et al., 2015). Baling residue inhibits animal selectivity, because both highly digestible and lesser digestible components are harvested.

Traditional baling methods result in reduced residue quality because the least digestible components are included at a greater concentration.

Advancements in harvest technologies have the potential to improve the feeding quality of baled corn residue. Stem is the least digestible plant part of corn residue with an *in vitro* dry matter digestibility ranging from 32.55 to 35.96% (Watson et al., 2015), while husk has the greatest digestibility of the corn residue components (60.54%). The New Holland Cornrower Corn Head (Straeter, 2011) allows producers to adjust the number of rows of stem being cut and baled changing the leaf: stem ratio in the bale, potentially increasing the quality of the bale. Though many studies have been conducted to look at how the changing quality of corn residue components affect performance of grazing animals, new information is needed to determine the effect changing leaf: stem ratio in the bale affects performance. 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

Residues for this study were harvested with 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. 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. This creates a 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 to create a high-stem corn residue. A conventional baled residue was also harvested to provide a comparison. The conventional baled residue was produced by 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 trailer plus bales weight and the remaining weight was divided by 11 to get the average weight of a bale.

Experiment 1

An 84-d growing trial was conducted utilizing 60 crossbred steers (initial BW = 283; SD = 32 kg; n =12 / treatment) that were individually fed with the Calan gate system (American Calan Inc., Northwood, NH). Steers were limit-fed a diet of 50% alfalfa and 50% Sweet Bran (Cargill, Blair, NE) at 2% of BW for 5 days prior to start of trial to reduce variation in gut fill (Watson et al., 2013), then 3 consecutive day weights were collected (Stock et al., 1983), utilizing the average as initial BW. 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) on day 1 of the trial. The study consisted of 5 treatments. Both the high-stem and conventional corn residues were used to provide diets containing additional RUP and diets without added RUP, allowing for comparison of the effect of supplemental RUP. Due to the limited availability of low-stem corn residue bales, only a diet containing additional RUP was included to ensure RUP requirements of cattle were being met. The 3 harvest methods were compared using the 3 diets with additional RUP. Supplemental RUP was added to treatment diets through the addition of a 50:50 blend of SoyPass® (Borregaard Lignotech, Rothschild, WI) and Empyreal 75® (Cargill, Blair, NE; Table 1) providing 0 or 3.3% supplemental RUP as a % of diet DM. The 50:50 blend provided RUP in a blend of amino acids 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, 1965, Method 935.29). 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 4.1.10). Crude protein was also analyzed by a combustion-type N analyzer (Leco FP 528 Nitrogen Analyzer, St. Joseph, MO). 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 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 the beginning limit-fed period for 5 days. Steers were weighed for 3 consecutive days with the average used to determine accurate 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 method (1963) with the modification of adding 1 g of urea / L buffer (Weiss, 1994). Residues were weighed in triplicate into 100 mL *in vitro* tubes. Rumen fluid from two 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 CO_2, 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 comparison of between run values. *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 kept in the water bath for an additional 24 h to stimulate abomasal digestion. Tubes were filtered through Whatman 541 ashless filters and placed in a 100°C forced air oven for 12 h to 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.

Proportion of RUP in the 3 residue types and the RUP digestibility in the small intestine was determined through a mobile bag procedure (Haugen et al., 2006). Dacron bags (Ankom Technology, Fairport, NY) with a 50-μm pore size (5 x 10-cm), were filled with 1.25 g of dried corn residue ground through a 2-mm screen of a Wiley Mill (Thomas Scientific, Swedesboro, NJ) 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, then removed and evenly divided with half being rolled and frozen.

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 who only had ruminal cannulations. Bags were 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 placed in the freezer 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) and dried in a forced-air oven for 48 h at

60°C, air equilibrated for 3 h, and weighed allowing for calculation of intestinal disappearance of RUP.

Data for the performance trial were analyzed using MIXED procedures of SAS (SAS Institute, Inc., Cary, N.C.). 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), and supplemental RUP inclusion (0 or 3.3%) were included in the model. Treatments (harvest method and supplemental RUP) were included as fixed effects and block was included as a random effect. Orthogonal contrasts were used to compare low-stem, high-stem, and conventional corn residue 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 x 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 vitro and *in situ* data were analyzed as completely randomized designs using the MIXED procedure of SAS. Residue harvest method was the treatment, and sample (*In vitro*) or 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 utilizing 9 crossbred wethers (initial BW = 42.4, SD = 7.0 kg) divided into 3 blocks based on initial BW. The digestion study was 4 periods in length with treatments assigned randomly 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) 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, 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 in length allowing for 10 d of adaptation and 7 d for total fecal collection. Feed was offered twice daily at 0800 h and 1600 h with 50% of daily DM fed at each feeding. Wethers were fed 97% ad libitum to prevent sorting of least digestible plant parts. Ad libitum was established in the 10 d adaptation period and averaged. Feed refusals were collected the following morning 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 h and 1600 h daily, weighed, and placed in individual sample bags in a cooler 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 d 14 and dried to correct for DM of each period. Feedstuff samples were ground first through a 2-mm screen of a Wiley mill, composited by period, and a subset of period composites were ground through a 1-mm screen of a Wiley mill. Samples were then analyzed for DM, OM, NDF, and DE to provide nutrient composition (Table 3).

