5-2019

Selective harvest methods and chemical treatment of baled corn residue for utilization in growing calf and dry cow diets

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SELECTIVE HARVEST METHODS AND CHEMICAL TREATMENT OF BALED CORN RESIDUE FOR UTILIZATION IN GROWING CALF AND DRY COW DIETS

by

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A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Animal Science

(Ruminant Nutrition)

Under the Supervision of Professor Mary E. Drewnoski

Lincoln, Nebraska

May, 2019

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Three studies were conducted to evaluate baled corn residue using selective harvest method and anhydrous ammonia treatments to assess utility in growing calf and dry cow diets. Baled corn residue was harvested using conventional rake-and-bale (CONV) method, or harvested using the New Holland Cornrower in which either eight rows (8ROW), or two rows (2ROW) of corn stalks were chopped into the windrow with tailings. Bales were either not treated or ammoniated at 5.5% DM. When fed to wether lambs in a mixed ration (65% residue, 30% wet corn gluten feed) to determine digestibility, the 2ROW residue had greater apparent DM, NDF, ADF digestibility, as well as *in vitro* DM and OM digestibility than either CONV and 8ROW, which were not different. Ammoniation resulted in a 20 to 26% increase in apparent DM, OM, NDF, and ADF digestibility and digestible energy content of the residue. When corn residue was baled as CONV, 2ROW, or using the EZ-Bale system (EZB) with a disengaged combine spreader (treated or ammoniated at 3.7% DM) and fed to growing cattle (65% with 30% wet distillers grains), only the 2ROW method increased ($P < 0.01$) ADG (1.06 kg/d) compared to CONV (0.96 kg/d) and EZB (0.99 kg/d). Ammoniation increased ($P < 0.01$) ADG from 0.75 to 1.26 kg/d and increased ($P < 0.01$) G:F from 0.158 to 0.179. Selective harvest methods altered ($P \leq 0.01$) plant part proportions, and ammoniation differentially increased the digestibility among the various plant parts. A third study used the same

treatments fed as whole bales to dry cows and measured intake, waste, and refusals. Ammoniation increased ($P < 0.01$) DM intake by 18% and waste including refusals ranged between 29.3 and 42.3% of offered DM. Ammoniated residues had sufficient CP to meet cow protein requirements throughout gestation, but only the ammoniated 2ROW and EZB residue had enough DOM to meet gestation energy requirements. Ammoniated corn residue increases digestibility and improves animal performance, and these effects can be enhanced when combined with some selective harvest methods due to changes in plant part proportion and increased susceptibility of cob to ammoniation.

ACKNOWLEDGEMENTS

Research is hardly a sole enterprise, and the unparalleled quality of education I have received at UNL has been the direct result of the people I have had the pleasure of working with during my time here. I would not have been successful in this most challenging endeavor without the care, dedication and genuine investment of my colleagues, teachers and advisors.

My deepest gratitude goes to Dr. Mary Drewnoski, who welcomed me as her first Ph.D. student. I have been indelibly changed by her dedicated mentorship. Her patience, guidance, knowledge, and encouragement have been fundamental to my accomplishments here, and I could not have asked for a better advisor for my final degree.

My appreciation also goes to the members of my advisory committee, Dr. Jay Parsons, Dr. Daren Redfearn, and Dr. Jim MacDonald. Through both the classroom and the conference room, each of you has been an excellent role model for the kind of teacher and researcher I want to become. Your advice, leadership, and perspective have been invaluable, and I will continue to look to all of you as examples of positive mentorship.

I am grateful to all of the graduate students, faculty and staff in the UNL Animal Science department. Working as part of a research team with my fellow students has been a priceless experience, and the friendships I have made are irreplaceable. I wish every one of you the very best. My regards to the hard-working employees in our building and our feedlot who keep so much of the day-to-day running in animal research; your efforts and dedication are valued and instrumental to our success. Many thanks to Angela and Kerry Knuth, who were exceptional on-farm research partners, and are exceptionally wonderful people.

Finally, I am overwhelmed with love and appreciation for my family. In particular, to my parents Shaun and Lorrie, who have always encouraged higher education: I suspect you knew this was my path long before I did, and you have never wavered in your support as I have found my way to this point. My beautiful sister Amber, who fearlessly pioneered the doctoral path and is as proud of me as I am of her: thank you for always believing in me. To the love of my life and true partner, Nathan: you joined this journey at the point when I needed you most, and your love and support has made this experience more rewarding than I ever could have imagined. You and Ethan will forever be the best thing Nebraska has given me.

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DEDICATION

To every young girl who feels "bad at math"… Refuse to let anything or anyone, including yourself, hold you back. A good scientist has an unquenchable curiosity and desire to understand, not an internal calculator.

INTRODUCTION

Corn residue is a valuable feed resource for beef producers in the Midwestern United States, offering economic opportunities for grazing background calves and cows over the winter, or to incorporate the residue into finishing rations as a baled product (Ward, 1978; Klopfenstein et al., 1987; Redfearn et al., 2019). Although considered a "low quality" forage due to the overall nutrient content and digestibility, corn residue is a unique feed resource due to the heterogeneous nature of the forage. Inherent differences in the digestibility of the various plant parts (cob, husk, leaf, and stem) allow cattle to select diets of higher digestibility while grazing to take advantage of the more nutritious husk and leaf (in addition to unharvested grain) while leaving the less-digestible cob and stem (Weaver et al., 1978; Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991a; Stalker et al., 2015). Selective harvest methods such as the New Holland Cornrower Corn Head (Straeter, 2011; Craig Welding, Mentone, IN) can vary the proportion of stem to leaf, husk, and cob (tailings) in the baled windrow by chopping and including either 2, 4, 6, or 8 rows of stem in the windrow for baling. Furthermore, the EZ-Bale harvest method promoted as a "one-pass" system includes disengaging the combine spreader and eliminates the raking process as opposed to a conventional rake-and-bale corn residue harvesting system. Previous work has shown that a low-stem bale produced with the Cornrower (two rows chopped and added to the windrow) will effectively create a more digestible bale than conventional bales, potentially increasing the feeding value (King et al., 2017). However, EZ-Bale corn residue has not previously shown an advantage in animal performance when compared to conventional residue (Welchons et al., 2017).

Additionally, the increase in both digestibility and intake of low quality forages, including corn residue, as a result of ammoniation is well established (Horton et al., 1979; Morris and Mowat, 1980; Saenger et al., 1982; Grotheer and Cross, 1986; Mason et al., 1988). However, given that the magnitude of improvement tends to be greater for forages with greater lignin content (less digestible forages), the wide variation in digestibility of the different plant parts suggests the possibility of differential effects of ammoniation on baled corn residue when combined with selective harvest methods (Knapp, et al., 1975; Sewalt et al., 1996).

CHAPTER I. A Literature Review: Integrating Cattle into Midwest U.S. Corn-Soybean Production through Utilization of Corn Residue

Agricultural specialization and the rise of integrated systems

United States agriculture production in the post-World War II era began a marked trend toward commodity specialization and away from traditional small-scale diversified systems (Dimitiri, 2005). This shift, influenced heavily by the trends in technological advancements and integration of American agriculture into global markets, has resulted in the reduction of the number of commodities sold per farm, with the average farm selling five commodities in 1900 and a farm in 2002 only selling one. This decline has coincided with a 1.9% annual increase in agricultural productivity between 1948 and 1999, and a well-noted decrease in the number of farms with a concurrent increase in average farm size (Dimitiri et al., 2005; O'Donoghue et al., 2011; MacDonald et al., 2013). While there have been advantages realized as a result of agricultural specialization, such as reduced land use, increased commodity productivity, and improved economic returns, there are notable disadvantages to agricultural specialization which include reduced biodiversity, limited ecosystem function, increased labor demand, and increased economic risk when information and infrastructure systems are inadequate (Klasen et al., 2016).

Recognizing the economic and ecological trade-offs due to agriculture specialization and intensification has led to a revived interest in re-integrating specialized systems, including novel methods of analysis for integrated system research (Sulc and Tracy, 2007; Russelle et al., 2007; Lemarie et al., 2014 Klapwijik et al., 2014; Thornton and Herrero, 2001). Agriculture provides both ecosystem services and disservices, and

investigating the extent to which services can be maximized and disservices minimized while maintaining positive economic returns is the challenge that researchers face (Swinton et al., 2007). Crop rotation is a common diversification strategy in crop production which can offer multiple agronomic and environmental benefits, such as decreased nitrate leaching, reduced soil erosion from water and wind, increased soil organic matter, and resilience to pestilent insects and disease (Russelle et al., 2007). When forages are included in crop rotations, integrating livestock enhances the potential for economic and environmental benefits, including increased rate of soil organic matter accumulation from manure and reduced feed costs for livestock owners (Russelle et al., 2007). The established benefits of integrating livestock are such that Sulc and Tracy (2007) hypothesize that integrated crop-livestock systems would be economically competitive with conventional systems with reduced environmental impact, and should be actively researched and encouraged in the U.S. Corn Belt region.

Research conducted in this region specifically investigating this hypothesis is abundant, and studies have focused specifically on strategies that could be employed in predominantly agricultural regions of the U.S., such as the Midwest and Corn Belt region. Integration of crops and livestock can be accomplished in two primary ways: among-farm (regional) integration, which utilizes partnerships or contracts between two separate entities, or within-farm integration, which incorporates crops and livestock both spatially and temporally (Sulc and Tracy, 2007; Russelle et al., 2007). Among other strategies, within-farm integration in the U.S. Corn Belt region can consist of three potential elements: 1) crop rotations with grains and perennial pastures, 2) crop rotations of grains with annual or short-season pastures, or 3) grazing of grain crop residues by

livestock (Sulc and Tracy, 2007). This third aspect of integration holds significant potential for exploration and investigation into the diverse ways crop residue can be an entry point for livestock integration, even beyond grazing. While the integration of perennial forage crops and short-season pastures into rotations with grain crops are a valuable strategy, the focus of this review will investigate the literature available on the role of grain crop residues in integrated crop-livestock systems, including management, utilization, and technological strategies for livestock integration with crop residues.

Corn Production and Residue Availability

The United States is the largest global corn grain producer, accounting for 35.5% of the world's corn in 2017, and the Midwest region accounts for the majority of U.S production. In 2017, approximately 82.7 million acres (33.5 million ha) of corn grain were harvested in the United States, producing over 14.6 billion bushels (371 million T) of corn grain (USDA, 2019). In the Midwest, the "Corn Belt" region refers to Indiana, Illinois, Iowa, Missouri, eastern Nebraska, and eastern Kansas, where the majority of the country's grain is produced. Of the totals reported by USDA in 2017, the Midwest Corn Belt states accounted for 57% of the corn acres harvested, and 59% of the national production of corn grain in both economic value and volume (USDA, 2019). These production values indicate that these six states alone produced 22% of the world's corn grain supply in 2017, and the importance of this crop in the Midwest region as a commodity cannot be overstated.

Of the total corn grain produced nationally, roughly 5.5 billion bushels (140 million T) of corn grain were used for the production of fuel alcohols, marking a 3.87% increase from 2016, which was a 1.34% increase from 2015. Policy changes targeting

renewable energy production began as early as the 1978 Energy Policy Act, which provided a 10.6 cents/L subsidy for ethanol, initiating a shift toward alternate fuels and a move away from fossil fuels (Tyner, 2008). During the period between 1978 and 2007, twelve pieces of legislation at the federal level opened up the ethanol industry for expansion with small subsides, tax exemptions, “fuel economy credits” for automobile manufacturers, and in 2005, a renewable fuel standard imposed criteria for fuel composition that removed the oxygen requirement for gasoline (Tyner, 2008). However, national ethanol production levels remained relatively modest between 1980 and 1999, with production remaining below 5000 million liters per year (Tyner, 2007). Annual industry growth remained at a steady average of 9% per year between the years of 1983 and 2001, but between the years of 2002 and 2010, there was an ethanol industry boom resulting in average annual growth of 25% (EIA, 1993; EIA, 2019). So-called “the Ethanol Decade,” this rapid increase in production was a culmination of several years of subsidy polices in conjunction with a substantial price increase in crude oil, from $10-20/barrel increasing to over $70/barrel, with prices topping $120/barrel in 2008 (Yacobucchi 2007; Tyner, 2008; Balat and Balat, 2009; Anderson and Coble, 2010). Market price for corn as an ethanol fuel substrate increased dramatically during this period of time as demand for both fuel and substrate increased, resulting in an increase in corn production (Solomon et al., 2007; Yacobucchi 2007; Wallander et al., 2011). More specifically, the attractive corn market between 2000-2009, with 20-40% increases in corn price, prompted farmers to increase the number of acres planted to corn by 10% (7.2 million acres), increasing corn production by 3.2 billion bushels (65 million metric tons) (Wallander et al., 2011).

As demand for ethanol (and subsequently, corn) grew rapidly during this time, producers were faced with a limited land base on which to grow the additional corn needed to meet demand. While the majority of corn acreage increases came from predominately soybean acres, with producers likely planting continuous corn as opposed to practicing previously-held corn-soybean crop rotations, nearly 1/3 of the new acreage converted to corn production was from land used for hay production, U.S. Conservation Reserve Program, or perennial grazing pastures (Wallander et al., 2011). Remaining pasture and hay land experienced a subsequent jump in value and forage resources for cattle producers became more expensive and less available. In the state of NE, land rental rates for livestock experienced a steady annual increase of 2.8%, from $14.80 per animal unit month (AUM) to $28.50/AUM between1991-2012 (USDA, 2019). Following this conversion of land previously used for cattle forage feed sources, a decrease in available forage resources resulted in an increasingly rapid rise in rental rates between 2013-2017, with annual growth rates rising to 7.2% on average and prices increasing to $39.80/AUM (USDA, 2019). High corn prices, reduced hay and pasture availability, and increasing land values and cash rental rates precipitated a precarious position for cattle producers, which continues through to present day.

In addition to ethanol co-products rising in popularity as an economical and nutritionally valuable animal feedstuff, the increase in corn acres and bushels harvested resulted in an increase in available corn residue for utilization. The amount of corn residue available, however, is an estimate at best, with the generally accepted 1:1 ratio of above-ground non-grain corn biomass (residue) to corn grain DM yield being promoted in extension publications (Pennington, 2013). This ratio is likely derived from several

studies which report corn biomass production ranges from 45-55% of the total corn grain yield on a DM basis (Leask and Daynard, 1973; Linden et al., 2000; Shinners and Binversie, 2007). However, the variability noted in these studies indicates that several factors influence the yield of corn residue and thus must be accounted for when estimating supply and availability. Harvest method, tillage practice, stage of maturity, and time of harvest will all influence the amount of biomass produced (Shinners and Binversie, 2007). These values can also be incorporated together and expressed as a harvest index, which is the metric included in a more comprehensive model reported by the USDA to better estimate the corn stover supply for the ethanol industry (Gallagher and Baumes, 2012). This model had previously used a constant value for harvest index (0.45), which suggested that the stover yield would be 55% of the corn grain yield. However, the report notes that as corn breeding has become more efficient, corn yields have increased while harvest index has declined. Therefore, they incorporate a linear function into their model for harvest index in relation to corn yield to better estimate biomass production (Gallagher and Baumes, 2012). Despite this variability, this model still predicts the yield to range between 45% and 55%, which suggests that the 1:1 ratio is a valid, although not necessarily precise, general rule with which to estimate corn residue yields. Based on NASS 2018 harvest estimates, this would indicate that at least 176 million metric tons of corn residue DM would be produced (USDA, 2019). When accounting for recommended residue removal rates between 25-50%, this would mean that between 44 and 88 million metric tons of corn residue would be available for utilization in both the livestock (both feed and bedding) and cellulosic ethanol industry. Using the model developed by Gallagher and Baumes (2012), an estimated 100 million

metric tons of residue would be available for cellulosic ethanol feedstock after the demand for animal feed and bedding, with the suggestion of very little competition between the two markets. This establishes corn residue as an abundant, low-cost feed resource for livestock in the Midwest region of the U.S (Graham et al., 2007; Gallaher and Baumes, 2012).

Agronomic Corn Residue Management Strategies

Residue characterization

As indicated previously, the amount of corn residue produced can be cumulatively expressed as a harvest index metric. However, this does not precisely describe the composition of the corn residue being produced. As corn residue is essentially the non-grain corn plant, all of the agronomic factors which would affect typical plant growth and performance should be considered in the outcome of the final product.

This was noted by Leask and Daynard (1973), who commented on the dearth of data (at the time) pertaining to the agronomic influences on corn stover production. The subsequent study attempted to address this shortage characterizing the relationship between grain and stover yields, change in moisture over harvest time, and the amount of variability in stover attributes for commercial hybrids available at the time. When plants were harvested at 80% black layer formation, the grain accounted for 49.7% and the non-grain biomass accounted for 50.3% (37% DM) of the total plant dry weight. In this study, the “stover” only included the stem, leaf, and husk, excluding the cob. When separating out the non-grain parts, cob was 11.8% of plant dry weight, husk was 8.9%, stalk was 17.6% and leaf was 12.0% of the plant dry weight (Leask and Daynard, 1973). There was

substantial variation in overall stover and corn yield among the 22 hybrid varieties sampled from the same location, and no strong linear relationship emerged, providing evidence that corn hybrid will affect both the plant performance and grain yield with an unpredictable relationship. There was similar variation in in vitro dry matter digestibility (IVDMD) of the different plant parts, with leaf ranging between 49 and 64%, stem ranging between 25 and 54%, and husk ranging between 47 and 72%. Overall IVDMD values of unseparated stover were approximately 42-63%, and these values were not visibly correlated with grain yield (Leask and Daynard, 1973). The authors found that the IVDMD for leaf, stem, and overall stover declined 1.5%/week when measured over a 3 week harvest period in October after grain maturity (Guelph, Ontario, Canada), but not for the husk component, which remained unchanged over the harvest period. The average crude protein of the stover did not differ based on harvest time or hybrid time, and the stover moisture remained high at approximately 80% until 20-30 days before the corn grain reached 30% moisture, at which time, the stover dried rapidly at 1.5 g of water lost per 100g fresh biomass per day. The authors concluded that residue yield, moisture, and nutritive value will vary greatly between hybrids, and called for more extensive investigation into stover for livestock feeding purposes.

After this initial characterization of corn stover, common themes regarding the composition of corn residue emerged in subsequent studies. After the corn grain reaches physiological maturity, the corn plant loses moisture rapidly, and there is a decline in the non-grain biomass digestibility, a decrease in soluble glycan and an increase in lignin (Fernandez-Riviera and Klopfenstein, 1989; Hunt et al., 1989; Pordesimo et al., 2005; Shinners and Binversie, 2007). Although Pordesimo et al. (2005) did not observe

differences in yield or compositional measurements between the two hybrids tested (a traditional and a Bt hybrid), most other studies note significant variation in biomass composition (nutrient components and DM yield) due to hybrid variety when a greater number of hybrids are compared (Templeton et al., 2009). There is also considerable variation in both harvest index (0.40 to 0.60 as biomass yields approached 15 Mg/ha) and corn stover nutrient composition (particularly in the cell soluble nutrients) due to harvest year (and thus, growing conditions) as well as geographical location, suggesting once again that precise estimates in corn residue nutrient composition cannot be adequately generalized without taking location and cultural practices into consideration (Linden et al. 1999; Templeton et al., 2009). With growing conditions, the nutrient composition of the entire corn plant is affected rather than differential effects to the different plant parts. When collected immediately post-harvest, dryland corn residue was greater in CP than irrigated, but there was no difference between irrigated or dryland corn plant parts (leaf and husk, stem and cob) for CP, NDF, and IVDMD (Fernandez-Riviera and Klopfenstein, 1989a). Biomass yields are greater for irrigated corn compared to dryland, and correspond well to grain yield when excluding the effect of hybrid (Fernandez-Rivera and Klopfenstein, 1989a). Conversely, the plant part biomass is differentially affected by growing conditions. The same authors observed dryland corn produced a lower proportion of stem to leaf and husk when compared to irrigated corn, but this study was confounded with higher plant density for irrigated corn. Other work confirms that the stem:leaf ratio increased with lower planting densities, resulting in a reduced biomass yield (Dhugga, 2007). Finally, although the effects of growing conditions on the corn plant parts are similar across the entire corn plant, there are inherent differences in the

digestibility and nutrient content of the different plant parts. Several studies show greater digestibility of husk and leaf compared to cob and stem (Leask and Daynard, 1973; Weaver et al., 1978; Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1991a). Gutierrez-Ornelas and Klopfenstein (1991a) reported IVOMD ranging between 61 to 73% for husk, 51 to 57% for leaf (not including sheath), and 43.6 to 44.4% for stem (including sheath). Cobs varied the most in digestibility, with IVOMD values ranging between 30% (irrigated) to 53% (non-irrigated).

Management as soil cover

With corn yields generating large amounts of biomass after grain removal, the annual question that crop producers face is how best to manage the remaining residue. Decisions such as how much residue to remove, whether to remove residue with either grazing or baling, and whether or not to incorporate the remaining residue with various tillage methods will all have tangible consequences. Traditionally, crop residues have been used a soil amendments to increase soil organic matter (SOM) and reduce erosion from rain and wind (Kumar and Goh, 1999; Nelson, 2002; Wilhelm, et al., 2004). Not only will biomass cover prevent topsoil loss by protecting soil from rain drops and wash, but decomposition of the vegetative material provides C and N (among other nutrients) to the soil microbial community, which increases carbon sequestration, enhances soil structure, and improves the water-holding capacity of the soil (Barber, 1979; Laflen and Colvin, 1981; Lindstrom, 1986; Kumar and Goh, 1999; Al-Kaisi and Yin, 2005). The rate and extent of decomposition of the residue can be predicted by several factors, including the biomass C:N ratio, the lignin content, residue particle size, age and moisture, and weather conditions (Kumar and Goh, 1999). There are numerous complex aspects of

residue degradation and soil characteristics which will affect the soil physical characteristics, tilth, and subsequent yields (Figure 1), and the scope of this review will focus on the managerial impacts that producers can exert through tillage and residue removal rates on soil health and crop yields.