Analysis of NDF for feeds and feces was conducted using the beaker method (Van Soest et al., 1991; Van Soest et al., 1964). Each beaker contained 0.5 g of sample, 0.5 g of sodium sulfite, and 100 ml of 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 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. Samples were then bombed to determine gross heat and calculate DE. Digestible energy is calculated by subtracting the energy that was lost in feces from the gross energy of the feed consumed (NASEM, 2016).

Fifth period collections allowed determination of contribution from non-residue feedstuff allowing digestibilities to be adjusted to reflect only residue. Known digestibility of the non-residue 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 digestible energy of the residue component only.

Residue nutrient composition was analyzed using MIXED procedure of SAS (SAS Institute. Inc., Cary. NC) with sample serving as experimental unit. Residue harvest method was the treatment and included in the model as a fixed effect. Total tract digestibility data were analyzed using the MIXED procedure of SAS. 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 treatment. Significance level was set at a *P*-value of 0.05.

Results

Experiment 1

No interactions between harvest method and supplemental RUP were observed ($P \geq 0.12$) for the 2 x 2 factorial. The addition of RUP resulted in an improvement in ADG (0.66, 0.58 ± 0.06 kg for supplemental RUP and no RUP, respectively; $P = 0.08$; Table 4), and G:F (0.116, 0.095 ± 0.020 for supplemental RUP and no RUP, respectively; $P = 0.02$) compared to the same diets without supplemental RUP.

Steers fed the low-stem residue diet had the greatest ADG (0.78, 0.69, 0.63 ± 0.07 kg for low-stem, high-stem, and conventional, respectively; $P < 0.05$; Table 5), and consequently a greater ending BW (345, 338, 334 ± 6 kg for low-stem, high-stem, and conventional, respectively; $P < 0.05$) compared to 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; $P < 0.01$). The conventional diet had similar DMI to steers fed the low-stem but differed from the high-stem diet ($P = 0.05$). However, feed efficiencies for high-stem and conventional did not differ (0.103, 0.108, respectively; $P = 0.11$).

Results from *in vitro* organic matter digestibility demonstrate low-stem residue had greatest digestible organic matter amount (55.0, 47.8, 47.1% for low stem, high stem, and conventional, respectively; $P < 0.05$; Table 6) compared to the other two residue harvest methods. The high-stem residue diet showed no improvements over the conventional corn residue diet, which is likely due to the high-stem bales containing a similar proportion of stem as the conventional bales.

In situ results showed no difference in RUP content as a % of CP (40%) and RUP digestibility (60%) among the three residues (Table 7.).

Experiment 2

Conventionally and low-stem residues had similar DM averaging 87.3% and were greater than high-stem (85.8%; $P < 0.01$). Residues differed in OM, NDF, and ash-free NDF (NDF_{om}) with low-stem being greater than high-stem and conventional ($P < 0.01$;

Table 8.). High-stem had a lower OM than conventional ($P < 0.01$) but higher NDF than conventional ($P < 0.01$).

No differences in total diet intake were observed among treatments for DM, OM, and NDF ($P \geq 0.34$; Table 9). Evaluating digestibilities of the total diet found low-stem to be greater in DM digestibility (DMD) and OM digestibility (OMD) over high-stem and conventional residues ($P < 0.01$). Digestibility of NDF was different among all treatments with low-stem being greatest, high-stem being intermediate, and conventional 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 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 DM intake, OM intake, or NDF intake were observed among residue types ($P \geq 0.28$). A tendency for low-stem to have greater NDF intake over conventional was observed ($P = 0.09$). No differences or tendencies 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 DMD than conventional and high-stem residues ($P < 0.01$; Table 10). There were no differences in DMD ($P = 0.63$) or OMD ($P = 0.86$) between high-stem and conventional residue. Low-stem had greatest OMD and NDF digestibility (NDFD, $P < 0.01$). High-stem had a greater NDFD conventional ($P < 0.01$).

The residues had the same ranking of digestibilities when examining ash-corrected NDF (Table 9).

Digestible energy for total diet was greatest for low-stem (2.79 Mcal / kg; Table 11) compared to high-stem and conventional (2.21 and 2.25 Mcal / kg; respectively; $P < 0.01$) estimates, with no difference between high-stem and conventional ($P = 0.64$). Partial digestible energy estimates for only the residue showed similar results with low-stem (1.56 Mcal / kg; Table 11) being greater than high-stem and conventional residues (0.99, 1.04 Mcal / kg, respectively; $P < 0.01$) and no difference observed between high-stem and conventional ($P = 0.50$).