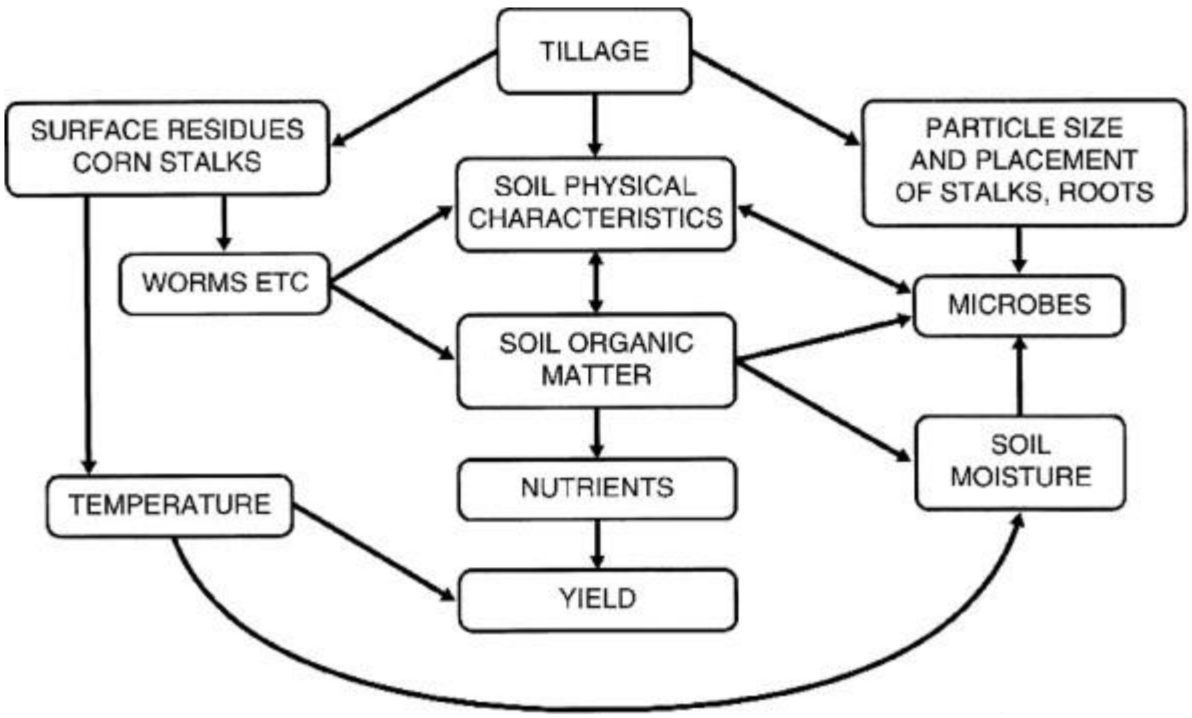

Figure 1. Interactions between residue management, tillage and soil characteristics as adapted from the literature (figure from Mann et al., 2002).

The primary effect of residue retention and incorporation can be seen in the soil characteristics. Several long-term studies have shown that the amount of residue removed from the field and the method of residue incorporation (if any) are management factors that influence the rate and extent of residue decomposition (Kumar and Goh, 1999; Wilhelm et al., 2004). Measurements of SOC, CO_2 emissions, and erosion indicators such as sediment concentration, water runoff and soil loss have all been extensively examined in relation to corn residue retention. Wilts et al. (2004) found over a 29 year period that when 100% of the harvested grain residue was returned to a field in a continuous corn

rotation and fully incorporated with a moldboard plow, total SOC and naturally occurring carbon increased, but only SOC declined when residue was removed. The authors also found that 5.8% of the carbon returned to the soil was from the corn residue, which is less than the 11% observed in a 12 -study by Barber (1979). Over a period of 13 years studying continuous no-till corn fields, Barber (1979) found that removing stover maintained SOC levels, but returning the residues to the field increased SOC levels by 14% (Clapp et al., 1999). Allmaras et al. (2004) showed that when corn residue was entirely removed at 100% compared to 0%, the corn-derived SOC was reduced by 35% and total soil carbon was reduced by 60% over a 13-year period. However, the authors found that when examining the effect of tillage method, no-till methods store more SOC compared to non-moldboard plows, while moldboard plowing at a tillage method stored the least SOC (Allmaras et al., 2004). Additionally, the distribution of SOC varied among soil depths depending on tillage method, with no-till storing more SOC in the shallower depths less than 7.5 cm and SOC storage greater at lower depths (10-30 cm) for systems with annual tillage. However, several other studies note that residue which is not incorporated with plows, chisels or disks will retain more SOC overall even though increased particle contact with soil will increased the rate of biomass decomposition (Karlen et al., 1994; Paustian et al, 1998; Clapp et al., 1999; Allmaras et al., 2004; Wilhelm et al., 2004). Regardless of residue incorporation, conversion to no-till systems from tillage will increase SOC between 0.13 Mg C ha^{-1} yr^{-1} to 0.60 Mg C ha^{-1} yr^{-1}, with the majority of the improvement occurring within the first 10 years (West and Post, 2002). Overall, the cumulative positive effects on soil health from no-till systems outweigh any minor benefits in residue decomposition rate, thus many producers are

being encouraged to minimized tillage practices, particularly for residue management (Al-Kaisi and Yin, 2005).

While some studies have compared either 0 or 100% removal of corn residue and found that the measurements of soil tilth and health increased with residue retention (Wilts et al., 2004; Al-Kaisi and Yin, 2005), others have found that the amount of residue removed will impact the soil outcomes. For instance, Maskina et al. (1993) included additional residue retention rates to better illustrate a “dose-response” effect, with residue retention of no-till and disked cornfields at either 0, 50, 100, or 150% over a 5 year period. These retention rates were managed with two adjacent fields where one field had all residue removed (0%) or half the residue removed (50%), and the second field had no residue removed (100%) or the researchers added residue that was removed from the first field to increase the residue to 150%. With increasing the residue retention rates, the retained SOC up to 30 cm increased from 24.7 to 25.3, 26.2 and 27.4 g/kg respectively, and these effects were sustained 3 years after the study (Maskina et al, 1993). This pattern follows data from Power et al. (1986) where soil temperatures, soil water storage and soil organic matter increased with the same residue retention amounts. Although these were not reported as statistically significant linear trends, validated linear models have been developed which describe the positive linear relationship between the amount of C input from crop residues and the change in SOC over time (Parton and Rassmussen, 1994; Parton et al., 1995; Weinhold et al., 2016). Parton and Rassumssen (1994) report that a minimum of 200 g C m^{-2} y^{-1} is required to maintain soil C levels, depending on N levels and fertilizer treatments in a model developed for wheat straw residue. Additionally Parton et al. (1995) acknowledge that the development of comprehensive

models which take in to account vegetative biomass inputs are complicated by factors such as tillage, N-levels or fertilizer treatment, prior existing SOC levels, and soil type. Indeed, Blanco-Canqui and Lal (2007) found that after 10 years of continuous no-till corn, corn stover removal rates greater than 25% (leaving less than 75% of the residue on the field) resulted in reduced SOC, but that the magnitude of this effect was not consistent between soil types and topographical conditions (Blanco-Canqui and Lal, 2007). As noted in the authors' publication, residue removal rates may have differing impacts based on soil type, water-holding capacity, and propensity for wind and water erosion (Blanco-Canqui and Lal, 2007). Subsequent work by Blanco-Canqui and Lal (2009) studied residue removal rates of 0, 25, 50, 75 and 100% and found that after 4 years, only the 0 and 25% removal rates showed no reduction in soil microaggregates, total N, and SOC. Furthermore, they demonstrated that the negative effects of stover removal were greater on sloping and erosion-prone soil types, once again confirming that the appropriate residue removal rate depends on more than just increased SOC goals from a management perspective. Considerations of soil type, slope, and existing soil properties should all be considered when evaluating the optimal rate of residue removal.

The most critical aspect of corn residue management is the impact of these different management methods (tillage and removal rate) on the subsequent crop yields. If increased SOC was a primary indicator as to the improved overall tilth of the soil, then this would be realized in increased grain and biomass yields in subsequent years following residue retention. This was not seen by Crookston and Kurle (1989), who returned 100% corn residue to a split corn-soybean plot in rotation for three years with no corresponding effect (increase or decrease) on the subsequent crop yields. The authors

concluded that since there was only a significant effect for previous year's crop rotation (presumably due to corn following the N-fixing soybeans), there was no evidence that the corn residue provided any positive or negative effects on crop yields (Crookston and Kurle, 1989). However, Power et al. (1986) showed in a 4-year study that returned 150% of the corn residue to the fields, corn grain and residue production increased by 126 % (soybean yields increased by 233%), suggesting substantial improvements can be made in crop production through residue retention. Contrary to both of these studies, Wilhem et al. (1986) found that subsequent crop grain and biomass yield was reduced by 0.13 and 0.29 Mg ha^{-1} respectively for every 1 Mg ha^{-}1 of crop residue removed. These studies highlight the complexity of this issue as a subject of research; understanding how the singular factor of crop residue removal is also part of a suite of influencing factors which can affect crop yield, including previous SOC levels, N-fertilization treatments, tillage strategies, soil type and propensity for erosion, as well as annual growing conditions and climate.

More recent literature attempts to account for these effects experimentally. Maskina et al., 1993 showed that grain yield increased by 24% from 0 to 150% residue retention after 3 years when no fertilizer was applied, with an average grain yield of 4430 kg ha^{-1}, and there was a net 10% increase with residue retention when fertilized at 60 kg N ha^{-1}, with an even higher average grain yield of 5480 kg ha^{-1}. Increases in residue yield were even greater when comparing 0% residue retention to 150%, increasing 35% for unfertilized plots from 2580 kg ha^{-1}, and increasing by 18% for fertilized plots from 3510 kg ha^{-1} (Maskina et al., 1993). More specifically, a 13 year study in Minnesota observed that retained residue only contributed to increased yields when growing season

precipitation was no more than 20-30% below the 9-year average; drier years showed no effect of residue retention (Linden et al., 2000). The authors concluded that the effects of retained residue and tillage are greater in soils with already limited water retention capacity, which speaks to the contribution of increased SOC and the downstream effects on soil physical properties (Linden et al., 2000). This is also supported by later work, where plant available water reserves and earthworm population were reduced in a short term (2.5 year) study after 8 years of no-till when 50% of available residue was removed (Blanco-Canqui and Lal, 2007). These residue removal rates also corresponded with reduced SOC and reduced grain and residue yields at 50% removal rates and greater, but only for one of the three soil types studied.

Overall, while there is still much to be understood regarding dynamics of residue management, in resilient (no-till systems), it is clear that opportunities to retain more corn residue compared to complete removal is beneficial to soil heath and crop yields. Because corn residue still holds economic value, grazing cattle as a residue management strategy may create a window of opportunity for both crop and livestock producers by increasing residue retention (compared to complete removal by baling), but utilizing the valuable residue as a feed resource.

Livestock Residue Management Opportunities

Although the utilization of crop residues is not a new practice, the economic dynamics associated with diversification and “re-integration” of cattle into cropping systems to utilize potentially available crop residues is not well understood within the context of highly specialized agriculture systems (Reid and Klopfenstein, 1983; Schmer et al., 2017). However, Poffenbarger et al. (2017) conducted a comprehensive economic

analysis focused on central Iowa between the years of 2008-2015, and found that when livestock and crop rotations were integrated and compared with continual cash crop harvests over 2 or 4 years, the net profits were equal between all systems. Moreover, partial budget analyses indicate that grazing oat and pea residue in the winter is more economically advantageous than pen feeding dry cows in early gestation, with a 36% and 28% reduction in winter feeding costs (Krause et al., 2013). Recent work has established that the utilization (either by grazing or by baling) of available residue ranges between 19.5-54% in NE, SD, KA, and ND, and these utilization numbers have the potential to feasibly be increased by at least 10% (Redfearn et al., 2019). This would add an estimated $15 million in value to crop producers who take advantage of available corn residue by integrating livestock, based on the value of corn residue rental rates and animal transport costs (Redfearn et al., 2019). Indeed, the economic opportunity for both livestock and crop producers is appealing.

However, the available improvement cited by Redfearn et al. (2019) demonstrates that there is currently economic opportunity being missed with corn residue utilization. In Nebraska in 2012, only 25% of cultivated corn acres were reported to be grazed (Stalker et al., 2012) and Cox-O'Neill et al. (2017) reported that 37% of producers responding to their survey were not allowing grazing of their corn residue. This suggests that even with availability and potential economic incentive around grazing corn residue, there are barriers to adoption that need to be examined. Survey work done in Nebraska indicates that 49% of crop producers who were unwilling to allow grazing cited inconvenience of infrastructure development (no fencing or water) as one of the primary barriers to adoption (Cox-O'Neill et al, 2017). Additionally, 55% of crop producers who responded

that they would not graze regardless of how much livestock producers were willing to pay for a rental fee cited “negative effect on farming practices” and the perception that grazing increases soil compaction as the most common reasons for their choices (Cox-O’Neill et al, 2017). Lack of fencing and water, as well as additional labor, were cited as the primary aversion to corn residue grazing by crop producers in an Extension survey done in Kansas (Johnson and Blasi, 2018).

Some, but not all, of these concerns are supported with evidence in the literature. For example, Poffenbarger et al. (2017) found that although the net profits between integrated and continuous cash crop system were not different, the overall labor and capital input requirements such as those associated with water, fencing, and planting for integrated systems (either grazing cattle, or simply a cover crop) were substantially increased over the unintegrated cash crop system. The authors also noted that variable costs (veterinary costs and death loss) and revenues (cattle prices) were greatest for the livestock-integrated systems. Also, the livestock enterprises resulted in negative returns to land and management due to the substantial increase in labor requirements associated with managing the livestock (-$30.00/head and -$42.00/hd for the 2-year and 4-year systems). Investigating strategies to overcome these tangible barriers and help producers fully realize the value of their excess crop residue should continue to be a focus of future work.

Grazing Corn Residues

While the term “crop residue utilization” includes harvesting bales for feed, bedding and cellulosic ethanol, the majority of corn residue in NE, SD, KA, and ND is grazed rather than baled (Redfearn et al., 2019). As such, considerable work has been

done to understand optimal livestock integration strategies specifically targeted toward grazing livestock. A primary concern regarding corn residue grazing for producers in the survey by Cox-O'Neill et al. (2017) was that cattle increased soil compaction. Producers in this survey were also asked about the effect of grazing on their subsequent corn and soybean yields, and producers who did not allow grazing were more likely to perceive that grazing negatively impacted subsequent crop yields (Cox-O'Neill et al., 2017). In fact, the effects of grazing cattle on soil compaction and subsequent crop yields are complex and multi-faceted, and must be carefully elucidated in order to combat misconceptions.

Livestock grazing can affect soil surface properties. However, this is a function of several factors including soil type, soil structure, time of year the grazing is occurring, and the intensity of the grazing as influenced by stocking rate and amount of biomass removal. In a recent comprehensive review of the literature, livestock grazing has been reported to increase surface compaction (upper 25 cm of the soil) as measured by penetration resistance by 0.27–0.84 MPa (Rakaar and Blanco-Canqui, 2018). This agrees with an older review on the same topic, which indicates that while livestock grazing can increase soil compaction, the magnitude of effect is typically small and limited to the top 5-15 cm of soil (Greenwood and McKenzie, 2001). Furthermore, both reviews conclude that this effect is likely magnified by the existing soil structure and moisture, with recently tilled or soft, wet soil (such as those that would occur during a spring thaw or mild winter) having a greater propensity to be compacted at a greater depth (Greenwood et al., 1997; Greenwood and McKenzie, 2001; Rakaar and Blanco-Canqui, 2018).

This is succinctly illustrated by a study reporting the cumulative effects of grazing over a 16-yr period, with long-term treatments of either fall or spring grazing compared to no grazing in an irrigated no-till system (Rakkar et al., 2017). When stocking rates for fall and spring grazing were kept between 4.2-6.2 animal unit months (AUM)/ha in the fall (grazed Nov-Feb) and 9.3-13.0 AUM/ha in the spring (grazed Feb to mid-April), there was no difference in soil bulk density, wet soil aggregate stability, particulate organic matter, soil organic carbon, or N, P, and K. However, the soil compaction parameter of cone index did increase by 1.3 to 3.4 times the control for spring grazing. The important note here is that while the cone index increased, it was below the threshold limit of 2 MPa (above which negative impacts on crop yields are seen), and the compaction effect was only seen in the upper levels of the soil (Rakkar et al., 2017). When corn residue removal rate by grazing was kept between 10-22%, the livestock had little or no effect on the soil properties over time, and, in fact, the effect on the soil microbial biomass was positively (although not significantly) influenced (Rakkar et al., 2017). Even more recently, Ruis et al. (2018) demonstrated that corn residue removal by grazing increased particulate organic matter and actinomyecte microbial biomass compared to both baling residue removal and no residue removal at all. This suggests that not only does corn residue grazing have little negative effect on soil properties, it can actually have positive effects on some aspects of soil health when managed with appropriate stocking densities, regardless of irrigation or tillage practice (Ruis et al., 2018). Several studies also show that the addition of manure to soil will increase the SOM concentration and N concentration, and subsequent compactability, similar to the effects of retained corn residue (Parham et al., 2002; Blanco-Canqui et al., 2016a).

Strictly speaking, there is evidence that livestock grazing will technically increase surface soil compaction, bulk density and penetration resistance. However, this does not readily translate to negative impacts of livestock grazing on subsequent crop yields. As summarized by Rakkar et al. (2017), ten studies since 2004 have shown that stocking rates varying between approximately 1.4 AUM/ha (Tracey and Zhang, 2008) up to 13.0 AUM/ha (Drewnoski et al., 2016) showed no effect of crop residue grazing on subsequent corn yields. More recently, Ulmer et al. (2018) demonstrated that over a 3-4 year multi-farm study, there was no difference in subsequent crop yields between grazed or baled corn residue (under a variety of management conditions) and the control with no residue removal. Clark et al. (2004) reported decreased soybean yields after grazing the corn residue when fields were stocked at 3.7 cows/ ha. However, Drewnoski et al. (2016) showed that soybean yields improved with fall grazing (4.4-6.2 AUM / ha) and tended to improve with spring grazing (stocked at 9.3-13.0 AUM/ha) regardless of a no-till of strip-tillage system over a 16 year period. Agostini et al. (2012) reported that corn yields increased in an integrated system cattle grazed volunteer wheat stubble either 90 or 250 days after wheat harvest with elevated stocking rates of 12 (420 kg BW) animals/ha when compared with both a no-grazing or a continuously-grazed system. Interestingly, these results corresponded with a simultaneous reduction in soil bulk density despite an increase in penetration resistance, which does not align with the available literature on the correlation between bulk density, compaction and yields. This suggests that there are likely other factors besides soil properties that will more acutely affect yield outcomes over a short-term basis, which may include the type of crop residue grazed (corn or small grain cereals), and that the cumulative effect on of grazing must be observed over a long

period of time and interpreted with context. However, overall, the effects of residue removal via grazing, when managed at stocking rates such that the removal rate is not more than 25% of available biomass, will have negligible effects on subsequent crop yields. With continued focus on integrated cropping systems with grazing crop residue, particularly corn residue, this is certainly an area worthy of further investigation.

Managing livestock grazing corn residue

Achieving adequate growth for backgrounding calves and maintenance requirements for dry, pregnant cows during late fall, winter or spring grazing is critical in the success of an integrated system. As such, there is an impetus to maintain appropriate stocking rates and residue removal rates of grazing cattle for reasons beyond soil health and subsequent crop impacts.

The stocking rate for grazing cattle is a primary driver of herbage allowance, and thus DMI, OM disappearance and animal performance (Zoby and Holmes, 1983; Redmon et al., 1995; Pinchak et al., 1996; Garay et al., 2004; Morgan et al., 2012; Stalker et al., 2015; Brunsvig et al., 2017). Higher stocking rates will also change grazing behavior to compensate for reduced herbage allowance, with more time spent grazing and bite frequency increasing in cattle (Zoby and Holmes, 1983). In pasture or perennial forage grazing, the limiting herbage allowance and subsequent effects on animal gain varies, with Garay et al. (2004) describing a curvilinear decline of bull ADG in relationship to increased stocking rates on the tropical forage Stargrass (*Cynodon nlemfuensis Vandyerst*). The relationship was strong, with the regression coeffecient for ADG ranging from $r^2 = 0.9235$ to 0.8522 over two years. Alternatively, regression equations developed based on steers (267-313 kg BW) grazing winter wheat describe the

relationship between herbage allowance, OM intake and estimated daily gain as linear up until a critical value, after which the intake and gain plateaued (Redmon et al., 1995). When daily herbage allowance was the independent variable, the strength of the relationship between daily OM intake was moderate, with an $r^2 = 0.5222$, and daily gain was slightly more correlated with herbage allowance at $r^2 = 0.5906$ (Redmon et al., 1995). Interestingly, the strongest relationship observed between herbage allowance in this study was with IVOMD, with an $r^2 = 0.6382$. The critical value of minimum herbage allowance to maximize gains was 23.0 kg DM/100 kg BW, while OM intake was 21.1 and IVOMD was 24.3. These data, and the curvilinear response observed by Garay et al. (2004) indicate that the animal performance in forage situations can be maximized at a certain point, and that the limiting factor is forage intake as a function of herbage allowance. Pinchak et al. (1996) report this critical value minimum of herbage allowance for 225 kg steers grazing winter wheat to be 27.3 kg/ 100 kg BW. The variability in these minimum values of herbage allowance suggests differences between forage and animal type that bear consideration.

The effect of available biomass on intake and subsequent animal performance is similar when grazing corn residue, with increased stocking rates reducing animal gains (Fernandez-Rivera and Klopfenstein, 1989; Crichton et al., 1998; Stalker et al., 2015). Although cattle will naturally select forages when grazing even homogenous perennial pastures such as wheat, oats or barley, the more heterogeneous nature of corn residue as well as the variability in corn grain (and thus residue) yields provides a unique challenge in determining limiting herbage allowance and predicting growth (Mulholland et al., 1977; Fernandez-Rivera and Klopfenstein, 1989). At higher stocking rates on corn

residue, not only will intake and gains decrease as is observed in pasture research, but the grazing pressure will increase the rate of diet selection, as is evidenced by forage IVDMD decreasing at a faster rate as stocking rates increased from 1.23 to 4.69 calves/ ha (246 kg BW) (Fernandez-Rivera and Klopfenstein, 1989). Although intake was not measured in this study, correlations between the dietary components remaining in the field were used to represent available forage. The authors found that the most influential indicators of ADG were the percent *in vitro* DM disappearance of leaf plus husk (r = 0.94), the available leaf plus husk available expressed as kg/animal (r = 0.85) and the overall *in vitro* DM disappearance of the whole diet at the end of the 8 week grazing period (r = 0.84). Interestingly, the authors also noted an equally strong negative correlation (r = -0.86) between the dietary CP composition at the end of the grazing period and ADG, leading them to posit that, unlike perennial pastures, grazing a lower quality forage such as corn residue accentuates complex interactions between energy intake and protein requirements for growing calves. This is also seen in work done by Stalker et al. (2015), who observed an increase in body condition of cows grazing corn residue at 2.5 AUM/ha, but cows grazing at 5.0 AUM/ha (grazing fields with average grain yields of 9.5 Mg/ha; treatments of 3.76 AUM/Mg of residue and 1.88 AUM/Mg of residue) maintained body condition during winter grazing from October to March. By assessing the abundance of the different plant parts (cob, husk, leaf, and stem) at the beginning and end of the grazing period, the authors were able to show that increased grazing pressure forced cows to select the higher quality plant parts (husk and leaf) to a greater degree earlier in the grazing season, resulting in declining diet quality over time (Stalker et al., 2015).

Observations from several studies have led to the hypothesis that the initial quality of the corn residue is higher in protein and digestibility with more husk and leaf in the field, but as selection pressure from grazing reduces the available higher-quality plant parts, the quality of the diet declines and RUP becomes limiting. Initial work by Fernandez-Rivera and Klopfenstein (1989a and 1989b) suggests that additional supplemental protein would likely be needed in corn stalk grazing situations, particularly with growing calves. The authors overserved a strong negative correlation between gain of growing calves and available CP of the diet at the end of the grazing period, even when they were supplemented throughout the grazing season to meet protein requirements for 0.6 kg ADG (Guierrez-Ornealas and Klopfenstein, 1991). The conclusion that protein is the first limiting nutrient for growing animals grazing corn residue is further supported by the complete disappearance of corn grain in the beginning of the grazing season and the disappearance of starch in the extrusa of the diet samples, with no corresponding negative correlation between dietary starch content and ADG (Fernandez-Rivera and Klopfenstein,1989a and 1989b). Although initial grazing will include dropped ears (Fernandez-Rivera and Klopfenstein [1989a] observed 134-348 kg/ha of corn grain in dryland and irrigated fields and Stalker et al., [2015] observed 406 kg/ha [2.5-8 bu/ac]), the cattle will learn to heavily select for grain as they graze, resulting in an initial abundance of energy followed by a rapid decline in available dietary energy (Fernandez-Rivera and Klopfenstein, 1989a and 1989b). Early work tested “escape protein” as the first limiting nutrient by feeding six different levels of a supplement formulated to offer increasing amounts of escape protein (ruminally undegraded protein; RUP) in a 50% CP mixture (Gutierrez-Ornealas and Klopfenstein,

1991b). The authors found that the effect of escape protein was not observable in the first 20 days of grazing, but after 20 d and through the end of the grazing period, increasing levels of escape protein increased gain by 3.35 g of ADG/g of EP consumed (Gutierrez-Ornealas and Klopfenstein, 1991b). Due to the noted interplay between energy and protein intake and given that this interaction is more noticeable in corn residue grazing situations due to diet selectivity and the lower quality of the forage, supplementation strategies must be considered to determine how best to meet nutritional requirements.

In addition to protein, Anderson et al. (1988) demonstrated that supplemental energy is also required to increase performance for growing calves that are grazing corn residue. Using five trials with both growing steers and heifers (trial averages ranged from 189 to 256 kg BW) on either brome pasture or winter corn residue, the authors compare soybean hulls or rolled corn to no energy supplement. Two of the five trials also offered a 51.5% CP supplement at 0.45 kg/d which consisted of soybean meal and corn gluten meal to meet protein requirements (Anderson et al., 1988). In these two trials, when cattle were grazing corn residue, both corn and soybean hull energy supplements resulted in faster initial daily gains (within the first 67 d) and greater overall gains were observed for both energy supplements compared to the control. Additionally, soybean hulls tended to support even higher gains than ground corn due to potential acidosis challenges with corn (Anderson et al., 1988). The benefit of additional energy with protein can be seen in work done by Jordan et al. (2001), where wet corn gluten feed (NEg value of approximately 0.30 Mcal/kg and averaging 23% CP) was fed to 250 kg steers grazing corn residue in the late fall and early winter at seven increasing levels (0.90 to 2.95 kg/hd/d in increments of 0.34 kg). After developing a response curve, the authors found that ADG increased from

0.41 to 0.84 kg/d as supplementation increased up to 2.72 kg/hd/d, after which no significant additional gain was observed (Jordan et al., 2001). This demonstrates that even when CP is not limiting, additional fermentable energy is still required in order to maximize microbial protein production and satisfy overall MP requirements.

Strategies for how best to meet both protein and energy needs were revolutionized with the introduction of corn ethanol co-products that became widely available during the "Ethanol Decade," particularly dried distillers grains with solubles (DDGS). Although spent brewers grains and distillers grains from the liquor industry had been fed to ruminant livestock on an industrial scale prior to this period, use was limited to geographical location to beer or alcohol distilleries and generally utilized only in dairy cattle diets (Murdock 1981; Firkins et al., 1985). However, with the advent of fuel ethanol, a relatively novel and unique feed stuff became more readily available. Both DDG and DDGS can be used as both an energy (104-108% TDN) and a protein (31-32% CP) supplement that can be high in RUP (38- 72% of CP; Li et al., 2012). This supports a response to overall metabolizable protein, allowing the animal to meet growth requirements more effectively than traditional supplements, such as molasses with urea, that do not support RUP requirements of growing cattle (Ham et al., 1994; Vander Pol et al., 2006; MacDonald et al., 2007).

The advantage of DDGS as an energy and RUP protein source when grazing corn residue was evaluated by Tibbitts et al. (2016). Growing steers (234 kg BW) were supplemented at equivalent TDN levels (targeting 1.42 kg of TDN per hd per day) with either dry rolled corn (DRC), DRC with RDP (urea), a blend of 60/40 Soy-Pass (non-enzymatically browned soybean meal as a source of RUP) and soybean meal, or DDGS

and compared to un-supplemented cattle. Animal performance increased significantly from control to the different supplement strategies with ADG for DRC < DRC+urea < DDGS < Soypass increasing from 0.14 to 0.67 kg/d (Tibbetts et al., 2016). The RDP balance in g/d was -235, 7, -161, and -1 for the respective treatments, but the MP balance based on gains observed was 126, 93, 144 and 258 g/d. The DRC+urea supplement improved gains over the straight corn (energy) supplement, establishing once again a clear need for protein for growing cattle grazing corn residue. However, the additional increase in performance with DDGS and the RUP/RDP protein supplement provides evidence that the nature of protein supplemented with energy is critical to meet metabolizable protein requirements (Tibbetts et al., 2016). These results show that DDGS is a valuable supplement for growing calves because it provides both energy and RUP to sufficiently meet MP requirements, and are further supported by a pooled analysis of three trials of calves grazing corn residue which show a quadratic increase in ADG to DDGS (Welchons and MacDonald, 2017).

Other investigations focused on supplementing DDG to growing cattle and developing heifers also show DDGS supplementation supporting increased gains for cattle grazing corn residue, native range, or bromegrass pasture (Gustad et al., 2006; Stalker et al., 2006; Jenkins et al., 2009; Rolfe et al., 2010; Ahern et al., 2011; Van de Kerckhove et al., 2011; Warner et al., 2011; Griffen et al., 2012; Tibbitts et al., 2016). A meta-analysis summarizes the effect of DDGS specifically on growing steers on a high-forage diet, showing that ADG and final BW increases linearly with DDGS supplementation when on pasture and responds quadratically when supplemented in confinement on high-forage diets (Griffen et al., 2012). Furthermore, the authors noted

that in confinement studies where intake was measured, total intake increased linearly with DDGS intake, but forage intake decreased, suggesting that DDGS supplementation replaces forage source in diets (Griffen et al., 2012). Specifically when looking at supplementation for cattle on corn residue, Gustad et al. (2006) found that steer calves (232 kg BW) fed increasing levels of DDGS increased ADG by a range 0.41 - 0.82 kg/d when supplemented at 0.29- 1.27% of BW (six treatment levels).

The response to supplementation of cows and heifers grazing corn residue is less predictable. Previous work supplementing cows in late gestation and lactation on native range (Nebraska Sandhills) with protein (50% sunflower meal, 47.9% cottonseed meal and 2.1% urea at 1.06 kg/hd every other day) found an improvement in BCS over the winter, increased weaning weights, and percent of calves weaned, but the additional protein did not improve subsequent pregnancy rates of cows (Stalker et al., 2006; Stalker et al., 2007). Furthermore, when Martin et al. (2007) evaluated the reproductive performance of heifer progeny from dams supplemented in this system, they found increased pregnancy rates and more heifers calving in the first 21 d of the calving season (despite similar age at puberty). This provides evidence of some positive fetal programming effects due to maternal cow nutrition on native range, despite no direct improvement of cow reproductive performance. However, when cows grazing corn residue were offered a DDGS supplement as a cube in late gestation, cow BCS was improved but it did not affecting calving interval, calf birth weight, calf weaning weight, or the reproductive performance of the heifer progeny (Warner et al., 2011). To investigate this difference more specifically, a comparison of winter grazing systems with late gestation cows was conducted comparing grazing native range or corn residue with

or without a DDGS protein supplement cube (31% CP, 47.6% RUP of CP) provided at 0.40 kg/d. The authors found that cows grazing corn residue both with and without DDGS supplementation had increased calf weaning weights compared to cows that were not supplemented on winter range (Larson et al., 2009; Funston et al., 2010; Larson et al., 2011). Supplementation also increased calf weaning weight and had a tendency to decrease age at puberty regardless of grazing system, but only the heifers from dams grazing corn residue with protein supplementation had significantly lower G:F ratio (an improvement, incidentally, that was not observed in the steer progeny, despite improved carcass quality grades). Therefore, the authors conclude that heifers from dams who were supplemented with DDGS while grazing corn residue were the most adequately nourished group when compared to heifers from dams grazing native range with or without supplementation, and this system had observable fetal programming effects on both heifer and steer progeny (Larson et al., 2009; Funston et al, 2010; Larson et al., 2011).

Overall, the value of a corn residue grazing system as an economical resource for either backgrounding calves or cows cannot be overstated (Redfearn et al., 2019). The low cost of renting corn residue acres and providing the DDGS offers a unique and cost-effective system for livestock production (Klopfenstein, 1987; Watson et al., 2011).

Baling Corn Residues

While grazing corn residue is considered the most efficient and economical strategy for feasibly integrating livestock into a cash cropping system, there are several advantages to baling crop residue for utilization (Ward, 1978). For instance, baling crop residue allows for feeding when summer pastures are spent, when winter feed resources

are low, or in confined feeding situations where grazing is unavailable (Ward, 1978). Some studies have shown that baling will result in greater residue removal than grazing, resulting in reduced SOC and increased propensity for water and wind erosion (Blanco-Canqui et al., 2016a; Blanco-Canqui et al., 2016b; Ruis et al., 2017). Despite this, evidence suggests that there is no difference between grazing and baling with regards to impacts on subsequent crop yields (van Donk et al., 2012; Ulmer et al., 2018). As discussed earlier, recommended residue removal rates vary depending on tillage method, soil type and current soil properties, geography, topography and crop rotation, ranging between 20-65% (Lindwall, 1994). However, even “complete” removal of corn stover through raking and baling results in removal of up to ranges between 20 and 70% of estimated available residue (Sokhansanj et al., 2002). Depending on machinery, field conditions, and tillage, baling can effectively remove valuable residue without negatively affecting yields, despite increased erosion potential, although removal rates must be carefully monitored on a situational basis.

Improving the feeding value of baled residue is key to compensating for increased costs of transportation, storage and potential long-term soil tilth costs. Chemical treatment of bales is one such method. However, as noted by Klopfenstein et al. (1987), the increased cost of quality improvement of baled residue is not always economical based on market prices of bales, chemicals and labor. Depending on the current economic climate, chemical treatment is an important factor to discuss when exploring additional methods of crop-livestock integration for crop producers without infrastructure or labor to allow grazing.

Chemical Treatment of Baled Corn Residue

Chemical treatment of low-quality forages improves the digestibility of the forage by altering different aspects of the chemical structure of the plant fibers. Treatments that have been historically investigated with regards to corn residue include sodium hydroxide, calcium hydroxide, potassium hydroxide, and ammonium hydroxide via anhydrous or aqueous ammonia saturation (Jackson, 1977; Klopfenstein, 1978; Van Soest et al., 1984). More recently, the ethanol industry has investigated novel chemical and mechanical techniques to capture more fermentable carbohydrates for cellulosic ethanol production, including pressurized steam fiber expansion with ammonia (AFEX), enzymatic pre-treatment and catalytic pyrolysis (heating rapidly under anaerobic conditions) (Barl et al., 1991; Kim et al., 2003 Uzun and Sarioğlu., 2009; Uppugundla et al., 2014). While our ability to measure precise chemical response has improved over the decades, our understanding of the principles of chemical treatment of forages has remained essentially unchanged, albeit more detailed. The strong alkali oxidation during the treatment process acts on forages in three ways: a) the hydrolysis of the H-bonds associated with the crystallinity of the β-sheets of cellulose, thereby “swelling” the sheets and creating space for enzymatic activity; b) the hydrolysis of uronic and acetic acid esters which partially solubilizes the entangled digestible structural carbohydrates (particularly hemicellulose) with indigestible lignin and silica; and c) the increased hydration of the forage to facilitate the ammoniation reaction increases rate and extent of bacterial colonialization thus ruminal fiber digestion (Jackson, 1977; Klopfenstein, 1978; Berger et al., 1994).

With chemical treatment of low-quality forages, including corn residue, there is a well-established and marked improvement in digestibility, intake, and animal

performance (Grotheer and Cross, 1986; Saenger et al., 1982). There is some variation in the efficacy between the different methods of chemical treatment, as noted by Klopfenstein (1987). When corn cobs treated with ammonium hydroxide (4% DM) were mixed in equal proportion with cobs treated with a 3:1 ratio of sodium and calcium hydroxide were fed to lambs, they gained equivalently to lambs fed cobs treated with only 4% sodium hydroxide (Klopfenstein, 1987). However, both groups were less efficient than the group fed only cobs with the 3:1 ratio, leading the authors to observe that ammonia treatment is effective, but not as effective as treatment with sodium and calcium (Klopfenstein, 1987). Other work with cattle showed cobs treated at 4% DM with ammonium hydroxide were mixed instead with calcium treated cobs (instead of the 3:1 cob mixture), the ammonia treatment resulted in similar gains to the 4% sodium treated cobs, but both performed better than 4% calcium treated cobs. Regardless of degree of efficacy, there are advantages of ammonia treatment over both sodium, calcium and potassium treatment. Residual nitrogen from the ammonia treatment can be utilized by rumen microbes as NPN, there is no risk of mineral residues in the forage which could affect animal metabolism or manure (and subsequently soil deposits), and ammonia treatment is an effective forage preservative which prevents molding, heating, and dry matter loss when stored (Knapp et al., 1975; Klopfenstein, 1987).

When this research was initially conducted (1970-1980), the annual average price for baled hay was between $20-50/ ton in Nebraska, and anhydrous ammonia cost was increasing sharply from $75/ton to $229/ton (average $156.90) (UNL Crop Watch). When adjusted for inflation, hay was priced at $133.18-$161.77/ton and ammonia was $499.43-740.90, suggesting the cost to ammoniate low-quality forages was not

competitive with the cost of medium to high-quality forages (USDA, 2019; Bureau of Labor and Statistics, 2019). As of February 2019, moderate quality hay was being sold at \$100.00-130.00/ ton, corn residue bales at \$52.50-60.00, and anhydrous ammonia prices between \$496.00-512.00/ton (Schnitkey, 2018; USDA, 2019). With the addition of marketable corn stalk bales, affordable low-quality forage and reasonable chemical prices suggest potential economic advantages to ammoniating and feeding baled corn residue.

Although an in-depth economic analysis has yet to be conducted exploring the boundaries of profitability and feeding value of ammoniated corn bales, quantifying the effect of ammonia treatment on corn residue bales has prior substantive work. Ammoniation of low-quality forages has been shown to increase forage digestibility, increase animal intake, and increase animal gains (Knapp et al., 1975; Jackson, 1977; Garrett et al., 1979; Jayasuriya et al., 1982; Saenger et al., 1982; Klopfenstein et al., 1987; Oliveros et al., 1993; Fahmy and Klopfenstein, 1994; Sewalt et al., 1996; Oji et al., 2007; Ramirez et al., 2007; Ali et al., 2009). Berger et al. (1994) cite 21 studies and report that NH_3 treatment resulted in an average increase in DMI of 22%, and 32 summarized studies showed DM digestibility on average increased by 15%.

The increase in forage digestibility is the most direct measurable response to chemical treatment, subsequently leading to observed increases in intake and gain. Digestibility kinetics are affected by chemical treatment, where increased digestibility corresponds with an increase in particulate passage rate and therefore intake (Oliveros et al., 1993; Berger et al., 1979). This response and relationship between digestibility and intake has been noted in chemically treated residue, where alkali treated corn stover was fed to lambs at 2% NaOH: 2% $Ca(OH)_2$, or 3% and 5% NH_3 DM, and the authors noted a

45-51% increase in organic matter intake and a 11-16% increase in organic matter digestibility (Oji et al., 1977). When Berger et al. (1979) fed cattle early and late harvested corn stalklage treated at 3:1 NaOH and Ca $(OH)_2$ at 4% DM, they observed a 12-17% increase in *in vitro* DM disappearance, which corresponded with a 4-13% increase in DMI and a 16-38% increase in average daily gain. Additionally, Saenger et al. (1982) ammoniated corn stover at 2% DM and found that the DMI of yearling steers increased by 24-31% and dry matter digestibility increased by 10-12% when fed ammoniated corn stover and compared to untreated stover supplemented with either corn or soybean meal (at 0.4% of BW). Paterson et al. (1981) fed *ad libitum* corn residue that was ammoniated at either 2, 3, or 4% of DM with anhydrous NH_3 to lambs (supplemented with blood meal at 3.3% of diet DM) and compared DMI to non-ammoniated corn stalks (fed with 3.3% blood meal and 1% urea), intake increased linearly with level of ammoniation from 398 g/d for untreated corn stalks increasing to 698, 777, and 997 g/d for the ammoniated corn stalks.

Due to the proposed mechanism of action of ammoniation, the correlation between "quality" of the forage and effectiveness of the chemical treatment is inversely related. The very components of the plant cell wall that are correlated with reduced digestibility, specifically lignin, are the target of alkali oxidation reactions, making more highly-lignified materials more responsive to chemical treatments (Cross et al., 1974; Van Soest et al., 1984 Jung et al., 1992; Bals et al., 2010). However, early work done by Van Soest et al. (1984) show that when eight different straws and forages were ammoniated, saponification values of the treated forages correlated with the digestibility of the forage, whereas the optical density values of the untreated forages correlated better

with digestibility, suggesting differences in digestibility are due to more than the phenolic residues (lignification). Bals et al. (2010) was able to quantify this variability between forages using the AFEX method of chemical treatment (ammonia fiber expansion). The authors used AFEX (exposing aqueous ammonia to material at 80-150 ˚C at 200-400 psi, then releasing the pressure rapidly to cause a rupture of the cell wall structure) to treat eleven ruminant feedstuffs which included corn silage, alfalfa, orchardgrass hay, rice straw, forage sorghum, corn residue, wheat straw, sugarcane bagasse, miscanthus, and two different varieties of switchgrass at early or late harvest. Although differences between forages were not statistically compared, the differences between the treated and untreated forages showed a slight linear trend ($r^2 = 0.348$, $P = 0.052$) between initial concentration of NDF and the amount of NDF removed due to treatment (Bals et al., 2010). This is illustrated more clearly when comparing the improvement in 48h NDF digestibility, with no difference in the treated and untreated corn silage, alfalfa hay, orchardgrass hay and early harvested switchgrass, with percent changes ranging between -2 and 32%. However, lower-quality forages such as rice straw, wheat straw, and corn residue showed increased digestibility of 46, 63, and 52% respectively (Bals et al., 2010). This study establishes a measurable connection between the initial indigestibility of the forage and the subsequent responsiveness to ammoniation, however it also illustrates that there is not one specific component of cell walls which can directly predict susceptibility to chemical treatment (or digestibility for that matter). However, NDF content and extent of lignification are generally appropriate indicators.

Given this difference between forage types response to ammoniation correlating with the digestibility, and the established difference in corn residue digestibility, there is

some foundation for a hypothesis that different corn plant parts will respond differently to chemical treatment. Klopfenstien (1987) noted that residues from different plant species respond differently in magnitude to chemical treatment when compared to corn cobs, and attributed this to mode of action. However there is some evidence that while the mode of action is the same, the susceptibility of different plant parts (and species) is a function of differences in the composition of the cell wall matrix. For example, when Sewalt et al. (1996) compared the composition and degradability of corn leaves and stems, they found that ammonia treatment increased the extent of fiber degradation for both plant parts, but only leaves showed decreased concentrations of hemicellulose (particularly arabinose residues) and increased rate of fiber digestion. This difference between plant parts was also seen when Ramírez et al. (2007) treated corn residue and corn cobs with feed grade urea at 0%, 4.5%, and 6% of DM. The authors found that the *in situ* effective degradability of DM (EDDM) of the treated residue increased by 14.6% and 26% over the control for residue, and by 55.0% and 40.0% for lambs fed cobs. They also found that the corn residue responded linearly to level of chemical treatment, but there was no difference in response to corn cobs between the 4.5% and 6% levels of treatment, suggesting cobs reached the maximum threshold of response (which was considerably greater) at lower levels of treatment than the whole residue (Ramirez et al., 2007). Conversely, Oji et al. (2007) treated corn husks, cobs, and stems with an aqueous ammonia and feed grade urea at 3% of DM and found that while treatment improved the IVDMD by 14% to 15% for stems, 16% to 17% for husks, and 14% to 15% for cobs, there was no difference in response to treatment between the different parts. In biofuel research, however, Duguid et al. (2009) investigated the response of fractionated corn

plant parts to 0.8% NaOH pre-treatment on cell-wall component release for ethanol fermentation, and found that husk, leaf and cob responded best to pre-treatment while the bottom part of the stem released significantly less glucan and xylan. Furthermore, Cui et al. (2012) examined the effect of a fungal pretreatment of leaf, stem and cob, and found that leaves showed the greatest response to pre-treatment as measured by lignin degradation (45%), while stem and cob were similarly recalcitrant to lignin, glycan and xylan degradation. Despite this, cob still yielded significantly more sugars upon enzymatic degradation than leaf or stem. While these studies do not show consistent responses of different plant parts, they do provide evidence that structural differences in the cell wall matrix will yield variable response in susceptibility to chemical treatment, perhaps accounting for differences in response between species and plant parts. Moreover, there is limited information on measurable markers that may be used to predict susceptibility to chemical treatment.

Another potential reason that variation exists in response to chemical treatment could be due to the effectiveness of the process itself. Ammoniation is a temperature dependent reaction, and temperature, moisture level of the forage, and the length of time the forage is exposed to treatment will all affect the extent of the reaction process (Cloete and Kritzinger, 1984; Schneider and Flachowsky, 1989). Investigations with wheat straw demonstrate that interactions between all three variables exist. Cloete and Kritzinger (1984) found that IVOMD was lower for straw ammoniated at 4 ˚C at both 25 and 37.5% moisture after 8 weeks of treatment. Also, the work demonstrated that increasing the temperature to 14 ˚C resulted in lower IVOMD for only the 25% moisture treatment, and that increased moisture resulted in acceleration of the ammoniation process at higher

temperatures. Additionally, they reported that shorter treatment times (1-2 weeks) at 35 ˚C resulted in comparable IVOMD values to straw ammoniated at 24 ˚C for a period of 6 weeks (Cloete and Kritzinger (1984). Similar observations were made by Schneider and Flachowsky (1989). Significant interactions between treatment duration and temperature led to their observation that the optimal conditions for ammoniating wheat straw to achieve maximum rumen dry matter digestibility would be at a rate of 3.0-4.5% DM with a moisture content of 30% at a temperature between 40-60 ˚C. Length of time only improved the response at temperatures lower than 55 ˚C, and increasing moisture level resulted in greater DMD (Schneider and Flachowsky, 1989). The effect of moisture, while not specifically investigated, could provide some explanation as to the differences in response between plant parts or species. Unless the treated material is uniformly brought to the same DM content with the addition of water, there could be inherent differences in the DM content of the parts which make them more or less susceptible to treatment.