Discussion

Animal selectivity occurs when grazing corn residue, with cattle choosing to consume the most digestible components of the plant first. Lesser digestible components are only consumed when availability of other plant components become 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). While grazing is the most economical method of utilizing 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 greatest ADG and a tendency for improved G:F compared to conventionally baled corn residue. Results from IVOMD support this finding with low-stem having greater digestibility than the high-stem and conventional, suggesting that harvesting fewer stems in bales leads to an increase in digestibility and quality of residue. This 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 to 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 to husk. No differences in total tract digestibility was observed for DM, OM, and NDF between residues harvested with 4 or 8 rows of stem, perhaps suggesting the rows of stem need to be less than 4 to detect significant improvement in digestibility. In the current study, high-stem and conventional residues both contained all rows of stem, resulting in similar DMD (47%) and OMD (51%) 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. The ability to decrease the amount of stem included in the bale is vital to increasing the quality of the bale. However, with this reduction in stem harvested, the yield of residue removed from the field is decreased. Harvest index, the proportion of grain relative to total above ground 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 1:1 resulting in a harvest index of 0.5 (Gupta et al., 1979; Graham et al., 2007). Inflation of stover produced can occur when harvest index is used to calculate stover quantities with corn weight at 15.5% moisture vs. dry weight of corn (Graham et al., 2007). Calculated as a bushel yield x harvest index, an estimated 9.48 metric ton/hectare of residue was produced on the field with about 50% being harvested with high-stem and conventional methods (Table 5). As the quality of the bale increases, the yield decreases down to 0.94 metric ton DM/hectare with the low-stem bales.

Steers consuming the low-stem residue refused 5.0% of their daily feed compared to 1.5% refused by steers consuming conventional corn residue in Exp. 1. Low-stem 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 to more digestible components, refusals collected were primarily cobs. Lambs fed at 97% ad libitum in Exp. 2, consumed the cobs which are lower in digestibility but still resulted in greater total tract and partial digestibility for the low-stem residue compared to high-stem and conventional residues. Even with the greater proportion of cob compared to conventional bales, the decrease in quantity of stem found in low-stem increased the proportion of husks, leaves, and leaf sheaths. The change in proportion of plant parts in the bale impacted digestibility which is supported by previous research that found husk to be greatest in digestibility (Lamm and Ward, 1981; Watson et al., 2015). However, low-stem may result in more refusals due to the greater proportion of cob.

The increase in ADG and improvement in G: F of low-stem vs. conventional from Exp. 1, is supported by the findings of the DE results observed in Exp. 2. Low-stem had the greatest DE and was significantly improved over high-stem and conventional corn residues which both included all 8 rows of stem in the bale. The gross energy for the residues from Exp. 2 appeared low compared to the observation of Pordesimo et al. (2005) who reported estimates from 16.7 to 20.9 kJ / g (4000-5000 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 to 18.36 kJ / g for low-stem, conventional residue fell intermediate at 16.34 kJ / g. However, Pordesimo et al. (2005) tested plants throughout maturation to develop a range, while the range observed in this trial were of material harvested after maturation. The high-stem and conventional residue harvest methods both fell below the average gross energy of 17.65 kJ / g reported for corn residue (Domalski, et al., 1986) while the low-stem had a greater gross energy.

Degradation of protein from forages is rapid meaning 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 quality of the forage decreases. Buckner et al. (2011) also observed a linear decrease in RUP digestibility over time. Though the RUP content of the forage increased, RUP digestibilities declined ranging from 25% to 60% for grasses (Buckner et al., 2011). The increase in RUP content as forages matures supports the findings of this study which found the RUP as a % of CP to range from 36 to 45% for the corn residues. Digestibility of RUP for the conventional residue falls in the range recommended by the NRC (2001) dairy which uses 60% to 75% RUP digestibility for grasses and hay, while the low-stem and high-stem had lower RUP digestibilities (58, 52%, respectively). The RUP digestibility is important to consider because greater RUP values could suggest that the forage is a good source of metabolizable protein (MP) to the animal. However, if the

RUP of the forage is indigestible, it supplies no MP. Therefore, growing cattle being fed forage diets require supplemental RUP to meet their MP requirements. The MP system evaluates the amino acid requirements and the fulfillment of those requirements through the absorption of amino acids from digested feedstuff (Burroughs et al., 1974). The MP system breaks the requirements into the needs of the rumen microbial population and the needs of the animals (NASEM, 2016). Microbial protein is synthesized from dietary protein which is degraded in the rumen and utilized by microbes as amino acids and proteins. Supplying RDP provides N for rumen microbial growth and production. Once the needs of the microbes have been met, excess degradable protein is excreted. Knowing the RDP requirements of the animal ensures efficiency and helps meet the MP requirements of the animal. Metabolizable protein used for growth of the animal is met with a combination of microbial protein and RUP (NASEM, 2016 and Burroughs et al., 1974).