Opportunities for livestock integration and gaps in knowledge

There are several key points to summarize from this review of the literature in order to address the gaps in knowledge and potential directions for future research. First, unique economic and cultural factors at the beginning of the 21st century resulted in an increase in demand for ethanol biofuels. The subsequent impacts of this has produced rippled effects throughout the agricultural sector manifesting in greater corn production and corn prices, reduced forage resources and increasing the cost of historical feeding practices substantially. In these climatic conditions, livestock producers have been able to take advantage of increased corn residue as a forage source for both grazing and baling,

and the ethanol co-products as a unique protein and energy supplement that is competitively priced with corn.

This situation has further prompted interest regarding ways to move away from specialized production systems and investigate ways in which livestock can be integrated in to modern cropping systems. Although integrated systems are not a new practice, there has been a renewed research effort into identifying economically feasible and agronomically sustainable management strategies to achieve modern integration. Work to this end has found that utilization of crop residues through grazing or baling can be economically viable. Specifically, corn residue removal in no-till and strip-till systems can be left at rates between 50-80% to provide soil tilth benefits, while still providing a proportion of residue for animal utilization. Grazing this residue is the most economical, despite different classes of cattle that may require additional protein and/or energy supplementation. Grazing cattle can affect the soil physical properties such as bulk density and penetration resistance, but there is little evidence to support the producer perception that this effect will have a negative impact on subsequent crop yields. Baling the residue for removal is also a viable use for livestock integration. Chemical treatment of the crop residue bales will increase the digestibility of the low-quality forage, resulting in increased intake and average daily gain. However, the magnitude of effect can vary between forage species, chemical type and treatment processing factors such as time, temperature and forage moisture.

When looking at future avenues of investigation in this area, there are several clear gaps in knowledge. A better understanding of the impact that grazing cattle can have on soil physical properties is needed. This includes relationships between soil type

characteristics, soil microbial community, and the potential influence that cover crop or double cropped annual forages grazed by cattle may have on the interaction of grazing cattle and subsequent crop production. For instance, a valuable meta-analysis would be to evaluate available literature and regress soil physical property measurement changes due to cattle grazing against soil type, cattle class, time of year and stocking rate. Similarly, there is a need to further explore agronomic thresholds that take into account time of year, weather, soil type, tillage practices, and the forage being grazed to establish improved recommendations for producers. There is also opportunity to explore ways to improve the baled corn residue. Harvest practices that mimic the selective grazing behavior of cattle to provide a higher-quality bale to livestock should be explored, which would capitalize on the inherent variability in plant part digestibility noted by previous studies. Furthermore, a better understanding of how physical characteristics of the plant alter the response to chemical treatment should also be explored. Given that chemical treatment is not always economical, establishing measurable forage characteristics that correspond with greater feeding value extracted from the treatment of said forage would be valuable. However, there is not enough information to define specific relationships between plant part digestibility, chemical composition and susceptibility to chemical treatment.

Overall, there remains a wealth of opportunity with regards to integrating livestock into modern cropping systems and enhancing agricultural diversification. Particularly focusing on different ways to utilize crop residues, especially corn residue, can offer substantial value to the cattle industry and our food production system as a whole.

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

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Published: Feb. 2019. Translational Animal Science. 3(1). doi.org/10.1093/tas/txz013.

ABSTRACT:

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

trend. Both IVDMD and IVOMD of the residue were affected ($P < 0.01$) by harvest method, with 2ROW being greater ($P < 0.01$) than both CONV and 8ROW. For IVDMD, 8ROW was not ($P = 0.77$) different from CONV, but was lower ($P = 0.03$) than conventional for IVOMD. Ammoniation improved ($P < 0.01$) DM, OM, NDF, and ADF digestibility of all harvest methods, resulting in a 26% increase ($P < 0.01$) in DE due to ammoniation. Similar digestibility improvements were observed *in vitro* with ammoniation improving IVDMD and IVOMD by 23% and 20%, respectively. Both selective harvest methods and ammoniation can improve the feeding value of baled corn residue.

INTRODUCTION:

Corn residue has been a valuable low-cost feed resource for cattle for many decades (Ward, 1978; Klopfenstein et al., 1987). More recently, the U.S. ethanol industry expansion from 2000 to 2009 resulted in the conversion of perennial pasture and hay acres to more high-value corn acres, which lead to reduced perennial forage resources but increased availability of corn residue in the Midwestern region of the United States (Wallander et al., 2011). Additionally, demand for substrate for the cellulosic ethanol industry resulted in a robust market for baled corn residue (Wilhelm et al., 2007). Survey data indicate 0.81 million ha in the U.S. were baled in 2010 (Schmer et al., 2017), and usage of baled corn residue in combination with ethanol byproducts has increased in growing and finishing diets in the Midwest (Klopfenstein et al., 2013).

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

rows chopped and added to the windrow) produces a more digestible bale when compared to conventionally harvested rake-and-bale (King et al., 2017).

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

MATERIALS AND METHODS:

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

Corn Residue Harvest and Ammoniation

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

Lamb digestibility trial

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

Diets consisted of 64.2% corn residue, 29.8% wet corn gluten feed (Sweet Bran, Cargill Wet Milling, Blair, NE), 3.3% smooth bromegrass hay, 0.75% limestone, and 2.0% trace mineral supplement on a DM basis (Table 2.1). The nutrient composition of the diets and the individual residues is reported in Table 2.2. Diets were fed over six 21 d periods which consisted of 14 d adaptation and 7 d total fecal collection. Lambs were fed *ad libitum* (110% of the previous day's DMI) during d 1-12 and reduced to 95% of *ad libitum* intake for d 13-21. Feeding occurred twice daily at approximately 0800 and 1500, and feed refusals were collected, weighed, and fed back during the adaptation period. Intakes were recorded daily, and values from d 7-11 were used for analysis of total diet intake. During the adaptation period, lambs were housed in individual pens with grate floors, individual feed bunks and automatic spout waterers, with each pen measuring approximately 1.5 m x 1 m.

At the end of the diet adaption period, lambs were moved to individual metabolism crates and fitted with harnesses and fecal collection bags. Prior to the beginning of the study, the lambs were trained and adapted to the metabolism crates and fecal bags. Total fecal output was collected twice daily beginning on d 14 at approximately 0800 and 1500, weighed and retained in a 2.7˚C cooler for the duration of

the collection period. Feed refusals were collected at feeding, weighed to determine feed allocation for the day, fed back, and any orts remaining at the end of the collection period were retained for analysis. Both fecal material and refusals were composited by lamb at the end of the collection period and three sub-samples were taken for analysis. Samples were dried in a 60˚C forced air oven (orts for 48 h and feces for 72 h) and then ground through a 1 mm screen in a Wiley mill.

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

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

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

In Vitro Digestibility

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

Statistical analysis

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

mean used in the statistical analysis was the average of each sample across the two runs. Treatment and harvest method were analyzed at fixed effects. The interaction between harvest method and treatment was initially included in the model but was removed as it was not significant.

RESULTS:

There was a harvest method by ammoniation interaction ($P < 0.01$) for *ad libitum* DMI (d 7-11) of lambs. Ammoniation increased intake for all harvest methods compared to non-ammoniated residue intake, but the amount of response varied among harvest method. The intake of diets containing non-ammoniated residue did not differ ($P \geq 0.92$) among harvest methods at 2.6% BW (Figure 2.1), but ammoniated residue intake was greatest for 2RAM at 4.1% BW, intermediate for COVAM at 3.6% BW and 3.1% BW for 8RAM, which were all different ($P = 0.03$) from each other as well as the non-ammoniated diets.

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

residue. The ADF digestibility of the residue was affected (*P* < 0.01) by harvest method. There was a numerical increase in ADFD of 4.6% (2.3 percentage units; *P* = 0.40) from CONV to 8ROW, and a 23.6% (11.7 percentage units; *P* < 0.01) increase from CONV to 2ROW. There was no effect (*P* = 0.30) of harvest method on DE.

Ammoniation improved (*P* < 0.01) DM, OM, NDF, and ADF digestibility of all harvest methods, resulting in a 24%, 21%, 37% and 19.6% increase, respectively (Table 2.3). Similarly, there was a 26% (*P* < 0.01) improvement in DE due to ammoniation.

There was no interaction (*P* > 0.34) between harvest method and ammoniation for IVDMD or IVOMD (Table 2.4). Both harvest method and ammoniation affected (*P* < 0.01) IVDMD and IVOMD of the corn residue. For IVDMD, there was no difference (*P* = 0.69) between CONV and 8ROW, but 2ROW was 14% more (*P* < 0.01) digestible than the other harvest methods. The IVDMD of the ammoniated residue increased (*P* < 0.01) by 20% when compared to the non-ammoniated residue. This pattern was similar to IVOMD, where the 2ROW residue was greater (*P* < 0.01) than both 8ROW and CONV, with only a tendency (*P* = 0.08) for the latter two to be different. The IVOMD of the ammoniated residue was 20% greater (*P* < 0.01) than the non-ammoniated residue.

DISCUSSION:

New corn harvesting and baling technologies designed to improve field efficiency have emerged to meet agronomic demands for more versatile equipment. Implements such as the New Holland Cornrower, while not specifically designed with the intention of selective harvest, will produce a bale with altered proportions of various plant parts by decreasing the number of rows of chopped stem added to the windrow while forming a mat for the tailings of husk and cob. Theoretically, this decreases the proportion of less

digestible part (stem) to more digestible corn plant parts in the subsequent bale (Gutierrez-Ornelas and Klopfenstein, 1991). Based on this, digestibility of the baled residue should be improved when stem is decreased and/or husk is increased, and the digestibility values presented in this study for the non-ammoniated residue bales are consistent with previous work investigating this selective harvest method (King et al., 2017).

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

It should be noted that in the current study and that of King et al. (2017), the *in vivo* values were determined using lambs as a model for total tract digestibility. Therefore, these data should only constitute comparative values for residues as they are not representative of digestibility that would be observed when fed to cattle given that sheep are less efficient at digesting low-quality forages than cattle (Prigge et al.,1984;

Soto-Navarro et al., 2014). Similar to what was observed by King et al. (2017), the *in vitro* values were numerically greater than the *in vivo* values though the pattern and relative differences among treatments remained consistent.

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

Paterson et al. (1981) fed *ad libitum* corn residues that were ammoniated at either 2, 3, or 4% of DM with anhydrous ammonia to lambs (supplemented with blood meal at 3.3% of diet DM) and compared DMI to non-ammoniated corn residue (fed with 3.3%

blood meal and 1% urea). The intake increased linearly ($P < 0.05$) with level of ammoniation, with the increase from non-ammoniated residue to the 4% ammoniated residue being 150% (398 to 997 g/d). Given that urea was provided to lambs fed the non-ammoniated residue this response is likely only due to changes in the accessibility of the structural carbohydrates as a result of the ammoniation process. Similarly, in the present study, the RDP available in the non-ammoniated diets would not have been limiting and thus the improvement in intake was due to accessibility of the structural carbohydrates when the residue was ammoniated.

The novel aspect of this trial was to determine if harvest method and ammoniation would interact resulting in differential responses among harvest methods to ammoniation. Although the overall effect of ammoniation between the treated and untreated bales was not unexpected, the working hypothesis was that the effect would be lower in magnitude for the more digestible harvest methods. However, 2ROW appeared to have a similar response to ammoniation with a 10.5% unit increase in DM digestibility compared to 8.8% and 11.3% for CONV and 8ROW, respectively. This lead to an additive response with the 2RAM (56.9%) being 16.6% units greater in DM digestibility than the CONV (40.3%). There is no available literature on the effect of ammoniation with selective harvest methods and the data available on the potential for differential responses of the various corn plant parts to chemical treatment is inconsistent. There is some evidence to suggest that corn plant parts respond to ammoniation to different degrees. Ramírez et al. (2007) ammoniated corn residue and corn cobs with feed grade urea at 0, 4.5, and 6% of DM, and showed that the *in situ* effective degradability of DM (EDDM) in lambs increased by 14.6% and 26% over the control for residue, and by 55.0% and 40.0% for

cobs as ammoniation level increased. The corn residue responded linearly, but the corn cobs did not, with both the 4.5% and 6% levels of ammoniation being not different ($P >$ 0.05) from each other. This suggests that not only do cobs show greater improvement in digestibility due to chemical treatment, but they also reached their maximum capacity for chemical reaction before the whole corn residue, raising the possibility that the inherent differences in the cellular structure of the different corn plant parts means that each part will respond differently to chemical treatment (Grabber, 2005). Conversely, Oji et al. (2007) treated corn husks, cobs, and stems with an aqueous ammonia and feed grade urea at 3% of DM, and found that while the improvement in IVDMD was statistically greater than untreated control plant parts, but there was no statistical difference between the three different plant parts. There was no interaction observed between the different plant parts, and numerical differences observed in IVDMD were 14-15% increase for stems, 16-17% increase for husks, and 14-15% improvement for cobs. While there no clear reason for the different responses in these two studies, it illustrates the need for more targeted investigation into the potential differential response of corn plant parts to chemical ammonia treatment.

In the present study, there was an interaction between harvest method and ammoniation for DMI, with ammoniation increasing DMI by 57.7% for 2RAM, 38.5% for COVAM, and by 19.2% for 8RAM. This differential response again suggests an additive effect of ammoniation although the interaction was not detectible in total tract or *in vitro* digestibility. This could be due to the changes in plant part proportion and different response on animal intake for each of the different plant parts when ammoniated. The 2ROW would have the lowest proportion of stem relative to CONV

and 8ROW, and the greatest proportion of cob. Also, it has been suggested that the 8ROW would preserve more tailings (cob, leaf, and husk) for baling and thus the proportion of stem harvested may be less. However, the intake and digestibility data suggests that there was not an advantage of the 8ROW over CONV. There was a qualitative observation that the animals ate the ammoniated residue with greater enthusiasm and less sorting when ammoniated, particularly the ammoniated cobs. This suggests that the DMI response may be due not only to changes in digestibility but also to changes in palatability, however, this was not measured. Once again, the evidence is not clear as to whether ammoniation will affect corn plant parts differentially, and this should be explored further.

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

CONCLUSIONS:

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

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Table 2.1. Composition of six treatment diets fed to lambs consisting of three differently harvested corn residues with and without ammoniation. Corn residue utilized was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower[1] header with all eight rows of corn plant added to the windrow (8ROW), or with only two rows added to the windrow (2ROW).

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

[1] New Holland, Craig Welding, Mentone, IN
[2] Ammoniated diets were formulated using portions of the same residue that was ammoniated at 5.5% DM (COVAM, 8RAM, and 2RAM).
[3] Sweet Bran, Cargill Wet Milling, Blair, NE
[4] Supplement consisted of 0.75% limestone and 2.0% commercial sheep trace mineral.

Table 2.2. Nutrient composition of total diet and corn residue based on laboratory analysis. Corn residue utilized was harvested using harvest methods of either conventionally harvested rake-and-bale (CONV), New Holland Cornrower[1] header with all eight rows of corn plant added to the windrow (8ROW), or with only two rows added to the windrow (2ROW). Ammoniated diets were formulated using portions of the same residue that was ammoniated at 5.5% DM (COVAM, 8RAM, and 2RAM).

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

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

Table 2.3. Effect of harvest method (HM) and ammoniation (AM) on total tract DM, OM, NDF, and ADF digestibility[1], and DE content of the corn residue component of the diet fed to lambs.

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

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

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

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

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

Table 2.4. Effect of harvest method (HM) and ammoniation (AM) on *in vitro* DM and OM digestibility of corn residue.

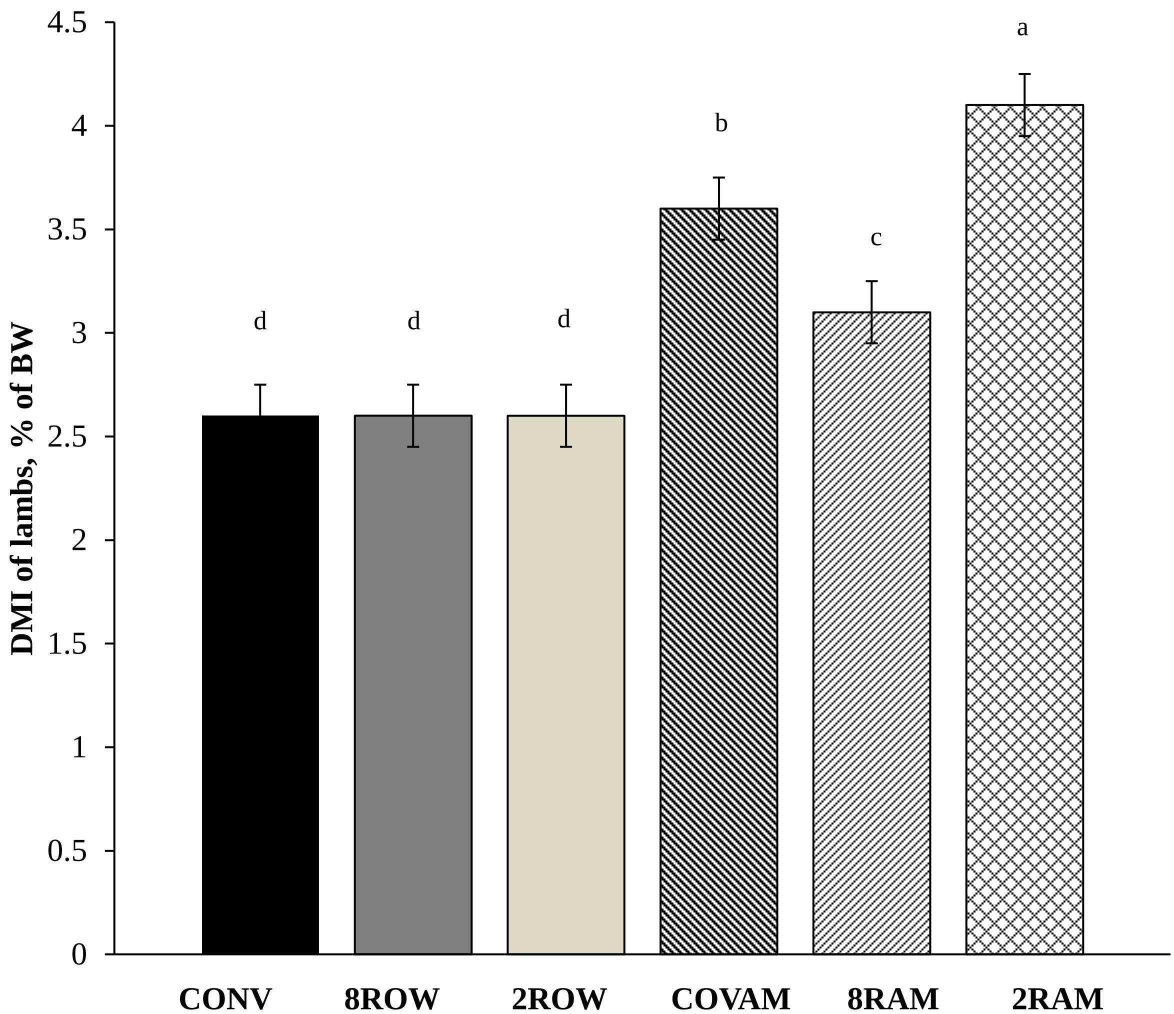
	Harvest method[1]			Treatment[2]			*P-values*[3]	
	CONV	8ROW	2ROW	UNAM	AMM	SEM	HM	AM
IVDMD, %	52.0[b]	51.8[b]	59.1[a]	49.3[B]	59.3[A]	0.53	<0.01	<0.01
IVOMD, %	56.9[b]	55.5[b]	62.8[a]	53.5[B]	63.3[A]	0.71	<0.01	<0.01

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

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

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

Figure 2.1. Dry matter intake (*ad libitum*) of total diet for lambs when fed diets containing corn residue at 64% of diet DM that was harvested using either rake-and-bale (CONV), New Holland Cornrower header (Craig Welding, Mentone, IN) with all eight rows of corn plant added to the windrow (8ROW), or New Holland Cornrower header with only two rows added to the windrow (2ROW). Ammoniated diets (COVAM, 8RAM or 2RAM) utilized corn residue from the same harvest methods, but were treated with anhydrous ammonia at 5.5% of DM. There was a harvest method by ammoniation interaction ($P < 0.01$). Bars lacking common superscripts are significantly different from each other ($P < 0.05$).



CHAPTER III: Effect of harvest method and ammoniation of baled corn residue on *in vitro* digestibility, intake and performance in growing beef cattle

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ABSTRACT:

In order to assess the feeding value of corn residue harvested using three different methods, with or without ammoniation, an *in vitro* incubation in conjunction with a growing calf feeding trial were conducted. The feeding trial was a randomized complete block design study with a 2 x 3 factorial treatment structure utilizing 120 crossbred steers (319 ± 22 kg). Animals were individually fed for 82 d via Calan gates one of six diets containing 65% of either untreated or ammoniated baled corn residue harvested one of three ways: conventionally harvested rake-and-bale method (CONV), harvested using the New Holland Cornrower with two rows of stem chopped into the windrow with tailings (2ROW), or harvested using the EZ-Bale system (EZB) with a disengaged combine spreader and tailings falling into a windrow. The remainder of the diet consisted of 30% wet distillers grains and 5% supplement which contained trace minerals, limestone, monensin and Soypass. Randomly selected bales were chemically treated with anhydrous ammonia for 60 d in late fall (CONVAM, 2RAM, EZBAM). Samples of two bales from each treatment were collected and hand-sorted to determine the proportion of corn plant parts, and parts were incubated with rumen fluid in a water bath for 48 h to determine *in vitro* dry matter and organic matter digestibility. No interactions ($P = 0.40$) between harvest method and chemical treatment were observed. Corn residue harvested as 2ROW resulted in increased ($P < 0.01$) ADG (1.06 kg/d) compared to CONV (0.96 kg/d) and EZB (0.99 kg/d), which did not differ ($P = 0.27$). Harvest method also significantly ($P = 0.04$) affected total diet intake, with 2ROW consuming more ($P = 0.01$) DM at 1.87% BW compared to 1.76% BW for CONV, but not EZB 1.80% BW ($P = 0.11$). Ammoniation increased ($P < 0.01$) ADG from 0.75 to 1.26 kg/d over non-

ammoniated residue. Feed efficiency was not affected by harvest method, but ammoniation increased ($P < 0.01$) G:F from 0.158 to 0.179. Although some alternative harvest technologies can increase animal performance by changing plant part proportions, chemical treatment of corn residue with anhydrous ammonia has a considerably greater impact on ADG and feed efficiency of growing cattle.

INTRODUCTION:

Corn residue is both a strategically and economically valuable feed resource for cattle producers. In the Midwestern region of the U.S. where corn acres have increased to meet the demands of the rapidly expanding ethanol industry, increased availability of corn residue has coincided with reduced perennial pasture and hay acres, limiting forage options for beef producers (Wallander et al., 2011). Between 2006 and 2008, farm level survey data suggest approximately 30% of the increase in corn acreage coming from uncultivated land, and this estimate increased to 77% between 2008 and 2012 (Wallander et al., 2011; Lark et al., 2015). In 2010, 0.81 million ha was baled (Schmer et al., 2017), and usage of baled corn residue in combination with ethanol byproducts has increased in growing and finishing diets in the Midwest (Klopfenstein et al., 2013).