Corn residue is a low quality forage and was observed to be low in crude protein (avg = 7.2%, Exp. 1) supporting the requirement for supplemental protein when residue-based diets are used for growing calves. Supplementation of RUP with an ad libitum low-quality forage resulted in 40% greater in digestibilities of DM, OM, and energy in sheep compared to those receiving no supplement and 13 to 18% greater than lambs supplemented with an energy source (Ferrel et al., 1999). Supplemental protein provided to growing 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 a limiting factor due to the inclusion of solubles in the diet. This is unlike 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 distillers grains plus solubles) were fed (Tibbitts et al., 2016).

Implications

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 had greatest overall digestibility and digestible energy with high-stem residue being intermediate and conventional harvesting being the least digestible and lowest digestible energy. However, with this reduction in stems, the yield of residue removed from the field is decreased.

Literature Cited

AOAC. 1965. Official method of analysis. 10th ed. AOAC, Washington, D.C.

AOAC. 1999. Official method of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlingtion, VA.

Buckner, C. D., M. F. Wilken, J. R. Benton, S. J. Vanness, V. R. Bremer, T. J. Klopfenstein, P. J. Kononoff, and G. E. Erickson. 2011. Nutrient variability of distillers grains plus solubles and dry matter determination of ethanol by-products. Prof. Anim. Scientist. 27:57-64.

Buckner, C. D., T. J. Klopfenstein, K. M. Rolfe, W. A. Griffin, M. J. Lamothe, A. K. Watson, J. C. MacDonald, W. H. Schacht, and P. Schroeder. 2013. Ruminally undegradable protein content and digestibility for forages using the mobile bag in situ technique. J. Anim. Sci. 91:2812-2822.

Burroughs, W., A. Trenkle, and R. L. Vetter. 1974. A system of protein evaluation for cattle and sheep involving metabolizable protein (amino acids) and urea fermentation potential of feedstuffs. Vet. Med. Small Anim. Clin. 69:713-722.

Domalski, E. S., T. L. Jobe, and T. A. Milne Jr. Thermodynamic data for biomass conversion and waste incineration. Golden, Colorado: Solar Energy Research Institute; 1986.

Fernandez-Rivera, S. and T. J. Klopfenstein. 1989. Growth response to escape protein and forage intake by growing cattle grazing cornstalks. J. Anim. Sci. 67:574-580.

Ferrell, C. L., K. K. Kreikemeier, and H. C. Freetly. 1999. The effect of supplemental energy, nitrogen, and protein on feed intake, digestibility, and nitrogen flux across the gut and liver in sheep fed low-quality forage. J. Anim. Sci. 77:3353-3364.

Graham, R. L., R. Nelson, J. Sheehan, R. D. Perlack, and L. L. Wright. 2007. Current and potential U.S. corn stover supplies. Agron. J. 99:1-11.

Gupta, S. C., C. A. Onsted, and W. E. Larson. 1979. Predicting the effects of tillage and crop residue on soil erosion. J. Soil Water Conserv. Spec. Publ. 25:7-9.

Gutierrez-Ornelas, E., and T. J. Klopfenstein. 1991. Diet composition and gains of escape protein-supplemented growing cattle grazing corn residues. J. Anim. Sci. 69:2187-2195.

Haugen, H. L., S. K. Ivan, J. C. MacDonald, and T. J. Klopfenstein. 2006. Determination of undegradable intake protein digestibility of forages using the mobile nylon bag technique. J. Anim. Sci. 84:886-893.

Lamm, W. D., and J. K. Ward. 1981. Compositional changes in corn crop residues grazed by gestating beef cows. J. Anim. Sci. 52:954-958.

Lark, T. J., J. M. Salmon, and H. K. Gibbs. 2015. Cropland expansion outpaces agricultural and biofuel policies in the United States. Environ. Res. Lett. 10: 044003 doi:10.1088/1748-9326/10/4/044003.

McPhillips, L. J., J. J. Updike, J. C. MacDonald, T. J. Klopfenstein, J. L. Harding, and M. L. Jolly-Breithaupt. 2016. Effect of corn residue composition on digestibility by lambs.

Neb. Beef Cattle Rep. MP101. The Board of Regents of the University of Nebraska, Lincoln, NE. p. 74-75.

National Academies of Sciences, Engineering, and Medicine. 2016. *Nutrient Requirements of Beef Cattle, Eighth Revised Edition*. Washington, DC: The National Acadamies Press. doi: 10.17226/19104

NRC. 2001. Nutrient requirements of dairy cattle. Natl. Acad. Press, Washington, DC.

Pordesimo, L. O., B. R. Hames, S. Sokhansanj, and W. C. Edens. 2005. Variation in corn stover composition and energy content with crop maturity. Biomass and Bioenergy. 28:366-374.

Stock, R., T. Klopfenstein, D. Brink, S. Lowry, D. Rock, and S. Abrams. 1983. Impact of weighing procedures and variation in protein degradation rate on measured performance of growing lambs and cattle. J. Anim. Sci. 57:1276-1285.

Straeter, J. E. 2011. Cornrower system of stover harvest. Presented at 2011 ASABE Annual International Meeting, Louisville, KY.

Tibbitts, B. J., J. C. MacDonald, R. N. Funston, C. A. Welchons, R. G. Bondurant, and F. H. Hilscher. 2016. Effects of supplemental energy and protein source on performance of steers grazing irrigated corn residue. Neb. Beef Cattle Rep. MP101. The Board of Regents of the University of Nebraska, Lincoln, NE.

Tilley, J. M. A., and R. A. Terry. 1963. A two-stage technique for the *in vitro* digestion of forage crops. Grass and Forage Sci. 18:104-111.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583.

Van Soest, P. J., and W. C. Marcus. 1964. Methods for determination of cell wall constituents in forages using detergents and the relationship between this fraction and voluntary intake and digestibility. J. Dairy Sci. 47:704.

Ward, J. K. 1978. Utilization of corn and grain sorghum residues in beef cow forage systems. J. Anim. Sci. 46:831-840.

Watson, A. K., B. L. Nuttleman, T. J. Klopfenstein, L. W. Lomas, and G. E. Erickson. 2013. Impacts of a limit-feeding procedure on variation and accuracy of cattle weights. J. Anim. Sci. 91:5507-5517.

Watson, A. K., J. C. MacDonald, G. E. Erickson, P. J. Kononoff, and T. J. Klopfenstein. 2015. Forages and pastures symposium: Optimizing the use of fibrous residues in beef and dairy diets. J. Anim. Sci. 93:2616-2625.

Weiss, W. P. 1994. Estimation of digestibility of forages by laboratory methods. Pages 644-681 in Forage Quality, Evaluation, and Utilization. G. C. Fahey Jr., ed. Am. Soc. Agronomy, Crop Sci. Soc. Am., Soil Sci. Soc. Am., Madison, WI.

Wilson, C. B., G. E. Erickson, T. J. Klopfenstein, R. J. Rasby, D. C. Adams, and I. G. Rush. 2004. A review of corn stalk grazing on animal performance and crop yield. Neb. Beef Cattle Rep. No. MP80-A. Univ. of Nebraska, Lincoln. p. 13-15.

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

Ingredient, % of DM	**Treatments[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
Distillers 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
Vitamin ADE	0.02	0.02	0.02	0.02	0.02
Rumensin®[3]	0.01	0.01	0.01	0.01	0.01

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

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

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

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

[5]SoyPass® is a branded soybean meal source high in RUP; 75% RUP, % of CP (49.0% CP).

[6]Empyreal 75® is a branded corn gluten meal source high in protein; 65.0% RUP, % of CP (80.0% CP).

[7]Diets were formulated to provide 200 mg/steer daily of Rumensin® at 7.26 kg DM consumption.

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

	Low-stem + RUP[1]	High-stem[2]	High-stem + RUP[3]	Conventional[4]	Conventional + RUP[5]
Dry Matter, %	55.90	54.97	54.97	56.15	56.15
Organic Matter, %	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
Crude Protein, %	12.71	11.72	13.03	11.79	13.10

[1]Diet contained corn residue harvested with 2 rows of stem and supplemental RUP at 3.3% of diet DM.
[2]Diet contained corn residue harvested with 8 rows of stem.
[3]Diet contained corn residue harvested with 8 rows of stem and supplemental RUP at 3.3% of diet DM.
[4]Diet contained corn residue harvested with traditional rake and bale method.
[5]Diet contained corn residue harvested with traditional rake and bale method and supplemental RUP at 3.3% of diet DM.

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

	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				
Dry matter, %	77.84	77.26	77.93	64.28
Organic matter, %	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
Crude Protein, %	8.80	9.38	9.44	20.29

[1]SBB represents a 9:1 ratio diet of Sweet Bran to brome grass hay.
[2]Low-stem residue is corn residue harvested with 2 rows of stem.
[3]High-stem residue is corn residue harvested with 8 rows of stem.
[4]Conventional residue is corn residue harvested with the traditional rake and bale system.
[5]Sweet Bran is a wet corn gluten feed product produced by Cargill, Blair, NE.

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

	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
Gain:Feed	0.095	0.116	0.006	0.02

[1]Interaction between residue harvest method and supplemental RUP was not statistically different ($P \geq 0.12$).
[2]No RUP diets had 0% supplemental RUP inclusion in the diet.
[3]Supplemental RUP diets had supplemental RUP included at 3.3% diet DM.

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

	Low-stem + RUP[1]	High-stem + RUP[2]	Conventional + RUP[3]	SEM	Contrasts		
					Low-stem vs. High-stem	Conv. vs. Low-stem	Conv. 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	0.77	0.68	0.63	0.10	0.17	0.03	0.41
DMI, kg/d	5.78	6.60	5.84	0.59	0.01	0.49	0.05
Gain:Feed	0.139	0.103	0.108	0.006	>0.01	>0.01	0.51

[1]Diet contained corn residue harvested with 2 rows of stem and supplemental RUP at 3.3% of diet DM.
[2]Diet contained corn residue harvested with 8 rows of stem and supplemental RUP at 3.3% of diet DM.
[3]Diet contained corn residue harvested with traditional rake and bale method and supplemental RUP at 3.3% of diet DM.