Although corn residue is typically considered a low-quality roughage, studies have shown that different parts of the corn plant vary in nutritive value and digestibility (Fernandez-Rivera and Klopfenstein, 1989; Gutierrez-Ornelas and Klopfenstein, 1989; Stalker et al., 2015). As such, increasing the proportion of more digestible plant parts (husk) to less digestible parts (stem) in the baled residue through the use of selective corn harvesting and baling technologies can potentially improve the feeding value of the baled product. The New Holland Cornrower Corn Head (Straeter, 2011; Craig Welding, Mentone, IN) varies the proportion of stem to leaf, husk, and cob (tailings) in the baled windrow by chopping and including 2, 4, 6, or 8 rows of stem in the windrow for baling. The EZ Bale system (Hauge, 2014) involves disengaging the combine spreader and dropping the tailings into a windrow, eliminating the raking step used in conventional corn residue baling thereby reducing the proportion of stalk in the bale. Previous work

has shown that a low-stem bale produced with the Cornrower (2-Row) produces a more digestible bale when compared to conventionally harvested rake-and-bale. *In vitro* organic matter digestibility increased to 55% from 47%, and growing calves gained 0.78 kg/d compared to 0.63 kg/d when fed a diet containing 65% 2-Row corn residue compared to conventional residue (King et al., 2017). Alternatively, previous work with a a second-pass harvest method (EZ-Bale system, where windrows are produced by disengaging the combine spreader and eliminating the raking step) showed no difference in average daily gain of growing cattle between conventionally harvested residue or EZ-Bale residue when fed a diet containing 56% corn residue with four different ratios of MDGS:DRC as 40% of the diet (Welchons et al. (2017). Although changes in apparent residue digestibility have been shown between some selective harvest methods, the hypothesis that these changes are the result of changes in plant part proportions has not been supported.

Chemically treating low-quality forages with ammonia also improves both digestibility and dry matter intake, and this has been previously observed with ammoniated corn residue (Horton et al., 1979; Morris and Mowat, 1980; Paterson et al., 1981; Saenger et al., 1982; Grotheer and Cross, 1986; Mason et al., 1988, Conway et al., 2019). Saenger et al. (1982) ammoniated corn residue at 2% of DM and noted a 31% increase in DMI of steers fed *ad libitum* with a corn supplement (approximately 0.4% of BW; 0.91 kg/h/d) compared to non-ammoniated corn residue. Moreover, the DM digestibility of the residue increased from 55.5% to 62.0% (Saenger et al., 1982). Recent work with the Cornrower has shown that while some harvest methods, such as two rows of stem included in the windrow as opposed to all eight, can improve digestibility, this

effect increased when used with ammoniation (Conway et al., 2019). Additionally, the possibility that some corn plant parts respond more favorably to ammoniation to improve digestibility differentially has been suggested, but this also remains unclear. Therefore, the two objectives of this study were: 1) to assess the effect of harvest method on the proportion of corn plant parts, and the effect of ammoniation on the *in vitro* digestibility of the various corn plant parts, and 2) to assess the combined effect of both harvest method and ammoniation on the intake and performance of growing beef cattle when fed baled corn residue.

MATERIALS AND METHODS:

Animal care and management procedures used were reviewed and approved by the University of Nebraska Institutional Care and Animal Use Committee.

Corn residue harvest and ammoniation

Residue was harvested in fall of 2016 from two adjacent non-irrigated fields (40.9 ha). Fields were planted to the same corn hybrid, and both grain and residue were harvested within a day of each other. Approximately 7.3 ha were harvested using conventional rake-and-bale methods using a John Deere S550 with a 608 8-row corn head (John Deere, Moline, IL) and a VR1428 High Capacity wheel rake (Vermeer Freeman Manufacturing, Inc., Freeman, SD) achieving an estimated 29% residue removal rate. The New Holland Cornrower Corn Head harvested 18.2 ha with only two rows of stem and leaf being chopped and added to the windrow, resulting in approximately 10% residue removal rate to produce the 2ROW bales. Finally, 15.4 ha were harvested using the same John Deere S550 with a 608 8-row corn head (John Deere, Moline, IL) as the

CONV treatment. The EZ Bale system (Poet-DSM Advanced Biofuels, Sioux Falls, SD) entails harvesting as normal, but disengaging the rear spreader of the combine to drop the tailings and stem and leaf into a windrow which does not require raking and can be followed immediately with a baler. This material was removed at approximately 12% and produced the EZB treatment bales. After baling, 65 bales (19 2ROW, 25 CONV, 21 EZB) with an average 90% DM were separated and stacked on a concrete pad lined with black plastic. Bales were stacked randomly in a 4 x 3 bale arrangement, covered with the plastic and sealed, and ammoniated with anhydrous ammonia at 3.7% of DM from 12 Nov 2016 to 11 Jan 2017 (60 days). Data-logging temperature probes were placed next to the stack during the ammoniation period the mean recorded ambient temperature was -1.1° C (minimum and maximum recorded temperature were -26.4° C to 29° C).

Plant part proportion and in vitro digestibility

At the beginning and end of the trial, bulk grab samples of approximately 2.5 kg of material from 12 bales (n = 4 for each harvest method, n = 6 for each chemical treatment) were collected to assess the proportions of each plant part in the bales. Total samples were weighed and residue was hand separated into husk, leaf (with sheath), stem and cob. Residual chaff at the bottom of each sample bag was separated through a 1 mm wire mesh screen. The residue not passing through the screen was considered leaf (due to excessive leaf shatter), and the remaining chaff was weighed. Each plant part was weighed, and sub-samples from each part were collected and dried in a 60˚C forced-air oven to determine DM. Proportion of each plant part (on DM basis) was calculated as a percent of the total weight of the sorted sample.

To assess composition and digestibility of the individual plant parts, plant fiber and *in vitro* analyses were conducted. Sub-samples for each plant part were ground through a 1 mm screen using a Wiley mill. Dry matter and organic matter (OM) were analyzed by drying 0.5000- 0.5040 g of sample in ceramic crucibles, drying them in a 100˚ C oven for 24 h, weighing them back to measure moisture loss, and then incinerating samples in a 600˚ C muffle furnace for 6 h to measure ash content. Neutral detergent fiber (NDF) with sodium sulfite added (0.5000g per sample) and acid detergent fiber (ADF) analysis was done using an ANKOM 2000 automated fiber analyzer (ANKOM Technology, Macedon NY), using 0.5000-0.5040 g of sample in 25 micron porosity fiber bags. Bags were analyzed sequentially for NDF and ADF, with acetone rinses after both steps (Van Soest et al., 1991). The *in vitro* analysis was done in a water bath using modified methods as described by Tilley and Terry (1963), McDougall (1948) and Mertens (1993). Rumen fluid was collected from two donor steers consuming a diet of 50% brome grass hay and 50% Sweet Bran. Samples were incubated for 48 h in triplicate with two incubations to account for run-to-run variation (Stalker et al., 2013). Standards of known *in vivo* digestibility values for three different corn residues, husk, and husklage were included in each run, and standard values were used to adjust results. Samples were filtered and dried to obtain *in vitro* dry matter digestibility (IVDMD) and then filters were incinerated in a 600 °C muffle furnace for 6 hours to obtain *in vitro* organic matter digestibility (IVOMD).

Calculated nutrient content and digestibility of bales

The DM, OM, NDF, ADF, and DOM contribution of each plant part to the whole bales were calculated. This was done by using the measured nutrient values for each part

and multiplying it with the respective proportion of plant part in each bale type. The digestible organic matter (DOM) of each part was calculated by multiplying the measured IVOMD values by OM content of the part, then the part DOM was multiplied by the proportion of the part in the bale. Chaff was not included in these calculations as it was negligible contributor to the nutrient content of the bale. The OM contribution from chaff did not differ among harvest methods ($P = 0.78$) and was 2.1, 1.8, and 1.0% for CONV, 2ROW and EZB, respectively. In order to better understand the effect of ammoniation on the influence of plant parts on DOM of the bales, difference in DOM between the non-ammoniated and ammoniated plant parts within each bale type were calculated and compared statistically.

Growing cattle feeding trial

A performance study utilized 120 crossbred steers (319 ± 22 kg) stratified by BW in a randomized complete block design with a 3 x 2 factorial treatment structure, with harvest method and ammoniation being the treatment factors (CONV, 2ROW, EZB, COVAM, 2RAM, EZAM). Diets consisted of 65% corn residue, 30% wet distillers grains with solubles, and 5% pelleted supplement which contained trace minerals, limestone, monensin and nonenzymatically browned soybean meal (SoyPass, LignoTech USA, Inc., Rothschild, WI) (Table 3.1; Table 3.2; DM basis). This resulted in six different treatment diets being fed, with 20 animals per treatment. Diets were formulated using non-ammoniated residue CP values to ensure RDP was not limiting to microbial growth and metabolizable protein (MP) did not limit gain of steers (NRC, 2000). Average CP value of the non-ammoniated residue was between 5.6-5.7% CP among bale types, and average ammoniated values among harvest methods ranged between 10.8-10.9%.

The 84-day trial was conducted at the Eastern Nebraska Research and Extension Center Mead, NE, at an individual-feeding barn equipped with a Calan Gate system (American Calan, Inc., Northwood, NH). Prior to the start of the trial, steers were limit-fed at 2% of BW a diet of 50% alfalfa hay and 50% Sweet Bran (Cargill, Blair, NE), and three-day empty body weights were collected on day, -1, 0 and 1, with weights from the first two days used to block cattle by BW (Watson et al., 2013). Steers were implanted with 36 mg zeranol (Ralgro, Merck Animal Health, Inc.) on day 0. At the end of the feeding period, they were limit fed with the same alfalfa/Sweet Bran diet for 5 days before collecting three-day weights to determine ending BW. At feeding, corn residue bales were ground through a 7.6 cm screen and fed in a total mixed ration. Feed was delivered between 0700 h and 0900 h, and bunks were managed to maximize intake with minimal sorting (approximately 103% of the previous day's intake). Feed refusals were collected daily, composited on a weekly basis and sub-sampled, then dried in a 60˚C forced-air oven to determine dry matter. Diet ingredients and whole diet samples were also collected weekly throughout the study to assess nutrient content.

Statistical analyses

Data were analyzed using the MIXED procedure of SAS 9.2 (SAS Institute Inc., Cary, NC, USA) and significance was declared at $\alpha = 0.05$ with tendencies declared at $0.05 < P \leq 0.10$. For the feeding trial, block, harvest method, and chemical treatment were tested as fixed effects, along with interactions between the three factors. Steer was the experimental unit and response variables included final BW, ADG, G:F, and intake. Proportions of corn plant parts were analyzed with harvest method as a fixed effect and bale as the experimental unit using the MIXED procedure. Estimated total bale nutrient

composition and the proportional contribution of each plant part to total bale composition for OM, NDF, and ADF were calculated from measured composition data. These estimates were analyzed using the GLIMMIX procedure with chemical treatment, harvest method, and plant part as fixed effects. To evaluate the differences in plant part digestibility, IVOMD disappearance data were analyzed using the GLIMMIX procedure where replicate (first or second sampling of bales) within incubation run was treated as a random effect, and chemical treatment, plant part, and harvest method were analyzed as fixed effects. SLICE statements were used to describe simple effect differences between three factors due to the three-way interaction, and bale was the experimental unit. Calculated estimates of DOM based on IVOMD and proportion of plant parts were compared using the GLIMMIX procedure, with chemical treatment and harvest method as fixed effects and replicate (first or second sampling of the bales) was included as a random effect.

RESULTS:

Plant part nutrient composition

The three-way interaction between plant part, harvest method, and ammoniation for OM, DM, and NDF were not significant ($P > 0.36$), nor were the two-way interactions of plant part by harvest method and plant part by ammoniation significant ($P > 0.34$) for DM, OM, or NDF. Plant parts did not differ ($P \geq 0.13$) in DM or OM content (Table 3.3). However, there were differences in NDF ($P = 0.01$) among plant parts with cob having the greatest NDF content, followed by husk, then stem, and leaf having the least NDF. There was a three-way interaction ($P = 0.01$) for ADF (Figure 3.1, Panel A).

When comparing ADF values within plant part and ammoniation, there were no differences between harvest methods ($P > 0.10$) with the exception of CONV husk being lower in ADF ($P = 0.05$) than EZB husk, COVAM leaf being less than ($P = 0.01$) EZAM leaf, and 2RAM stem being lower than ($P = 0.01$) both COVAM and EZAM. In general, the ADF content of the stem (53.8%) and cob (51.0%) was the greatest, followed by the husk (48.2%) and leaf (45.7%).

Plant part in vitro digestibility

Like ADF, there was a three-way interaction ($P = 0.01$) for IVOMD between harvest method, chemical treatment, and plant part (Figure 3.1, Panel B). Within plant part and chemical treatment, harvest method had no effect ($P > 0.10$) on IVOMD with the following exceptions: 2ROW husk compared to EZB husk ($P = 0.014$; 69.1 and 63.7%), CONV stem compared to EZB stem ($P = 0.04$; 36.2 and 40.7 %), and a tendency for CONV leaf to be greater than 2ROW leaf ($P = 0.06$; 47.5 and 43.3%).

When comparing the IVOMD for each non-ammoniated or ammoniated plant part by harvest method, there was no difference ($P > 0.10$) between harvest methods for cob or husk. However, there was a significant effect ($P = 0.02$) of harvest method when comparing COVAM leaf to both 2RAM and EZAM leaf (62.2% compared to 57.3 and 57.5% IVOMD, respectively), and there was a tendency ($P = 0.10$) for 2RAM stem to be greater than COVAM and EZAM ($P = 0.06$; 52.6 compared to 49.0 and 48.4%). Given that harvest method was not expected to have a significant impact and particularly considering that the effect of harvest method was not consistent between ammoniated and

non-ammoniated plant parts, it is possible that the plant part by harvest method by chemical treatment interactions are due to differences in hand-sorting of the plant parts.

When the plant part response to ammoniation was assessed as the calculated difference in IVOMD between non-ammoniated and ammoniated parts, within harvest method, there was harvest method by plant part interaction (P = 0.04; Figure 3.3). Response of husk to ammoniation was lowest (P = 0.02) for CONV and 2ROW, and these values were not different (P > 0.12) from EZB leaf and stem. However, EZB leaf did not differ (P = 0.09) from the remaining parts within harvest methods, with husk, leaf and stem responding similarly (P > 0.17) to ammoniation treatment regardless of bale type. Cob showed the greatest (P = 0.04) increase in IVOMD due to ammoniation compared to the other three plant parts. While there was some variation in response of plant parts due to ammoniation observed between bale types, specifically EZB parts responding inconsistently, the increase in IVOMD of cobs (21.2 percentage units) was greater than leaf (13.2 percentage units), stem (11.9 percentage units) and husk (8 percentage units).

There was no interaction (P = 0.20) between harvest method and plant part for percent DOM found in individual plant parts, but there was an ammoniation by plant part interaction (P = 0.01) for DOM (Figure 3.4). All plant part DOM content increased due to ammoniation (P < 0.01), but the magnitude of response was different between parts. There was only a 12% (P = 0.01; 7.4 percentage units) increase in husk and a 24% (P = 0.01; 10.3 percentage units) increase in leaf due to ammoniation compared to the non-ammoniated plant part samples. Stem showed a 32% (11.4 percent unit) increase and cob

responded the most with a 46% (P < 0.01; 20.8 percentage units) increase in DOM content due to ammoniation.

Plant part proportion

Proportions of corn plant parts in the bales differed between harvest methods (Figure 3.2). There was a tendency for changes in proportions of husk (P = 0.06), with no difference between 2ROW (16%) and EZB (17%), but CONV containing less husk (12%). Leaf content of CONV was greater (P = 0.03) than both 2ROW and EZB, with CONV leaf comprising 39% of the bale, compared to 31% of the 2ROW and 32% of the EZB bale. Cob was different (P < 0.01) for all three harvest methods, with CONV having the least at 9%, EZB being greater than CONV at 19%, and 2ROW being the greatest at 31%. Stem proportion was greater (P = 0.03) in CONV and EZB at 33% and 30%, respectively when compared to 18% in 2ROW. The chaff (unsortable material) was not different (P = 0.39) between harvest methods, representing 7%, 4%, and 2% of CONV, 2ROW and EZB residue, respectively.

Calculated estimates of bale composition and digestibility

When the individual plant part nutrient composition was multiplied by the proportion of each plant part in the bale, the resulting calculated value represents an estimate of the contribution of each plant part to the total composition of the bale for each respective nutrient. For DM, OM, NDF, ADF, and DOM, ammoniation did not (P > 0.44) change how each plant part contributed to the total nutrient content of the bale (no chemical treatment by plant part interaction). However, interactions (P < 0.01) were observed between harvest method and plant part for all nutrients (Table 3.4). Cob

contributed approximately twice as much DM and OM to EZB bales when compared to CONV bales (108% and 109% increase respectively; $P < 0.01$), and cob contributed approximately four times as much DM and OM to 2ROW bales than CONV bales. Cob contribution of DM and OM was 62% greater (11.2 percentage units; $P < 0.01$) for 2ROW compared to EZB. Similar to DM, the contribution of husk to OM of the bale was not different ($P < 0.84$) between 2ROW and EZB bale, being 47% and 52% more than CONV. These values were numerically greater when compared to the husk contribution of CONV bales, but the difference was only significant ($P = 0.05$) between EZB and CONV, as the difference between 2ROW and CONV was a tendency ($P = 0.07$). Leaf contribution to bale OM was lower ($P < 0.01$) in 2ROW and EZB when compared to CONV. Interestingly, there was no difference ($P = 0.52$) in stem contribution to OM between CONV and EZB; only 2ROW had a lower ($P < 0.01$) OM content from stem. These patterns were similar to the NDF and ADF contribution, with some minor differences. The NDF contribution by husk to the bales followed the same numerical trend, with 4.2 percentage units more ($P = 0.08$) NDF in 2ROW compared to CONV and 5.0 percentage units more ($P = 0.04$) NDF from husk in EZB compared to CONV. This was also seen in the ADF contribution by husk. Similar to OM, both NDF and ADF showed nutrient contribution from cob increasing significantly ($P < 0.01$) from CONV to EZB to 2ROW. However, only 2ROW showed a reduced ($P < 0.01$) NDF and ADF contribution by stem compared to CONV. With the exception of husk, which was not different ($P = 0.15$) between all three harvest methods, the patterns in DOM contribution from each plant part remained the same as the other nutrients.

When the total nutrient composition of the whole bale was calculated based on proportional contribution of the plant parts without chaff, the harvest method by chemical treatment interaction was not significant for OM, NDF, ADF or DOM (Table 3.5). There were no differences ($P \geq 0.14$) in total bale OM or ADF content due to either harvest method or chemical treatment. There was a significant ($P = 0.04$) effect of harvest method on the NDF content of the bale, where CONV had less NDF than both 2ROW ($P = 0.06$) and EZB ($P = 0.02$), and no difference ($P = 0.32$) between 2ROW and EZB. The DOM of the CONV bales was less ($P = 0.03$) than both 2ROW and EZB, which did not differ ($P = 0.88$). Total bale OM digestibility was 27% (11.5 percentage units) greater in ammoniated bales and the NDF content of the bales was considerably reduced ($P < 0.01$) by ammoniation.

Feeding trial

There was no interaction ($P = 0.17$) between harvest method and ammoniation for intake of total diet as a percent of BW (Figure 3.5). Both harvest method ($P = 0.04$) and ammoniation ($P < 0.01$) affected intake as a percent of BW. Diet intake for 2ROW residue was 1.87% and greater ($P = 0.01$) than CONV intake (1.76 %). Intake for EZB was intermediate (1.80 %) between 2ROW and CONV, and not different from either ($P = 0.11$ and $P = 0.37$, respectively). Ammoniation increased diet intake from 1.52% to 2.11% of BW. Feed refusals for each animal were analyzed as a percent refused of total DM offered over the trial period, and there was a significant ($P = 0.03$) interaction between harvest method and treatment (Figure 3.6). The CONV residue diets were refused at 2.4% of the offered DM, and were significantly less ($P < 0.01$) than both the 2ROW diet refused at 5.5% and the EZB diet refused at 4.4% of the offered DM, which

were not different from each other (*P* = 0.30). However, these differences were not observed when the residue was ammoniated, with no difference (*P* > 0.85) between the three harvest methods and the average percent refused for CONVAM, EZAM, and 2RAM being 0.4%, 0.5% and 0.6% respectively.

There were no significant interactions (*P* = 0.40) between harvest method and ammoniation for ending BW, ADG, or G:F. Harvest method did affect (*P* = 0.01) ADG and had a tendency to affect (*P* = 0.07) ending BW (Table 3.6). There was no difference (*P* = 0.27) in ADG between CONV and EZB, but 2ROW cattle gained more (*P* = 0.03) than CONV and EZB. However, harvest method did not affect (*P* = 0.70) G:F. Ending BW and ADG were greater (*P* <0.01) for steers fed ammoniated residues compared to non-ammoniated residues. Despite the increased intake in the ammoniated treatments compared to the non-ammoniated, the increase in ADG resulted in a 13% increase (*P* < 0.01) in G:F.

DISCUSSION:

One of the primary objectives of this study was to examine how the changes in plant part proportion from selective harvest methods would affect the whole bale nutrient composition and subsequent cattle performance. Indeed, the 2ROW did have significantly less stem and leaf when compared to the CONV, and showed a substantial increase in cob. The EZB had less leaf and more cob than the CONV, but similar amounts of stem. When examining the IVOMD of the non-ammoniated plant parts, cob (47.4%) and leaf (45.7%) were most similar in IVOMD, but stem was less digestible than the other plant parts (38.1% IVOMD). Interestingly, there was lack of a negative correlation between IVOMD and ADF content of the plant parts. The non-ammoniated husk (66.5%) was

much more digestible than the non-ammoniated leaf (43.7% IVOMD), but contained a similar amount of ADF (48 vs 45%, respectively). This suggests that ADF is likely a poor predictor of the digestibility of corn residue.

When the DOM of the bale was calculated, both 2ROW and EZB did not differ and were greater in DOM than CONV, yet cattle only showed increased intake and gain with the 2ROW residue. It is well noted in the literature that in high-fiber diets, gut fill will limit animal intake, which has been correlated with the forage NDF content (Mertens, 1987). Interestingly, the NDF content of the bales were not inversely related to intake in the present study. The NDF content of 2ROW did not statistically differ from CONV or EZB. The fact that intake did not appear to be related to NDF is most likely due to the heterogeneous nature of the corn residue, and provides more evidence that caution is required when evaluating the fiber content of diets to predict intake and performance (Beauchemin, 1996). Due to the different plant part proportions in the bale, the contribution of NDF from the various plant parts was different. For instance the stem contributed 36, 18, and 23% of the NDF in the CONV, 2ROW and EBZ. There may be differences the rate of digestion of the various plant parts that corresponds to the differences in intake observed as the intake response cannot be explained by the NDF content of the bales.