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

	Low-stem[1]	High-stem[2]	Conventional[3]	SEM	*P*-value
IVOMD, %	56.1[a]	50.0[b]	49.7[b]	0.47	<0.01
DOM[4], % DM	55.0[a]	47.8[b]	47.1[b]	0.45	<0.01
Residue yield, t/ha (DM)[5]	0.94	5.04	4.97	--	--
TDN[6], t/ha	0.57[a]	2.67[b]	2.59[b]	0.97	<0.01

[a,b,c]Means within a row with differing superscripts are different

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

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

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

[4]Amount of digestible OM as % of DM. Calculated as OM content x IVOMD.

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

[6]Total digestible nutrients (TDN) assumed equal to DOM

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

	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,c]Means within a row with differing superscripts are significantly different.

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

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

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

Table 8. Composition of residues harvested with varying methods

	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,b,c]Means within a row with differing superscripts are significantly different ($P < 0.05$).
[1]Low-stem residue is corn residue harvested with 2 rows of stem.
[2]High-stem residue is corn residue harvested with 8 rows of stem.
[3]Conventional residue is corn residue harvested with the traditional rake and bale system.
[4]NDF accounting for ash.

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

	Low-stem[1]	High-stem[2]	Conventional[3]	SEM	*P*-values
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,b,c]Means with differing superscripts are different.

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

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

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

[4]Neutral detergent fiber accounting for ash.

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

	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,b,c]Means within a row with differing superscripts differ ($P < 0.05$).

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

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

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

[4]NDF_{om} is neutral detergent fiber accounting for ash.

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

	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,c]Means within a row with differing superscripts are significantly different.

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

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

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

Chapter IV. Effect of Fecal Sample Drying Method on Subsequent Lab Analysis

T. M. King[*], J. L. Gramkow[*], H. C. Wilson[*], and J. C. MacDonald[*]

[*]Department of Animal Science, University of Nebraska-Lincoln Lincoln, NE 68583

Abstract

Standardized procedures are established for preparing samples for laboratory analysis to maintain uniformity. These procedures are also followed to ensure that subsequent analyses are not affected. Procedures are created to maintain the integrity of sample and be as efficient and economical as possible. The following study was conducted to compare the drying method of fecal samples and its effect on subsequent lab analysis. Fecal samples were dried utilizing 1 of 3 methods: 1) 60°C forced air oven for 72 h; 2) 100°C forced-air oven for 72 h; or 3) freeze dried. Samples were then analyzed for organic matter (OM) and fiber content and digestibility estimates were calculated. Drying method of fecal samples had no effect on OM content ($P = 0.17$) but had an effect on fiber content ($P < 0.001$) where fecal samples dried in a 100°C oven had a greater NDF content (70.8%; $P < 0.01$) compared to fecal samples dried in a 60°C forced-air oven (69.0%) or freeze dried (68.2%), which did not differ ($P = 0.19$). Samples dried via freeze drying and at 60°C did not differ in NDF content ($P = 0.20$), but samples dried with both drying methods differed in NDF content from those dried at 100°C ($P < 0.01$). Though different fiber content was observed among drying methods, there was no effect on digestibility of OM or NDF ($P > 0.05$).

Introduction

Moisture can lead to dilution of energy, protein, minerals, and vitamins in samples. Therefore, methods used to determine the moisture content are important due to its influence when evaluating nutrient contents (Ahn et al., 2014; Thiex and Richardson, 2003). Many studies have been conducted to determine protocols for drying various feedstuffs (i.e. forages vs. byproducts), the temperature, and the time needed to dry the feedstuff. Proper nutrient content and laboratory analysis of feed is needed for determining diets and intakes, while proper handling of feces for analysis is also important when determining digestibilities. Drying of fecal samples can lead to a potential loss of OM due to microbial fermentation.

Loss on drying (LOD; oven) methods are the most commonly used practices in laboratories today (Thiex, 2009). Due to the heating of samples, volatiles substances besides water can also be lost causing overestimation of moisture for LOD methods. Factors to consider when using the LOD method is temperature of the oven, length of time spent in the oven and the type of sample. Lyophilization is another method used to remove moisture where samples are first frozen in a laboratory freezer and then placed on a freeze dryer. Freeze dryers are a piece of specialty equipment that causes samples to go through the process of sublimation, when frozen liquid goes directly into the gaseous phase (Labconco, n.d.). Lack of passage through the liquid phase can prevent some changes in the product that occurs when moisture of samples goes from liquid to gaseous phases. Though expensive, specialty equipment is needed to ensure that the proper temperature and pressure conducive to sublimation. Samples are dry when pressure drops. Some methods do not remove all the moisture causing discrepancies while other samples lose volatile substances changing the observed moisture content (Thiex and Van Erem, 1999). Underestimation of dry matter content leads to an underestimation of digestibility and an overestimation of feeding value (Mo and TjØrnhom, 1978).

While a multitude of studies have been conducted evaluating the effects of drying method on moisture determination of feedstuffs, studies evaluating the effect of drying method on fecal samples and subsequent analysis on fecal matter are limited. Therefore, the objective of this study was to determine the effect of drying method on subsequent analysis of fecal matter.

Materials and Methods

The study was conducted in conjunction with an ongoing digestion study (chapter II.). Nine crossbred wethers (initial BW = 42.4; SD = 7.0 kg)) were fed residue-based diets for 4 periods. The periods were 17-d long, allowing 10 d for adaptation to the diet and 7 d for total fecal collection. Feces were collected twice daily at 0800 and 1600 h from fecal collection bags. Samples were then weighed and placed in individual bags in a cooler. At the conclusion of the period, fecal samples were composited and mixed. Subsamples were then dried using 1 of 3 methods: 60°C forced-air oven for 72 h, 100°C forced-air oven for 72 h, or freeze dried. Subsamples for the forced-air oven dry methods were placed in tin pans providing three 100-g samples per temperature. Time length of 72 h was used to ensure that the pellet of fecal matter was dried completely. Two subsamples of 100-g were dried using a freeze dryer (Freezemobile 25ES, VirTis, Gardiner, NY). These were placed in Whirl-Pak® (Nasco, Fort Atkinson, WI; 710 ml) bags and frozen in the laboratory freezer (Model 425F, Thermo Fisher Scientific, Waltham, MA) before being placed in the freeze dryer.

Dry samples were ground through a 1-mm screen in a Wiley Mill (Thomas Scientific, Swedesboro, NJ). Samples were then analyzed for OM and NDF to calculate digestibilities.

Analysis of OM was conducted by placing crucibles containing 0.5-g of sample in a forced air oven set at 100°C for 12-24 h and then weighed. This provided laboratory corrected DM of samples. Crucibles were then placed in a muffle furnace and ashed at

600°C for 6 h. Samples were then cooled and weighed allowing for calculation of OM using the following calculation:

$$Ash = \frac{Ash\ wt. - Crucible\ wt.}{Sample\ wt. * Lab\ Corrected\ DM}$$

$$OM = 1 - Ash$$

Neutral detergent fiber was analyzed using the beaker method (Van Soest et al., 1964; Van Soest et al., 1991). Beakers containing 0.5 g of sample, 0.5 g of sodium sulfite, and 100 ml of NDF solution were placed on hot plates, covered with condensers, and brought to a boil. Upon boiling, heat was reduced and samples were refluxed for 1 h. Samples were 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 of the sample was then determined by placing the filter in a crucible in a 600°C muffle oven for 6 h and weighed back. Ash-free NDF was calculated using the following equation:

$$Ash - free\ NDF = \frac{Filter\ with\ sample\ wt. - Filter\ wt. - Ash\ wt}{Sample\ wt * Sample\ Lab\ Corrected\ DM * Sample\ OM}$$

Total tract digestibilities were calculated for OM and NDF by using the following calculation:

$$Digestibility = \frac{(intake - output)}{intake}$$

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Lamb within period served as the experimental unit with residue type and drying method included in the model as fixed effects. The effect of drying method was examined in this study.

Results

Drying method had no effect on OM of fecal samples ($P = 0.17$) but had an effect on fiber content ($P < 0.01$; Table 1.). Samples dried via sublimation in the freeze dryer had the numerically lowest fiber content but did not differ from the 60°C forced-air oven ($P = 0.20$) with NDF contents of 68.16% and 69.01%; respectively. Samples dried in the forced-air oven at 100°C had the greatest NDF content ($P < 0.01$; 70.8%). No effect on estimation of OM or NDF digestibilities were observed in this study ($P \geq 0.49$; Table 1).

Discussion

The potential for organic matter losses in different drying methods were not observed which is different than hypothesized. Jacobs et al. (2011) compared similar drying methods: 55°C forced air oven for 48 h, 100°C forced air oven for 48 h, and freeze dried and also did not observe differences between the three methods for drying swine feces for DM, N, C, or S concentrations. Hinnant and Kothmann (1988) observed no differences in fecal samples when comparing oven drying and freeze drying, dried for 24 h at 60°C in a forced-air oven or freeze dried. However, Falvey and Woolley (1974) observed greater N losses as temperature of the oven increased. Gallup and Hobbs (1944) also observed differences when comparing N concentrations between dried and undried samples with losses observed in dried samples compared to undried. While all drying methods, especially increased temperatures, showed losses in N compared to undried feces, method of drying appeared to have no effect on OM in this study.