Differences in plant part proportion due to harvest method resulted in different contributions of plant part to the DOM composition and subsequent total digestibility of the bale. For both 2ROW and EZB, the total DOM remained similar, but the cob contribution to DOM (37%) was considerably greater for 2ROW than for EZB (23.4%)

and CONV (12.7%). Conversely, stem contributed a considerably smaller proportion of the DOM to 2ROW (16.6%) than in EZB (28.1%) and CONV (33.0%).

It is well noted that ammoniation of low-quality forages, including corn residue, will result in increased DMI corresponding with increased digestibility (Saenger et al. 1982). In both the present study and in previous work, a significant increase in DMI has been observed due to ammoniation, and the magnitude of this response differs between 2ROW and CONV (Conway et al., 2019). In a lamb feeding study, a 57% increase in 2RAM DMI compared to 2ROW was observed, but a significantly lower 38.5% increase in DMI when CONV residue was ammoniated. The present work shows a 42.2% increase in intake between 2RAM and 2ROW, and a 43.3% increase in COVAM residue compared to CONV, eliminating the possibility of an interaction.

The *in vitro* data presented here show that cobs show the greatest response to ammoniation when compared to the other three plant parts. Although there is some variability in the response for the EZB plant parts, which could be due to hand sorting error, the overall response of individual plant parts to ammoniation agrees with the limited available literature. Sewalt et al. (1996) found that when corn leaves and stems were treated with ammonia, only the leaves showed a significant (11.3 percentage unit) increase in IVDMD compared to both upper and lower stem (4.3 percentage units; not significant). Ramírez et al. (2007) demonstrated that when either corn residue or strictly corn cobs were alkali treated with urea at 4.5% DM, the increase in *in situ* effective dry matter degradability of corn residue was 14.6 %, but the cobs increased by 55%. The present study similarly demonstrates a 44% increase in IVOMD for cobs due to

ammoniation, but only a 12%, increase in husk, 29% increase in leaves, and a 31% increase for stems, a clear differential response to ammoniation among plant parts.

Although there was no interaction for total bale DOM between harvest method and ammoniation, the simple means numerically suggest a greater response due to the increased cob in 2ROW and EZB, with total bale DOM for CONV bales increasing from 40.3% to 50.8% (10.5 percent unit increase), 2ROW increasing from 43.1% to 56.3% (13.2 percentage units) and EZB increasing slightly less from 43.9% to 55.0% (11.0 percentage units). It is clear that changing the plant part proportions will alter the nutrient content and digestibility of the baled corn residue.

In agreement with previous literature regarding selective harvest with the New Holland Cornrower, cattle eating corn residue with two rows of stem added to the windrow performed better than eating conventionally harvested residue (King et al., 2017). When comparing the simple means for the non-ammoniated residue in the present study, cattle eating conventionally harvested residue gained 0.69 kd/d compared to 0.80 kg/d for cattle eating 2ROW (low-stem) residue, a 16% magnitude improvement. This corresponds closely with the 0.63 and 0.78 kg/d gain for conventional and low-stem residue reported by King et al. (2017). The ammoniated gains were considerably higher for all harvest methods, with daily gains of 1.2, 1.3 and 1.2 kg/d for COVAM, 2RAM and EZB respectively, which agrees with literature on the improvement of corn residue when ammoniated (Saenger et al., 1982).

The results observed in the present study also correspond with previous work feeding EZB residue to growing cattle. Welchons et al. (2017) demonstrated growing cattle, fed a diet containing 56% corn residue with four different ratios of MDGS:DRC as

40% of the diet, gained 0.76 kg/d for EZB compared to 0.81 kg/d for conventionally harvested corn residue, which were not significantly different. This lack of performance response was seen in the present study as well, with only 3% increase in ADG between CONV and EZB residue, which was not significantly different. These data agree with current available work which shows that there does not appear to be an advantage for EZB harvest over CONV for animal gain, but cattle fed residue produced with the 2ROW harvest method will exhibit higher average daily gains.

There is enough evidence to suggest that some corn plant parts do indeed respond to ammoniation more so than other parts, and this can be detected as changes in digestibility, nutrient composition of the bale, and intake between harvest methods. However, in the current study, this effect of ammoniation on different plant parts due to harvest method was not strong enough to observe a corresponding interaction response in animal performance. This is perhaps due the effect of reduced sorting, as indicated by the considerable reduction in feed refusals among all harvest methods when ammoniated. The feed refusals were not evaluated for plant parts or nutrient content, however, visual observation indicated that orts primarily consisted of cob and stem, particularly when diets were not ammoniated. The effect of diet selectivity is worth exploring when feeding either non-ammoniated or ammoniated corn residue in future studies.

Although 2ROW bales and EZB had similar DOM, 2ROW resulted in greater intake and gain, which maybe the result of EZB having less cob and more stem than 2ROW. This difference in plant part composition may have resulted in an increased rate of digestion and passage rate for the 2ROW compared to EZB. Furthermore, the intake response was increase by ammoniation, potentially due to increased digestion and

passage rate resulting from the susceptibility different plant parts (particularly cobs) to treatment, of which 2ROW had the highest proportion. Although extent of digestion at 48h as determined by IVOMD and expressed as DOM of the total bale is not different between 2ROW and EZB, the present study does not include measurements of passage rate or disappearance rate. Digestibility kinetics associated with ammoniated corn residue have been shown to be affected by alkali treatment, where increased digestibility will correspond with an increase in particulate passage rate, but comparisons between different plant parts have not been made (Berger et al., 1979; Oliveros et al., 1993). To quantify and verify this effect, further investigation into the specific digestion kinetics of individual corn plant parts should be done, particularly with regard to ammoniation.

CONCLUSIONS:

Selective harvest methods of corn residue will change the proportion of corn plant parts in the bale as hypothesized in previous studies, resulting in a bale that is more digestible *in vitro*. When individual plant parts were incubated *in vitro* and values were multiplied by the measured part proportions, the calculated DOM of the bale showed both selective harvest methods to be more digestible than conventionally harvested residue. However, the increase in bale digestibility did necessarily correspond with increased animal performance, suggesting rate of digestion and passage rate may be different between harvest methods due to differences in plant parts composition. There is also a potential effect of sorting, as there was an equivalent increase in amount of gain between harvest methods regardless of ammoniation. Plant part digestibility data show that cob responded to ammoniation significantly more than leaf, husk, and stem. The 2ROW residue had considerably more cob and less stem than either CONV or EZB. Therefore,

we suggest that although selective harvest methods will improve the digestibility of baled corn residue, the improvements in performance associated with the increase in digestibly are dependent upon the specific parts that are selected. Finally, this study once again highlights the considerable improvement to animal performance and digestibility that ammonia treatment can result in when treating a low-quality forage such as corn residue.

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Table 3.1. Composition of treatment diets fed to growing steers in an individual feeding study

Diet Ingredients	% of diet DM
Corn Residue	65.0
Wet Distillers Grains w/ solubles (WDGS)	30.0
Supplement[1]	5.0

[1] Pelleted supplement consisted of 3.5% nonenzymatically browned soybean meal (SoyPass, LignoTech USA, Inc., Rothschild, WI), 1.0% limestone, 0.13% tallow, 0.3% salt, 0.05% trace mineral, 0.02% vitamin pre-mix, and 0.014% monensin (as a percent of total diet).

Table 3.2. Nutrient composition of total diet consisting corn residue[1], modified distillers grains with solubles, and a pelleted supplement[2] fed to growing steers.

	CONV	2ROW	EZB	CONVAM	2RAM	EZAM
DM, %	72.6	73.4	73.0	71.0	70.9	71.1
			% of diet DM			
OM, %	87.9	90.1	90.4	88.4	91.0	91.7
NDF, %	66.4	68.2	68.8	62.9	63.9	64.5
ADF, %	44.7	42.2	42.7	44.4	43.0	42.7
CP, %	18.5	18.5	18.4	21.9	21.9	21.9

[1] Corn residue utilized was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with two rows of corn plant added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB). Ammoniated diets were formulated using portions of the same residue that was ammoniated at 3.7% DM (CONVAM, 2RAM, EZAM).

[2] Pelleted supplement consisted of 3.5% nonenzymatically browned soybean meal (SoyPass, LignoTech USA, Inc., Rothschild, WI), 1.0% limestone, 0.13% tallow, 0.3% salt, 0.05% trace mineral, 0.02% vitamin pre-mix, and 0.014% monensin (as a percent of total diet).

Table 3.3. Least square means for corn residue plant part nutrient composition, and plant part nutrient interactions between harvest method (HM) and ammoniation (AM)[1]

	Plant part				SEM	*P-values*[2]		
	Cob	Husk	Leaf	Stem		Part	Part Interactions HM*Part	Part Interactions AM*Part
DM, %	87.8	90.3	87.6	88.7	4.19	0.68	0.94	0.87
OM, %	95.8	92.0	93.2	94.6	1.14	0.12	0.34	0.67
NDF[3], %	87.2[a]	85.1[a]	74.2[d]	79.9[c]	0.77	< 0.01	0.65	0.42

[1] Corn residue was harvested using three methods: conventionally harvested rake-and-bale, New Holland Cornrower header with two rows of corn plant added to the windrow, or the spreader disengaged on the back of the combine. Bales from each harvest method were ammoniated at 3.7% of DM. Means shown are averaged across the three harvest methods and ammoniation.
[2] Means which share a common superscript are not significantly different from each other ($P > 0.05$). Superscripts are for differences between means for the main effect of plant part.
[3] A significant ($P = 0.02$) HM*AM interaction was observed for NDF.

Table 3.4. Calculated[1] contribution of each plant part to the total nutrient composition of the bale on a proportional basis.

		Harvest Method[2]			**SEM**		***P-values***	
	Part [3]	*CONV*	*2ROW*	*EZB*		HM	Part	HM x Part
DM, %	Cob	8.7^{de}	29.3^{b}	18.1^{c}	1.87	0.66	< 0.01	< 0.01
	Husk	11.0^{d}	15.2^{cd}	16.1^{cd}				
	Leaf	37.6^{a}	30.2^{b}	30.8^{b}				
	Stem	32.1^{b}	17.3^{c}	29.0^{b}				
	Chaff	6.4^{ef}	3.7^{ef}	2.2^{f}				
OM, %	Cob	8.6^{e}	29.6^{b}	18.0^{c}	1.83	0.75	< 0.01	< 0.01
	Husk	10.3^{de}	15.1^{cd}	15.6^{c}				
	Leaf	37.3^{a}	29.6^{b}	30.0^{b}				
	Stem	31.3^{b}	17.0^{c}	29.0^{b}				
	Chaff	2.1^{f}	1.8^{f}	1.0^{f}			.	
NDF, %	Cob	8.3^{e}	27.1^{ab}	16.7^{c}	1.81	0.33	< 0.01	< 0.01
	Husk	10.0^{de}	14.2^{cd}	15.0^{c}				
	Leaf	29.3^{a}	23.5^{b}	24.6^{ab}				
	Stem	27.0^{ab}	14.5^{cd}	25.2^{ab}				
ADF, %	Cob	4.2^{f}	15.4^{abc}	9.3^{d}	0.97	0.41	< 0.01	< 0.01
	Husk	5.4^{ef}	7.7^{de}	8.3^{d}				
	Leaf	17.4^{ab}	14.5^{c}	15.0^{bc}				
	Stem	18.2^{a}	9.4^{d}	16.6^{abc}				
DOM, %	Cob	5.9^{e}	19.1^{a}	11.9^{cd}	1.53	0.41	< 0.01	< 0.01
	Husk	6.8^{de}	9.7^{de}	9.8^{de}				
	Leaf	18.4^{ab}	14.0^{c}	14.9^{bc}				
	Stem	15.3^{abc}	8.5^{de}	14.3^{bc}				

[1] Contribution was calculated by multiplying the laboratory-measured nutrient values by the proportion of each plant part in the bale to determine each part's contribution to the whole bale.

[2] Corn residue harvest method is either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with two rows of corn plant added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB). Ammoniated treatments consisted of bales from the same harvest methods which were ammoniated at 3.7% DM (CONVAM, 2RAM, EZAM).

[3] Plant parts were hand-sorted according to visual assessment, with leaf sheath included in the leaf portion of the sample. Chaff was also sorted, and considered to be material that was sifted through a 1 mm wire mesh screen. Chaff was not included in NDF, ADF, and DOM calculations.

Table 3.5. Total nutrient composition and digestible organic matter (DOM) of the whole bales for main effects of harvest method (HM) and ammoniation (AM). Calculation based on proportional contribution of each plant part when summed together, disregarding the contribution of chaff.

	Harvest Method[1]			**Chemical Treatment[1]**		**SEM**	***P-values***		
	CONV	*2ROW*	*EZB*	*NAM*	*AMM*		HM	AM	HM x AM
OM,%	87.4	90.3	92.6	90.3	90.0	2.91	0.14	0.86	0.65
NDF, %	72.9[b]	77.6[ab]	79.8[a]	80.9	72.6	2.50	0.04	0.01	0.30
ADF, %	45.5	47.2	49.2	46.6	48.0	1.40	0.15	0.34	0.83
DOM, %	45.6[b]	49.7[a]	49.5[a]	42.5	54.0	1.89	0.04	0.01	0.59

[1] Corn residue harvest method is either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with two rows of corn plant added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB). Ammoniated treatments used bales from the same harvest methods ammoniated at 3.7% DM (AMM) and are compared as a main effect to non-ammoniated bales (NAM).

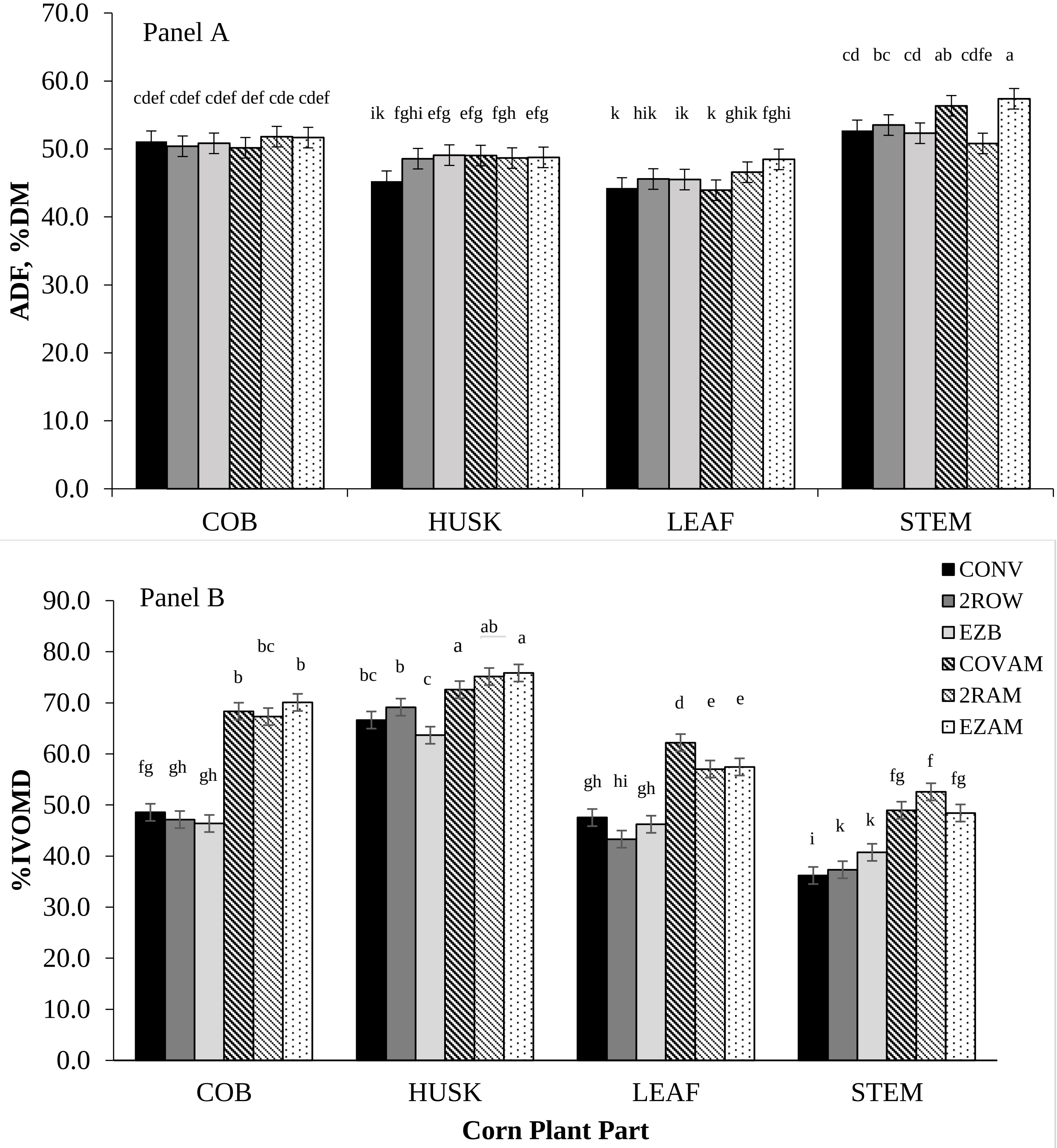
Table 3.6. Summary of individual cattle performance when fed corn residue harvested conventionally (CONV), EZ baled (EZB), or with two rows selecting for husk and leaf components (2ROW) as affected by harvest method (HM) and ammoniation (AM).

	Harvest method[1]			Treatment		*P-values*[2]		
	CONV	2ROW	EZB	NAM	AMM	SEM	HM	AM
Initial BW, kg	318	319	319	319	319	2.6	0.95	0.92
Ending BW, kg	399[b]	409[a]	402[ab]	382[B]	424[A]	3.1	0.07	< 0.01
DMI, kg/d	6.34	6.84	6.52	5.31	7.82	0.12	0.02	< 0.01
DMI, %BW	1.76b	1.87[a]	1.80[ab]	1.52[B]	2.11[A]	0.047	0.04	< 0.01
ADG, kg/d	0.96[b]	1.06[a]	0.99[b]	0.75[B]	1.26[A]	0.023	0.01	< 0.01
G:F	0.150	0.154	0.152	0.143[B]	0.162[A]	0.0037	0.70	< 0.01

[1] Corn residue utilized was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with only two rows added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB). Ammoniated treatments used bales from the same harvest methods ammoniated at 3.7% DM (AMM) and are compared as a main effect to non-ammoniated bales (NAM).

[2] Means with differing superscripts within row are significantly different ($P < 0.05$)

Figure 3.1. Individual simple means for three way interactions between harvest method, ammoniation, and plant part. Panel A shows ADF composition and Panel B shows *in vitro* organic matter digestibility after 48 h incubation for hand separated corn plant



[1] Shared letters indicate no significant difference from each other at $P < 0.05$ ('j' is not used for visual clarity)

[2] Corn residue was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with only two rows added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB). Ammoniated treatments used portions of the same residue that was ammoniated at 3.7% DM (CONVAM, 2RAM, EZAM).

Figure 3.2. The effect of harvest method (n = 4) on the proportion of corn plant parts in the baled residue as determined by hand sorting and passing leaf portion through 1mm separation screen to remove chaff and unsortable material. Corn residue was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with only two rows added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB).

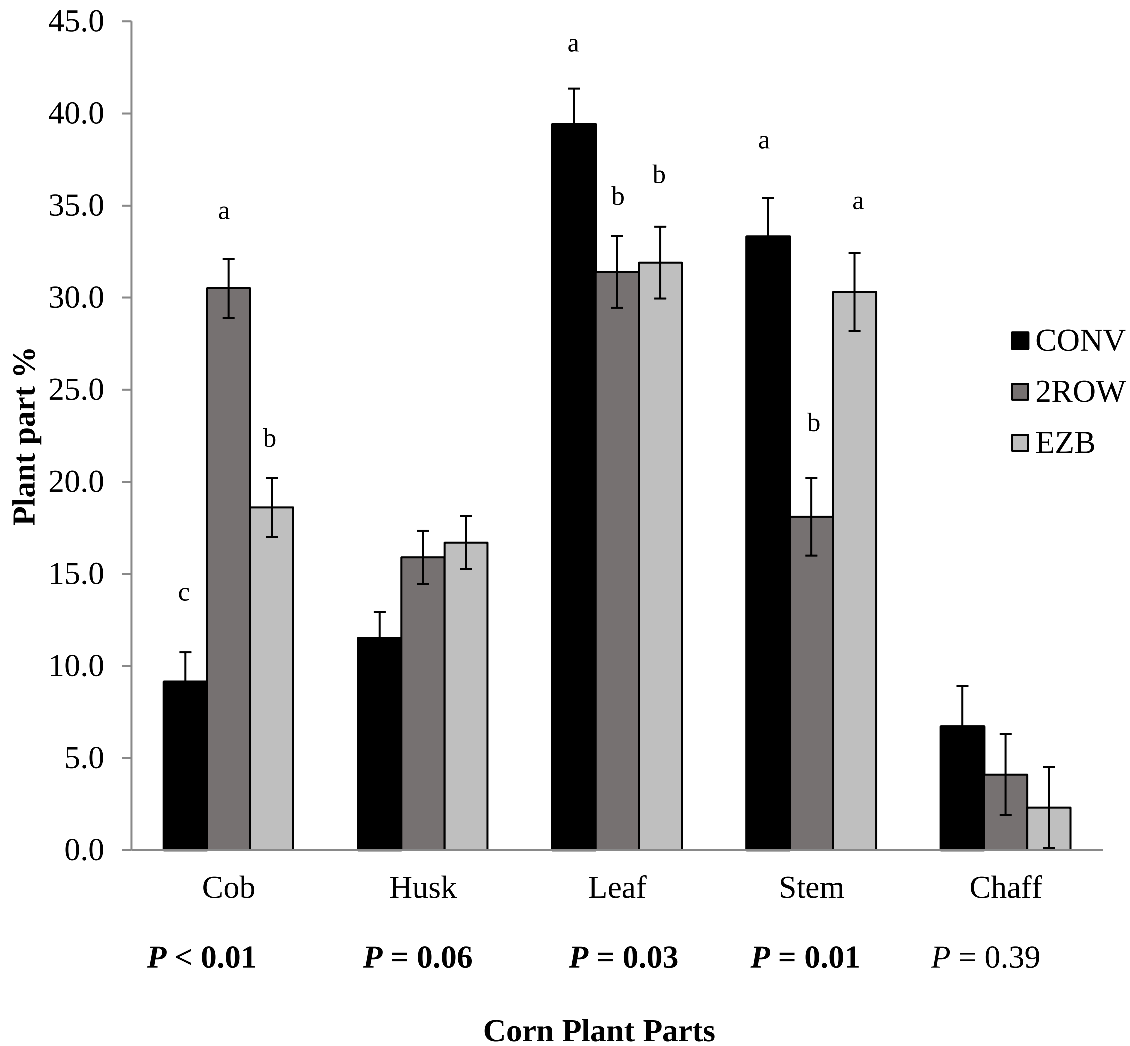


Figure 3.3. The calculated percentage unit difference in IVOMD between unammoniated and ammoniated corn plant parts within harvest method. This value represents the relative response of each plant part to ammoniation. Corn residue was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with only two rows added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB).

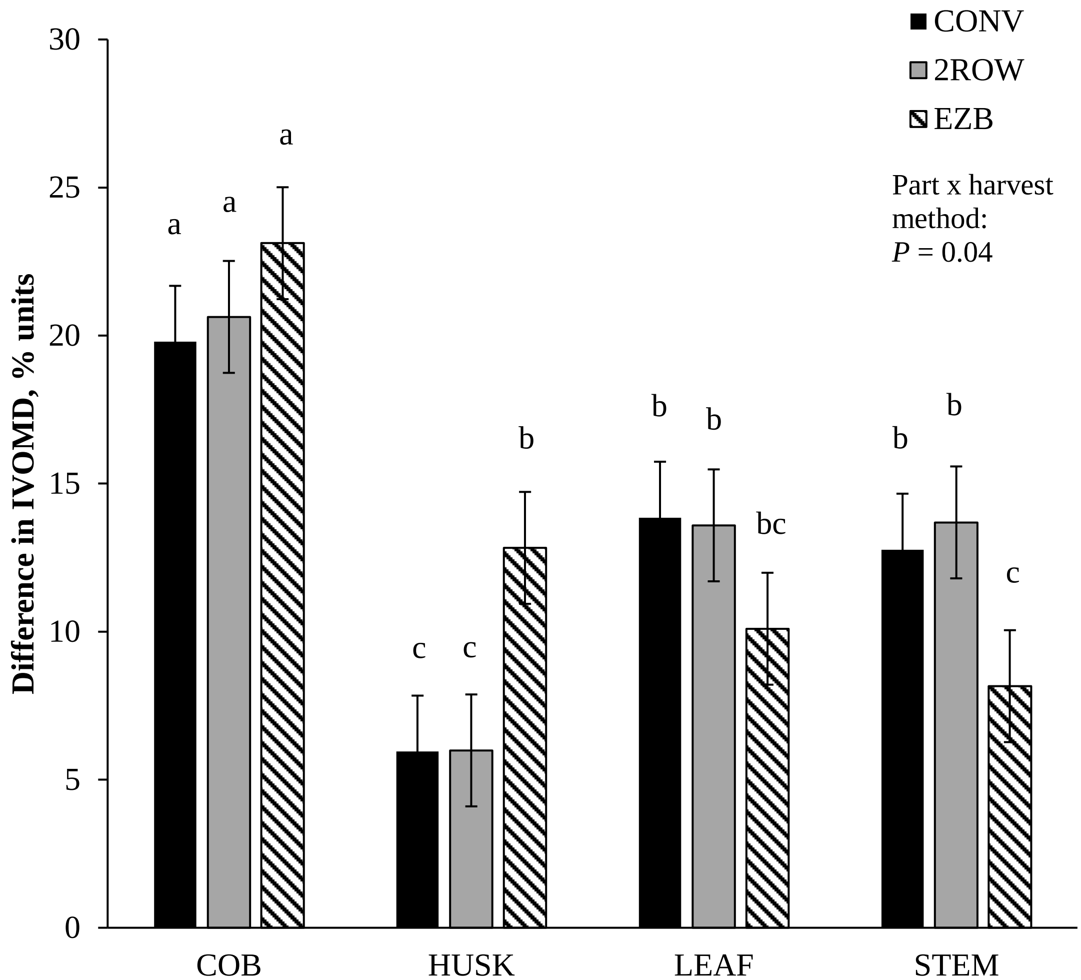


Figure 3.4. The digestible organic matter (DOM) content calculated based on organic matter content and *in vitro* organic matter digestibility of the corn plant parts from corn residue bales that were either not ammoniated (NAM) or treated with anhydrous ammonia (AMM) at 3.7% of DM.

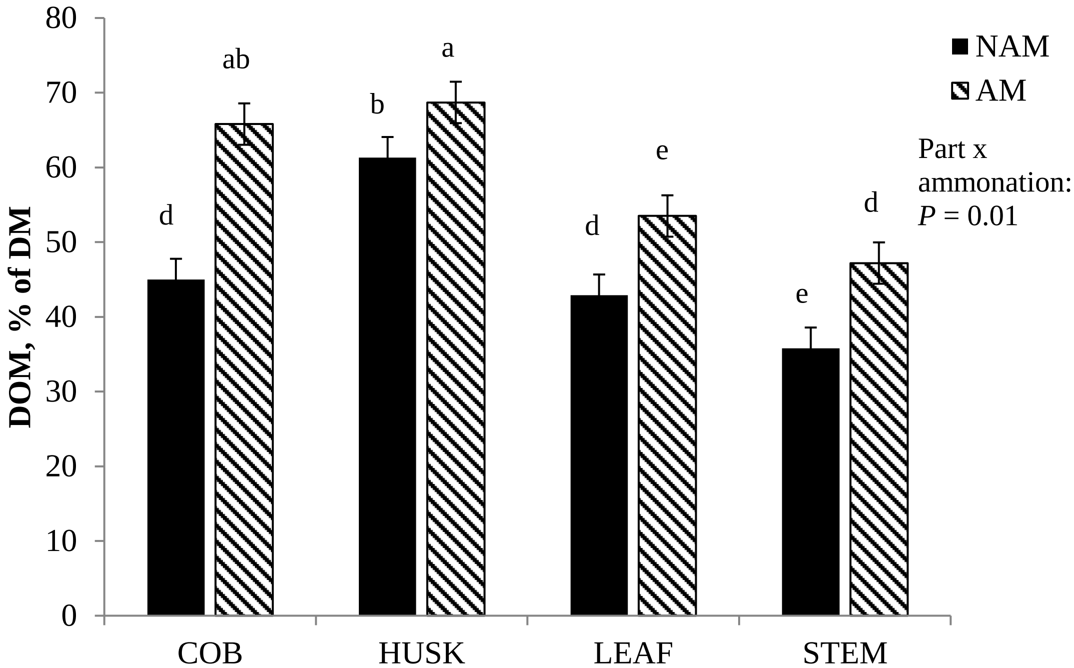
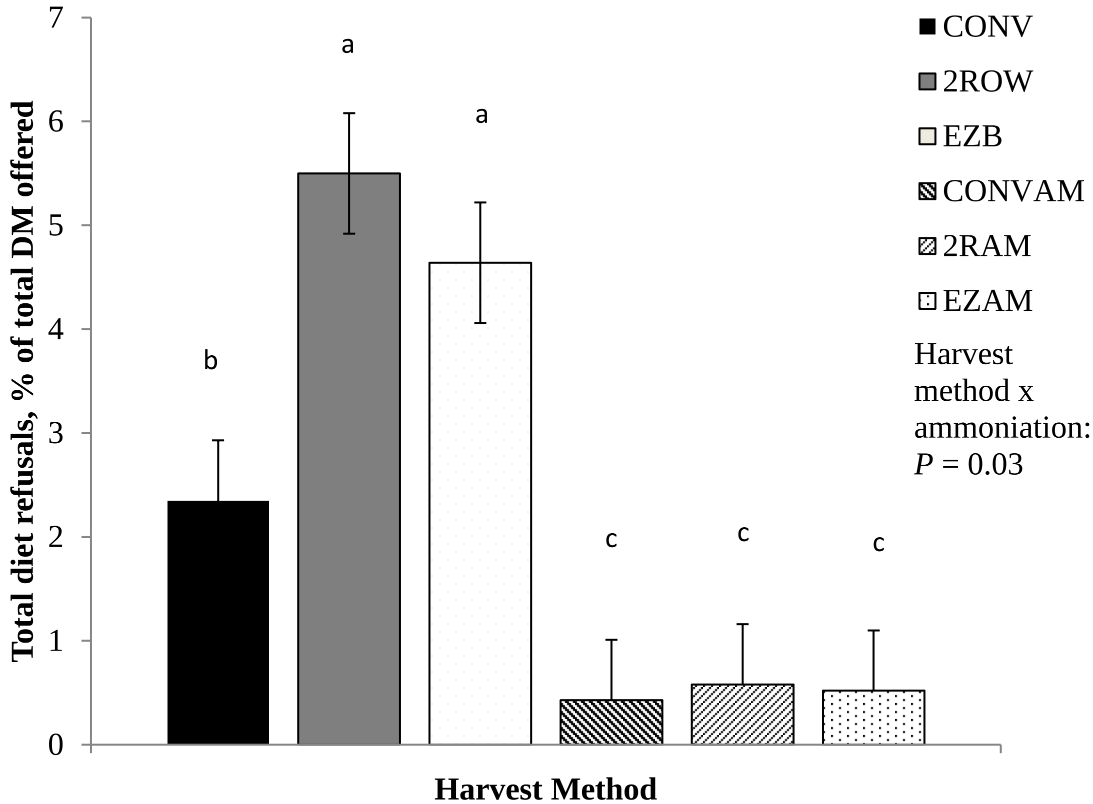


Figure 3.5. Average feed refusals for each diet at a percent of DM offered over 84 d trial with growing steers when fed corn residue harvested one of three ways: using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with two rows of corn plant added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB). Ammoniated diets were formulated using portions of the same residue that was ammoniated at 3.7% DM (CONVAM, 2RAM, EZAM).



CHAPTER IV: Effect of ammoniation and harvest method on waste and consumption characteristics of corn residue bales fed to cows in a round bale feeder

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ABSTRACT:

To determine the effects of harvest method and ammoniation (3.7% of DM) on consumption and waste of baled corn residue, a 6 x 6 Latin square with a 3 x 2 factorial treatment structure was conducted. Six treatments consisted of either non-ammoniated or ammoniated residue, harvested one of three ways: conventional rake-and-bale (CONV), New Holland Cornrower with two rows of stem chopped into the windrow with tailings (2ROW), or EZ-Bale system (EZB) with a disengaged combine spreader and tailings dropped in a windrow. Open beef females (12 heifers and 30 cows) were blocked by parity and weight into 6 pens (7 hd/pen) such that each pen had similar total BW. One bale was fed to each pen during each of six 7 d periods using round-bale ring feeders with closed bottom panels. Residue falling around (waste) and remaining in (refusals) the feeder was collected and weighed. Harvest method affected ($P < 0.05$) total wasted and refused residue, with 2ROW bales having the least (29.3%), EZB wasting 37.5%, and CONV wasting the most (42.3%) residue. Ammoniation reduced total waste and refusals from 41.1 to 31.6 regardless of harvest method. Harvest method affected ($P = 0.01$) intake of residue, with cattle consuming CONV residue at 0.95% of BW), EZB at 1.17% of BW, and 2ROW at 1.40 % BW, but ammoniation only tended ($P = 0.09$) to increase DMI from 1.1 to 1.3%. Intake of DM, OM, NDF, ADF, CP, and DOM all differed ($P \leq 0.03$) due to harvest method, and intake of nutrients due to ammoniation was greater ($P \leq 0.05$) for everything except NDF intake ($P = 0.42$). The CP intake of non-ammoniated residue was not sufficient to meet the protein requirement of a pregnant cow, but all ammoniated residues were sufficient in CP to meet requirements without protein supplementation. Only the ammoniated 2ROW and EZB residue had enough DOM to

meet the energy requirement of a cow throughout her gestation. Both selective harvest methods and ammoniation can effectively reduce bale waste and selectively harvested ammoniated residue can be fed to non-lactating pregnant cows as sole feed source.

INTRODUCTION:

Feed costs are the most critical control point for profitability in beef cattle production, and costs associated with winter feeding are particularly high (May et al., 1999; Ramesy et al., 2005, Miller et al., 2002). These costs can be reduced by fall or winter corn stalk grazing, which is the currently the most economical option for corn residue utilization (Schmer et al., 2017; Redfearn et al., 2019). However, only 12% of corn acres were grazed in 2010, and survey data of Nebraska producers suggest underutilization of grazed corn residue, citing lack of infrastructure such as fencing and water as a primary discouraging factor (Cox-O'Neill et al., 2017). Alternatively, baled corn residue can offer low-cost forage to cattle producers who may not have access to grazing acres. Previous work has only evaluated baled corn residues when fed after grinding and mixing into a total mixed ration. Little information is available on the feeding value and waste of whole bales of corn residue in ring feeders, which may be more feasible for cattle producers without access to grinding or ration-mixing equipment.

Inherent differences in the nutritive value of the different corn plant parts have been noted, with husk being the most digestible, stem being the least digestible, and cob being highly variable (Fernandez-Rivera and Klopfenstein, 1989b; Gutierrez-Ornelas and Klopfenstein, 1991). Selective harvest methods can change the plant part proportion in the corn residue bales, changing the digestibility of the baled corn residue (King et al.,

2017; Conway et al., 2019a) and increasing animal performance when fed as a part of a total mixed ration (Straeter, 2011; Conway et al., 2019b). The ability of cattle to select higher quality dietary components when grazing is well noted, particularly with corn residue (Lamm and Ward, 1981; Fernandez-Rivera and Klopfenstein, 1989a; Fernandez-Rivera and Klopfenstein, 1989b; Gutierrez-Ornelas and Klopfenstein, 1991). Furthermore, ammoniation has also been shown to increase intake, digestibility, and CP content of low-quality forages (Saenger et al, 1982; Fahmy and Klopfenstein, 1994) and there is some evidence that it will differentially affect individual corn plant parts, particularly cob (Ramirez et al., 2007; Conway et al., 2019). It is currently unknown how cattle will select, eat and waste corn residue when fed free choice in round bale feeders, and the possible effects of selective harvest and ammoniation on these factors has not been quantified. The objective of this study was to quantify and characterize the intake and waste profile of corn residue bales when fed to dry cows in a round bale feeder in order to assess the effects of three different harvest methods both with and without ammoniation.

MATERIALS AND METHODS:

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

Corn residue harvesting and ammoniation

Corn residue used in this trial was harvested in October 2016. Residue was baled and removed from two adjacent, non-irrigated fields within 48 hours of corn harvest. A

total of 40.9 ha of the same corn hybrid were harvested using three different harvest methods. Using a conventional John Deere S550 with a 608 8-row corn head (John Deere, Moline, IL) followed with a VR1428 High Capacity wheel rake (Vermeer Freeman Manufacturing, Inc., Freeman, SD), 7.3 ha of corn residue were harvested using a conventional rake-and-bale method (CONV), removing an estimated 29% of total available residue. Another 15.4 ha were harvested using the same John Deere S550 combine with a 608 8-row corn head (John Deere, Moline, IL), but without the rake-and bale for residue removal in a method promoted as the “EZ Bale system” (Poet-DSM Advanced Biofuels, Sioux Falls, SD). This harvest method entails harvesting as normal, but disengaging the rear spreader of the combine to drop the tailings and stem and leaf into a windrow that does not require raking and can be followed immediately with a baler. This material was removed at a rate of approximately 12% of available reidue and produced the EZB treatment bales. Finally, the New Holland Cornrower Corn Head (Straeter, 2011; Craig Welding, Mentone, IN) was used to harvest 18.2 ha. The Cornrower attachment has individual chopping units underneath the corn head which can be turned on or off in pairs, and the corn stem and leaf that is harvested is chopped and dropped into the resulting windrow. Two rows of stem and leaf were chopped and added to the windrow in this harvest method, resulting in approximately 10% residue removal to produce the 2ROW bales. After baling, 65 bales (19 2ROW, 25 CONV, 21 EZB) with an average 80% DM were separated and stacked on a concrete pad lined with black plastic. Bales were stacked in a 4 x 3 pyramid arrangement with harvest methods randomly placed in the stack. The stack was covered with the plastic and sealed, and anhydrous ammonia at 3.7% of DM was allowed to circulate in the sealed stack for 60 days (12-

Nov-2016 to 11-Jan-2017), creating three subsequent treatments (COVAM, 2RAM, EZAM).

Feeding trial

A 52 d feeding trial was conducted at the University of Nebraska-Lincoln Eastern Nebraska Research and Extension feedlot facilities near Mead, NE between August and October of 2017. A total of 42 open commercial cross-bred beef females were used, and ranged in age and parity from first-calf heifers to multiparous 7 yr. old cows. The pool included 12 heifers and 30 cows, so the animals were stratified and blocked by BW to produce two light “heifer” blocks (448 kg ± 49.6; 6 heifers and 1 cow per pen) and four heavy “cow” blocks (649 kg ± 65.9; 7 cows per pen). This resulted in 6 pens of 7 animals. The experiment was designed as a 6 x 6 Latin square with a 3 x 2 factorial treatment structure, with six 1 wk periods plus a 10 d adaptation period. Six treatment diets (Table 4.1) were whole round bales of non-ammoniated corn residue from one of three different harvest methods (CONV, 2ROW, EZB), or the ammoniated bales of the same three harvest methods (COVAM, 2RAM, EZAM). During the adaptation period, animals were fed whole round bales of conventionally harvested corn residue to adapt to the pen conditions and eating bales from the ring feeders. Each pen was supplemented with a commercial mineral supplement as part of a cooked molasses lick tub with no added urea or salt (guaranteed analysis: 7.5% CP, 3.0% crude fat, 2.00% crude fiber, 5.0-6.0 % Ca, 6.0% P, 1.5% Mg, 4.0% K, 2100 ppm Zn, 1165 ppm Mn, 730 ppm Cu, 75 ppm Co, 68 ppm I, 13 ppm Se, 80,000 IU/lb Vitamin A, 20,000 IU/lb Vitamin D, 100 IU/lb Vitamin E). Animals were given one bale per period, and were fed wheat straw on

the occasion they ate the entire bale before the end of the 1 wk period (this only happened once over the feeding trial, and the pen was only fed wheat straw for one day).

Prior to the start of each period, every individual bale was weighed and core sampled using a 60 cm x 1.5 cm drill-powered probe (Hay Probe, Hart Machine Company, Madras, OR). Each bale was sampled at random locations and angles of the bale between 5-7 times. At the beginning of each period, every pen received their respective treatment as one whole, unground round bale in a round bale feeder with the mesh wrapping removed. All feeders were round bale ring feeders with straight sides and a panel situated in the middle of the concrete apron, with one of the six feeders having a panel at both bottom and top of the feeder. Each pen of animals was allotted two 9.8 x 28 m open-air pens during the feeding trial, which were separated by a combination of electric and fixed fence and gate. Animals alternated pens at the end of each period, and were moved to the neighboring pen with their respective feeder in order to assist with pen cleaning and final period sample collection. Each pen had a 9.8 x 6.7 m concrete apron extending from the bunk, and the back of the pen was packed soil. Cattle also had access to 4.9 m of bunk space and shared fence line automatic waterers.

Collection period methods and sampling

The collection periods began and ended on Wednesdays. During each 1 wk period, the corn residue falling outside of the feeder was raked and collected three times (Friday, Monday, and Wednesday for final collection, weighing and sampling. Using household yard leaf rakes, the residue collected during the period was separated visually into “clean” and “contaminated” waste. Clean waste was dry and unsoiled, and was put in

the feed bunk to maintain access to potentially edible material as well as prevent further contamination. The contaminated waste was shoveled to the edge of the pen, and was typically unable to be raked as it was wet, heavily soiled with feces and urine. During the period, the entire concrete apron was raked and collected; the remainder of the pen was not raked as there were negligible amounts of waste residue outside of the apron. The material during this time was only collected and separated, but not weighed or sampled.

At the end of the period (Wednesday), cattle were moved to their alternate pen with their feeder and given their next treatment bale. At this time, the remaining residue waste was collected, and the total weights of the clean and contaminated waste were weighed. Any refusals (orts) remaining inside of the ring feeder were also collected and weighed. Approximately 0.1 m^3 of material (using standard brown paper grocery bags measuring 26 x 36 x 15 cm) was collected using the four-corners sampling method for all clean, contaminated and refusals samples for DM and nutrient analysis. Once weights and samples were taken, the pens were cleaned and concrete aprons were scraped to prepare for the next period. Total residue waste and refusals were adjusted for DM and reported as a percent of the initial bale weight. Wasted and refused residue values were added together, and this value was subtracted from the total offered DM to estimate residue disappearance as a measurement of animal intake.

Quality sample analysis

Quality samples for clean, contaminated and refusal residue, as well as the bale core samples from each period, were analyzed for dry matter (DM) using a forced-air oven at 60° C for 48-72 hours, with samples being weighed back when there was less

than 0.02 g fluctuation between three consecutive weights taken. These samples were then ground through a 1mm screen using a Wiley mill. Lab DM was assessed with 24 hr in 100° C oven, and the organic matter (OM) of the samples was measured by incinerating in a 600° C muffle furnace for 6 hr. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed using an automated ANKOM 2000 fiber analyzer (ANKOM Technology, Macedon NY). Approximately 0.5000-0.5040 g of each sample was measured in a 25 micron porosity fiber bags and bags were analyzed sequentially with equal parts sodium sulfite included in the NDF analysis and acetone rinses after both steps. Nitrogen content was measured with an N/protein configured FlashSmart elemental analyzer (Thermo Fischer Scientific, Inc.) using dynamic flash combustion (Dumas method) with EDTA and amino acid standards before to ensure machine calibration. An *in vitro* analysis of the waste samples and bale cores was done in a water bath using modified methods as described by Tilley and Terry (1963), McDougall (1948) and Mertens (1993). Two donor steers consuming a diet of 50% brome grass hay and 50% wet corn gluten feed (Sweet Bran, Cargill Inc., Blair, NE) provided equal parts rumen fluid for sample inoculation. Between 0.5000 and 0.5040 g of each sample was incubated in 100 ml tubes in triplicate for 48 h. Two incubation runs were conducted for each sample type to account for run-to-run variation (Stalker et al. 2015). Three different corn residues, husk, and husklage samples of known *in vivo* digestibility values were included as standards for each run. The measured standard values were used to adjust results by averaging the difference between the known and measured digestibility and adding it to the measured sample values. Incubated samples were filtered and dried to obtain *in vitro*

dry matter digestibility (IVDMD) and then filters were incinerated in a 600 °C muffle furnace for 6 hours to obtain *in vitro* organic matter digestibility (IVOMD).

Statistical Analyses

All data were analyzed using SAS 9.2 software for Windows (SAS Institute, Inc., Cary, NC) using the GLIMMIX procedure. Data were first tested for outliers using Cook's D test and one observation was removed from the data set as an outlier. Since bale was the experimental unit for the Latin Square, both animal block (n = 2; light and heavy) and period (n = 6) were included in the model as fixed effects. Harvest method, chemical treatment, and the interaction between the two factors were also analyzed as fixed effects, and the interaction was removed from the model if found to be not significant (P > 0.10). Results with a P-value of < 0.05 are considered to be significant, with a tendency to be significant when P > 0.05 and < 0.10.

RESULTS

Residue quantification

No interaction between harvest method and ammoniation (P = 0.88) was observed for the initial bale weight. There was a difference (P < 0.01) in total bale weight (Table 4.1) between harvest methods. The 2ROW bales were heaviest compared with both EZB and CONV ($P \leq 0.01$). The EZB was intermediate and different ($P \leq 0.02$) from either of the other harvest methods. The CONV bales ($P \leq 0.01$) weighed the least. Despite the differences in bale weight, when calculated for each pen on a percent of BW, there was no difference (P = 0.89) in initial offered DM between harvest methods. Ammoniation did not affect (P > 0.80) bale weight or initial offered DM on a % of BW basis.