While studies have determined the effect of drying method on N and energy, few have evaluated the effects of drying method on fiber content, which could potentially be altered due to continuation of fermentation in the feces during the drying procedure. Oven drying can lead to losses of volatile fatty acids in ensiled forages. Thiex and Van Erem (1999) also found the overestimation of moisture in feeds containing urea and decomposition of urea when dried in an oven. The effect of drying method on corn silage was evaluated by Fox and Fenderson (1978) utilizing saponification, oven drying at 60°C for 24 or 48 h, and oven drying at 100°C for 24 or 48 h. Oven drying at 60°C and 100°C led to underestimations of DM by 8.4% and 11.5%, respectively compared to saponification. Mo and TjØrnhom (1978) observed an underestimation of DM by 3.8% in silage but determined that accurate estimates of losses from volatile organic matter were dependent on the origin of the carbon when drying silage samples in a nitrogenous atmosphere for 22 hrs at 103°C. Due to these errors with LOD methods, Byers (1980) utilized water saponification and freeze drying to analyze samples of fermented feeds and found no differences. These discrepancies demonstrate the importance of standardizing procedures. Fiber content was affected by drying method potentially due to the loss of volatile nutrients as temperature increased causing the fiber content to become more concentrated. Similar increases in concentrations of nutrients are observed when evaluating distiller's grains. The removal of starch in the dry milling procedure leads to an increase concentration of other nutrients compared to corn. Ham et al. (1994) found wet distillers grains to contain minimal starch compared to corn but four times the NDF content, three times more CP and fat, and two times more ash.

The results from this study conclude that all 3 drying methods were effective in drying fecal samples. The drying method had no effect on organic matter but did affect fiber content. Though there was an effect on fiber content it did not lead to an effect on digestibility.

Literature Cited

Ahn, J. Y., D. Y. Kil, C. Kong, and B. G. Kim. 2014. Comparison of oven-drying methods for determination of moisture content in feed ingredients. Asian-Australas J. Anim. Sci. 27(11):1615-1622. doi: 10.5713/ajas.2014.14305.

Byers, F. M. 1980. Determining effects of monensin on energy value of corn silage diets for beef cattle by linear or semi-log methods. J. Anim. Sci. 50:1136-1144.

Falvey, L. and A. Woolley. 1974. Losses from cattle faeces during chemical analysis. Aust. J. Exp. Agric. Anim. Husb. 14:716-719.

Fox, D. G. and C. L. Fenderson. 1978. Influence of NPN treatment, oven temperature, and drying time on error in determining true corn silage dry matter. J. Anim. Sci. 47:1152-1156.

Gallup, W. D. and C. S. Hobbs. 1944. The desiccation and analysis of feces in digestion experiments with steers. J. Anim. Sci. 3:326-332.

Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Hinnant, R. T. and M. M. Kothmann. 1988. Collecting, drying, and preserving feces for chemical and microhistological analysis. J. Range Management. 41(2):168.

Jacobs, B. M., J. F. Patience, W. A. Dozier III, K. J. Stalder, and B. J. Kerr. 2011. Effects of drying methods on nitrogen and energy concentrations in pig feces and urine, and poultry excreta. J. Anim. Sci. 89:2624-2630.

Labconco. n.d. A guide to freeze drying for the laboratory (Industry Service Publication). https://www.nbtc.cornell.edu/sites/default/files/freeze_drying_guide.pdf (Accessed 17 February 2017).

Mo, M. and T. TjØrnhom. 1978. Losses of carbon-containing substances during dry matter determination by oven-drying. Acta Agric. Scandinavica. 28:196-202.

Thiex, N. 2009. Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles. J. AOAC Int. 92:61-73.

Thiex, N., and C. R. Richardson. 2003. Challenges in measuring moisture content of feeds. J. Anim. Sci. 81:3255-3266.

Thiex, N., and T. Van Erem. 1999. Comparisons of Karl Fischer method with oven methods for determination of water in forages and animal feeds. J AOAC Int. 82:799-808.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583.

Van Soest, P. J., and W. C. Marcus. 1964. Methods for determination of cell wall constituents in forages using detergents and the relationship between this fraction and voluntary intake and digestibility. J. Dairy Sci. 47:704.

Table 1. Effect of drying method of fecal samples on OM content, fiber content, and digestibilities.

	60°C forced-air oven[1]	100°C forced-air oven[2]	Freeze dry[3]	SEM	*P*-value
OM[4], %	85.71	85.47	85.15	0.21	0.17
NDF[5], %	69.01[a]	70.77[b]	68.16[a]	0.46	< 0.01
OMD[6], %	51.04	51.85	51.76	0.53	0.49
NDFD[7], %	51.78	51.47	50.89	0.60	0.57

[a,b]Means within a row with differing superscripts are significantly different ($P < 0.05$).
[1]Fecal samples were dried in a forced-air oven at 60°C for 72 hrs.
[2]Fecal samples were dried in a forced-air oven at 100°C for 72 hrs.
[3]Fecal samples were dried using a freeze dryer to dehydrate samples.
[4] Organic matter content.
[5]Neutral detergent fiber content.
[6]Organic matter digestibility.
[7]Neutral detergent fiber digestibility.