There were no interactions (*P* > 0.32) between harvest method and ammoniation when measuring the wasted and refused (orts) residue (Table 2). There was a tendency (*P* = 0.06) for harvest method to affect the amount of wasted residue, with cows consuming EZB having greater waste (*P* = 0.02). Cows consuming CONV tended (*P* = 0.08) to waste more residue than cows eating 2ROW. However, the difference between EZB and CONV waste was not significant (*P* = 0.50). Ammoniation reduced (*P* = 0.01) waste by 25% (5.7 percentage units). The amount of refused residue did not differ (*P* = 0.11) by harvest method and ammoniation did not affect (*P* = 0.26) the amount of refused residue. There was no interaction (*P* = 0.21) between harvest method or ammoniation for residue disappearance, and both harvest method (*P* = 0.05) and ammoniation (*P* = 0.03) affected disappearance. Disappearance of 2ROW was greater than CONV (*P* = 0.02) but did not differ from (*P* = 0.12) EZB. The disappearance of CONV and EZB did not (*P* = 0.34) differ. There was a 16% (9.5 percentage unit) increase in residue disappearance when the residue was ammoniated.

Residue nutrient characterization

There were no interactions (*P* > 0.37) between harvest method and ammoniation for the nutrient content of the residue offered to cows as measured in the bale core samples (Table 3). Harvest method did not affect (*P* > 0.58) the DM or CP content of the bales. However, there was an effect (*P* ≤ 0.01) of harvest method on the OM, NDF, ADF, IVOMD and DOM of the bales. The 2ROW and EZB bales did not differ (*P* ≥ 0.32), but were greater (*P* < 0.01) in OM, NDF, and IVOMD and lower in ADF content compared to CONV bales. When calculating the DOM content, DOM of CONV bales was lesser (*P* ≤ 0.01) than 2ROW and EZB, which did not (*P* = 0.87) differ. Ammoniation had a

tendency ($P = 0.08$) to result in increased OM compared to non-ammoniated bales. As expected, ammoniation decreased ($P < 0.01$) NDF and increased ($P < 0.01$) CP, IVOMD, and DOM content of the residue.

No interactions between harvest method and ammoniation were noted ($P > 0.23$) in the nutrient content of either waste or orts. There was a tendency ($P = 0.10$) for DM content of the orts to be different among harvest methods, with no difference between CONV and 2ROW ($P = 0.30$) or CONV and EZB ($P = 0.25$), but 2ROW being greater ($P = 0.03$) than EZB. No effect of harvest method ($P > 0.17$) was observed on any of the other nutrients measured for both wasted and refused material (Table 3). Ammoniation did not affect ($P \geq 0.28$) the nutrient content of waste or orts with the exception of DM content of the waste from ammoniated bales being 3.9 percentage units lower ($P = 0.02$) than non-ammoniated bale waste.

Based on the residue disappearance, the estimated daily DMI was calculated as a percent of average pen BW (Table 4). The interaction between harvest method and ammoniation was not significant ($P = 0.11$). Harvest method had a significant ($P = 0.01$) effect on estimated DMI with cows consuming 2ROW having greater ($P \leq 0.03$) DMI than EZB and CONV, while EZB was greater ($P = 0.04$) than CONV. Ammoniation tended ($P = 0.09$) to increase intake from 1.1 to 1.3% of BW.

Based on the difference between what was offered and what remained in the waste and refusals, the estimated nutrient intake was calculated (Table 5). There was no interaction between harvest method and ammoniation ($P > 0.12$) for DM, OM, NDF, ADF, or DOM intake on a kg hd^{-1} d^{-1} basis. However, there was a tendency ($P = 0.08$) for

an interaction between harvest method and ammoniation for CP intake. The CP intake tended to be greater ($P \geq 0.07$) for non-ammoniated EZB (0.38 kg hd^{-1} d^{-1}) compared to non-ammoniated CONV (0.20 kg CP hd^{-1} d^{-1}), but there were no differences ($P \geq 0.29$) between non-ammoniated CONV and 2ROW (0.31 kg CP hd^{-1} d^{-1}) or non-ammoniated 2ROW and EZB (SEM ± 0.073 kg). Ammoniation increased ($P < 0.01$) all CP intakes compared to non-ammoniated residue, but the ammoniated 2ROW CP intake (1.13 kg CP hd^{-1} d^{-1}) was greater ($P > 0.02$) than both ammoniated CONV and EZB (0.84 and 0.89 kg CP hd^{-1} d^{-1}, respectively).

Harvest method significantly ($P \leq 0.03$) affected the intake of DM, OM, NDF, ADF, CP and DOM (Table 5). For all nutrients, CONV intake was lesser ($P \leq 0.01$) than 2ROW. Nutrient intake of 2ROW and EZB did not differ ($P \geq 0.12$) except for DOM intake in which 2ROW tended to be greater ($P = 0.08$) than EZB. Nutrient intake of EZB did not differ ($P > 0.22$) from CONV for DM, ADF, and CP intake, but EZB was greater ($P \leq 0.01$) than CONV in OM, NDF, and DOM intake. Ammoniation increased the intake of all nutrients ($P \leq 0.04$) with the exception of NDF intake, which did not differ ($P = 0.42$) between non-ammoniated or ammoniated residue.

DISCUSSION:

This study demonstrates that cows with access to intact bales of corn residue will exhibit increased intake with selective harvest methods, and as a result, can consume more DOM and CP. However, despite the total DOM composition 2ROW and EZB bales both being greater than CONV, cows did not consistently have greater intake of various nutrients with EZB over CONV. This, in conjunction with the intermediate intake

response of EZB suggests the possibility that animals eating EZB were not able to fully select the same quality of diet as animals selecting 2ROW diets through sorting. Given that Conway et al. (2019) showed EZB had greater stem relative to 2ROW (similar proportions to CONV stem), the effect of diet selectivity and sorting on consumption of intact bales could have an effect on animal intake. Furthermore, animals ate the bales such that the nutrient composition of what remained was similar across all harvest methods, further demonstrating that they selected the highest quality diet they were offered.

The overall intake response due to harvest method in the present study is partially consistent with previous work with selective harvest methods (New Holland Cornrower 2-Row residue and the EZ-Bale system). King et al. (2017) did not observe an increase in intake due to harvest method when growing steers were fed 65% corn residue, 30% distillers solubles, and 3.3% supplemental RUP in a total mixed ration, with cattle eating the diet at 1.9% of BW, regardless of either 2ROW (low-stem) or CONV harvest methods. However, a subsequent study with growing steers fed the same amounts of residue as a mixed ration with wet distillers grains showed an increase in residue intake from CONV to 2ROW residue (1.44 to 1.56% of BW) (Conway et al., 2019). However, no difference between CONV and EZB intakes was observed when fed in the mixed ration, which was contrary to the EZB response observed in the present study. It is possible that the difference in intakes due to harvest method in the present study could be due to the form the feed is offered in, which may provide more opportunity for diet selectivity.

Typically, however, ammoniation has resulted in a significant increase in baled corn residue intake, but the increase was only a tendency in the present study. The overall increase in intake due to ammoniation was 18%, compared to previous work which reports increases in whole diet intake (where residue was 65% of the diet) of CONV, EZB and 2ROW harvest methods ranging between 38.5 to 57% (Conway et al., 2019b). Thesis work by Moore (2013) showed that intakes of cows fed whole bales of non-ammoniated corn residue ranged between 1.94 and 2.08, and ammoniated corn residue intakes ranged between 2.05 and 2.29% BW (Moore, 2013). Although their study design did not allow for statistical comparison, the 6 to 18% numerical increase would suggest the intake response to ammoniation for cows eating whole bales of corn residue was similar to the present study. Both studies offered supplemental protein (2.18 kg hd^{-1} $d^{-1}$of DDGS by Buskirk et al. compared to the 7.5% CP cooked molasses tub offered in the present study) to meet RDP requirements, indicating the intake response is strictly due to diet digestibility. Moore (2013) also provided a mineral supplement targeted to provide 200 mg hd^{-1} $d^{-1}$of monensin whereas no ionophore was provided in the present study. Monensin supplementation on high-forage diets has been shown to affect feed efficiency, digestion kinetics, and animal performance, however the intake effects are not consistent and have not been sufficiently tested with corn residue diets in either a grazing or bale-fed situation (Ward et al., 1990; Galloway et al, 1993; Rodrigues et al., 2004). In the present study, each period was limited to one bale, therefore it is possible that intake was limited on ammoniated diets at the end of the period if these bales were eaten more quickly. Only twice during the study were two pens fed supplemental wheat straw for the

last day of the period due to lack of available residue, but it could be possible that intake would have been greater if an additional bale had been offered.

Interestingly, there was a difference in NDF intake due to harvest method, which did not statistically match the overall intake pattern observed. Animals ate similar proportions of NDF in kg/hd/d as was offered in the bale, with 2ROW and EZB having the greatest NDF intake compared to CONV. However, overall intake diverged from this pattern, with 2ROW intake being considerably greater than EZB, which in turn was considerably greater than CONV. Similar discrepancies in NDF content and intake were observed in the study by Conway et al. (2019b), with overall intakes being similar despite greater NDF content measured in 2ROW residue. This once again suggests that measured NDF content does not appear to be a good predictor of intake with heterogeneous forages such as corn residue, particularly when animals are given greater opportunity to select.

When expressed as kg of daily intake per animal, ammoniation increased the amount of DM, OM, ADF, CP, and DOM regardless of harvest method. Since ammoniation increased CP and DOM in the initial offered bales, the cows were able to consume a higher quality diet. Particularly notable was the CP intake, which showed that when fed ammoniated residue, cows in this study could meet their CP requirements in both early and late gestation. However, assuming DOM is equal to TDN, a 650 kg cow will require between 5.26 to 6.57 kg per day to meet her energy needs throughout her pregnancy. In the present study, the lowest offered DOM was non-ammoniated CONV residue at 2.21 kg, and the highest offered was the ammoniated 2ROW residue 6.03 kg of DOM. When ammoniated, the CONV residue increased to 3.9 kg, and EZB increased to 5.17 kg. This indicates that while the ammoniated selective harvest methods offer enough

DOM and CP to meet the energy and protein requirements of a pregnant cow, CONV harvested residue may require additional supplementation to meet requirements.

The physical characteristics of corn residue and the opportunity for part selection makes evaluating the waste between corn residue and other hay types complex. “Waste” as measured by previous work has been exclusively the forage that was pulled or fell outside of the feeder. In the current study, “waste” and “refusals” must be considered together as overall “uneaten waste”, as the unpalatability of certain corn plant parts (ie: stem) will make complete consumption of the bale unlikely. Nutrient values in the present study for refused and wasted residue were equivalent, suggesting that the refused material would not have been eaten if animals had been given more time to eat the remaining bale. Furthermore, impact of feeder design on amount of wasted forage is the primary objective of most previous work, and these studies have successfully demonstrated that both forage type and feeder design will influence feeding behavior and bale waste (Buskirk et al., 2003; Landblom et al., 2007; Martinson et al. 2012; Moore and Sexten, 2015). Cattle that were fed alfalfa hay or tall fescue in round feeders with bottom paneling and open centers similar to the feeders in the present study, but with tapered sides and neck openings, wasted 4.9% and 13.5% respectively, with an interaction between forage type and feeder (Moore and Sexten, 2015). In the present study, feeder design or forage type did not confound the results, however these factors should both be considered when comparing previously reported waste values.

When controlled for the factors of feeder and forage type in the present study, overall bale waste and refusals were reduced with the 2ROW selective harvest method, but not EZB when compared to CONV, demonstrating that selective harvest method can

influence how the bale is eaten and wasted. Overall, the treatment with the most true waste was non-ammoniated CONV (47.3%), which decreased at most to 20.0% for ammoniated 2ROW residue. Ammoniation decreased CONV waste to 37.3%, and the overall response to ammoniation indicates that this in itself is a successful strategy to reduce the waste of corn residue. In comparison with other work, Buskirk et al. (2003) reported that ring feeders with straight sides and bottom paneling that matched the feeders used in the present study (Weldy Enterprises, Wakarusa, IN; model R7 ring feeder) resulted in 0.7 kg/hd/day wasted alfalfa hay and orchardgrass hay. When the values in the present study were expressed as kg/hd/d, waste from the CONV bales was 0.24 kg and waste from 2ROW and EZB was measured at 0.38 and 0.35 kg/hd/d respectively. This suggested that cows wasted less corn residue than alfalfa hay or orchardgrass when fed from the same feeder type. However, corn residue in the present study was collected and stored in the feed bunk in the pen, allowing the cows to potentially continue eating the residue after it had been collected, compared to the Buskirk et al. (2003) study where residue was collected and removed on a daily basis. In the present study, the quality characteristics of the waste and the refusals did not differ, suggesting that the refused residue (12.4 kg/hd/d for CONV, 9.9 for 2ROW, and 10.7 for EZB) may not have been consumed if animals had continued access to the bales. As such, it may be appropriate to include these refusals as potential DM loss when feeding *ad libitum* corn residue bales compared to hay. Alternatively, thesis work by Moore (2013) fed baled corn residue to 18 dry, open crossbred beef cows, and showed that corn residue waste, when expressed similarly, ranged between 13% (cone feeder) and 38.5 % (ring feeder with straight sides but not bottom paneling). A closed-bottom ring feeder with

tapered sides that was most similar to the feeder used in the present study found that cows wasted 31.7% of the corn residue (Moore, 2013). These corn residue waste values are comparable with what was observed in this study.

In addition to feeder and forage type having an effect on hay waste, Moore and Sexten (2015) noted a relationship between the bale size of the two different forage types and the amount of waste. Although the bale size was not an analyzed factor in the study, the authors observed that the alfalfa hay bales were smaller in diameter and mass compared to the tall fescue hay bales, and this smaller size coincided with less waste. The authors postulate that the smaller bale diameter required cows to reach further into the feeder to eat and pull hay out, reducing the amount of hay dropped outside the feeder, a behavior associated with reduced waste noted in an study with self-feeding head gates (Schultheis and Hires, 1982). In the present study, bale mass was different due to increased bale densities associated with the selective harvest methods. However, the DM offered as a percent of BW was not different, and the bales did not vary in diameter between harvest methods. It is possible that the increased density of the bales was a factor in the reduced waste as the bale did not tend to “crumble” apart as the animals were eating. However, no previous studies have measured the effect of bale size or density on the amount of waste beyond observing differences in forage type. Even so, when taking into account differences in forage and feeder type, the values observed in the present study appear reasonable and add valuable metrics to the limited body of literature available for bale feeding, particularly for corn residue.

CONCLUSIONS:

Cows that consumed intact bales of unground corn residue wasted between 42.3 to 29.3% of bale DM when fed in ring feeders with bottom panels. This amount was reduced using some selective harvest methods, but there was variation in the response between 2ROW and EZB methods. When measuring waste and refusals, total residue disappearance was greater for 2ROW residue compared to CONV harvested residue, and EZB was intermediate between the two other harvest methods. Ammoniation of corn residue effectively reduced bale waste by 25%. Expressed in kg of daily intake per animal, both selective harvest method and ammoniation generally increased nutrient intake compared to non-ammoniated or conventionally harvested residue. The CP in ammoniated corn residue was increased to levels where ammoniated bales provided enough CP to meet nutritional requirements without additional protein supplementation. This study quantified consumption and waste values for cattle fed intact bales of corn residue, and further demonstrated that cattle actively selected a diet when corn residue was offered as an intact bale.

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Table 4.1. Weight of corn residue bales (average DM offered during period) and amount of offered DM as a percent of average BW by harvest method from a 52 d feeding trial with 42 dry commercial beef cows. Main effects shown for harvest method (HM) and ammoniation (AM)

	Harvest Method[1]			***P-values***[2]			
	CONV	**2ROW**	**EZB**	**SEM**	**HM**	**AM**	**HM*AM**
Bale wt, kg DM	447[c]	542[a]	506[b]	21.9	<0.01	0.80	0.88
Initial offered DM, % of BW	1.80	1.84	1.76	0.131	0.89	0.89	0.78

[1] Corn residue utilized was harvested using either conventionally harvested rake-and-bale (CONV), New Holland Cornrower header with two rows of corn plant added to the windrow (2ROW), or the spreader disengaged on the back of the combine (EZBale; EZB). Ammoniated residue was treated at with anhydrous ammonia at 3.7% DM.

[2] Means which share a common superscript are not significantly different from each other ($P > 0.05$).

Table 4.2. Amount of wasted, refused and disappearance of corn residue bales fed to cows in a round bale feeder from three different harvest methods (HM) either with or without ammoniation at 3.7% of DM.

	Harvest Method[1]			***Chemical Treatment***[2]			***P-values***[3]		
	CONV	***2ROW***	***EZB***	***UNAM***	***AM***	***SEM***	***HM***	***AM***	***HM* AM***
	% of offered residue DM								
Wasted residue, %	20.9[ab]	16.4[b]	22.5[a]	22.8	17.1	2.67	0.06	0.01	0.46
Refused residue (orts), %	21.4	12.9	14.9	18.3	14.5	4.49	0.11	0.26	0.32
Total remaining[4], %	42.3[a]	29.3[b]	37.5[ab]	41.1	31.6	5.52	0.05	0.03	0.21
Residue disappearance[5], %	57.7[b]	70.7[a]	62.5[ab]	58.9	68.4	5.52	0.05	0.03	0.21

[1] CONV: conventionally harvested rake-and-bale, 2ROW: New Holland Cornrower header with two rows of corn plant added to the windrow, EZB:spreader disengaged on the back of the combine (EZBale).
[2] UNAM: non-ammoniated corn residue bales; AM: Ammoniated residue at 3.7% of DM.
[3] Means which share a common superscript are not significantly different from each other ($P > 0.05$).
[4] Total remaining residue was estimated by adding the wasted residue and the refused residue.
[5] Residue disappearance was estimated by subtracting the total remaining DM from the amount of initial offered DM.

Table 4.3. Nutrient composition of baled corn residue fed to dry cows as measured by laboratory analysis. Values include measurements for bale cores, wasted residue and refused residue (orts).

		Harvest Method[1]			***Chemical Treatment***[2]			***P-values***[3]		
		CONV	**2ROW**	**EZB**	**UNAM**	**AM**	**SEM**	**HM**	**AM**	**HM*AM**
DM, %	Cores	83.5	83.0	83.7	83.9	82.9	1.10	0.90	0.47	0.90
	Waste	83.5	82.7	80.7	84.2	80.3	2.19	0.37	**0.02**	0.95
	Orts	85.2	90.0	79.9	86.3	83.8	3.22	0.10	0.51	0.40
					% of DM					
OM, %	Cores	88.1^{b}	91.9^{a}	92.5^{a}	90.1	91.5	0.64	**<0.01**	0.08	0.79
	Waste	57.9	56.4	60.7	56.3	60.3	6.62	0.89	0.59	0.61
	Orts	58.4	63.8	56.5	61.2	58.0	6.30	0.67	0.70	0.80
NDF, %	Cores	78.9^{b}	81.0^{a}	81.9^{a}	83.7	77.5	0.55	**0.01**	**<0.01**	0.66
	Waste	76.9	76.6	76.2	76.5	76.6	1.80	0.96	0.94	0.38
	Orts	79.9	79.2	76.0	78.8	77.9	2.04	0.68	0.37	0.54
ADF, %	Cores	57.7^{a}	54.6^{b}	54.9^{b}	55.6	55.8	0.46	**<0.01**	0.66	0.37
	Waste	54.0	53.7	52.8	53.4	53.6	1.04	0.65	0.81	0.88
	Orts	55.3	54.5	53.7	53.4	55.6	1.41	0.17	0.75	0.77
CP, %	Cores	8.3	8.2	8.2	5.6	10.8	0.10	0.58	**<0.01**	0.99
	Waste	7.8	7.6	7.1	7.7	7.4	0.70	0.76	0.69	0.23
	Orts	7.5	7.5	7.0	7.7	6.9	0.75	0.83	0.35	0.61
IVOMD, %	Cores	50.0^{b}	54.6^{a}	54.4^{a}	46.9	59.1	0.65	**<0.01**	**<0.01**	0.76
	Waste	42.8	42.1	41.1	41.0	42.9	1.53	0.70	0.28	0.95
	Orts	41.7	40.6	41.0	39.8	42.3	1.87	0.26	0.92	0.38
DOM, %	Cores	44.1^{b}	50.3^{a}	50.4^{a}	42.3	54.1	0.67	**<0.01**	**<0.01**	0.52
	Waste	35.8	34.9	33.2	34.6	34.7	1.56	0.96	0.45	0.94
	Orts	35.5	36.5	33.2	34.3	35.8	2.27	0.57	0.57	0.34

[1]CONV: conventionally harvested rake-and-bale, 2ROW: New Holland Cornrower header with two rows of corn plant added to the windrow, EZB:spreader disengaged on the back of the combine (EZBale).
[2] UNAM: non-ammoniated corn residue bales; AM: Ammoniated residue at 3.7% of DM.
[3] Means which share a common superscript are not significantly different from each other (*P* > 0.05).

Table 4.4. Estimated daily intake of dry cow consuming bales of corn residue fed in round bale feeders.

	Harvest Method[1]			***Chemical Treatment***[2]			***P-values***[3]		
	CONV	***2ROW***	***EZB***	***UNAM***	***AM***	***SEM***	***HM***	***AM***	***HM*AM***
		% of average pen BW							
Estimated daily residue DMI	0.95[c]	1.40[a]	1.17[b]	1.1	1.3	0.095	0.01	0.09	0.11

[1]CONV: conventionally harvested rake-and-bale, 2ROW: New Holland Cornrower header with two rows of corn plant added to the windrow, EZB:spreader disengaged on the back of the combine (EZBale).
[2] UNAM: non-ammoniated corn residue bales; AM: Ammoniated residue at 3.7% of DM.
[3] Means which share a common superscript within harvest method are not significantly different from each other (*P* > 0.05).

Table 4.5. Least squares means for estimated nutrients consumed by dry cows eating baled corn residue.

	Harvest Method[1]			***Chemical Treatment***[2]			***P-values***[3]		
	CONV	***2ROW***	***EZB***	***UNAM***	***AM***	***SEM***	***HM***	***AM***	***HM*AM***
			Kg hd^{-1} d^{-1}						
DM	6.02[b]	8.51[a]	7.32[ab]	6.70	7.86	0.485	0.01	0.04	0.14
OM	5.43[b]	7.96[a]	7.25[a]	6.20	7.57	0.378	0.01	0.01	0.13
NDF	4.80[b]	6.97[a]	6.20[a]	5.83	6.15	0.339	0.01	0.42	0.12
ADF	3.61[b]	4.70[a]	4.07[ab]	3.81	4.44	0.279	0.03	0.05	0.14
CP	0.52[b]	0.72[a]	0.65[ab]	0.30	0.96	0.049	0.02	<0.01	0.08
DOM	2.96[b]	4.72[a]	4.36[a]	3.16	4.88	0.174	<0.01	<0.01	0.13

[1]CONV: conventionally harvested rake-and-bale, 2ROW: New Holland Cornrower header with two rows of corn plant added to the windrow, EZB:spreader disengaged on the back of the combine (EZBale).
[2] UNAM: non-ammoniated corn residue bales; AM: Ammoniated residue at 3.7% of DM.
[3] Means which share a common superscript are not significantly different from each other ($P > 0.05$).