STRATEGIES TO IMPROVE CORN RESIDUE UTILIZATION

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

STRATEGIES TO IMPROVE CORN RESIDUE UTILIZATION

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a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

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Strategies to improve corn residue utilization

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Dr. Justin Sexten, Thesis Supervisor

Two experiments investigated methods to increase corn residue utilization by forage processing, water and supplement addition, and harvest method. In the first experiment, feeding high-moisture, lower fiber corn stover (CS) both increased DMI and reduced waste. Further processing and bunk feeding dry stover decreased waste but showed no effect on DMI. No harvest method effect was observed within dry stover feeding strategies. Processing and feeding CS in bunks was not effective at increasing DMI, however waste was reduced. Waste was increased in ring feeders compared to bunks due to feeder design and increased sorting ability. In Experiment 2, mixing CS with water and protein supplement was not effective at increasing CS DMI compared to CS fed protein supplement separately. No difference was observed in CS waste between treatments. Mixing liquid protein supplement with CS increased protein supplement waste and ability to sort CS for higher quality fractions. Mixing water or water and supplement with CS resulted in greater NDF and lesser CP in ORTs compared to offered indicating sorting. Increased sorting in moisture-added treatments was due to increased sorption rate of husk and leaf fractions compared to stalk portions resulting in increased husk and leaf palatability without improving stalk palatability.
Chapter 1

Literature Review

Introduction

Cow-calf producers spend between 60 and 70% of their total operating costs on feed (Miller et al., 2001; ERS, 2014). Over fifty percent of herd-to-herd variation in profit can be attributed to feed costs (Miller et al., 2001). Thus, attaining affordable feedstuffs can impact producers’ profitability. This can be a challenge due to large variations in feed costs from year to year. Since 2005, hay prices increased 85% while hay production decreased 6% (NASS, 2014). Hay prices increased 67% in the 2 yr. immediately following the most recent wide-spread drought in 2012, with over 70% of the U.S. land area classified as being under drought conditions (EPA, 2014; NASS, 2014). During these low-supply, high-cost years, cow-calf producers must find affordable alternative forages.

Since 2005, corn grain yield has increased 7% while corn acres planted increased 12% (NASS, 2014). Corn grain production increased 28% in the same time period (NASS, 2014). Corn grain accounts for approximately 50% of the total corn plant dry mass (Prewitt et al., 2007; Shinners and Binversie, 2007). Corn stover (CS), consisting of
cobs, husks, leaves, and stalks, makes up the remainder. Using similar calculations to Sokhansanj et al. (2002), more than 306 million t of CS were produced in 2014, a 28% increase compared to 2005 (NASS, 2014). Harvesting CS can result in warmer soil temperatures, easier planting, and increased disease and insect control in residue remaining on the field (Mann et al., 2002). Excessive CS harvesting can reduce soil organic carbon as well as increase soil erosion (Johnson et al., 2010).

Harvesting CS provides a cellulosic material with many potential uses including a feedstock for ethanol production, livestock bedding, and alternative ruminant forage. In 2014, the United States produced over 14.3 billion gal of ethanol with 1.75 billion gal coming from cellulosic ethanol (RFA, 2014). The Renewable Fuels Standard (EPA, 2014) requires cellulosic ethanol production to be 16 billion gal by 2022. Crop residues are the most common bioenergy feedstock, with CS being the largest crop residue source (USDOE, 2011).

High absorptive qualities and low costs have also made CS a prevalent livestock bedding source. Sawdust availability is the primary limitation for compost bedded barns. Corn stover has similar water holding capacity to sawdust making it a viable alternative (Collins, 2011). Utilizing CS as a ruminant feedstuff has been examined in various feeding strategies including grazing and as harvested forage (Berger et al., 1979; Russell et al., 1993); however, little research has examined harvest method and supplementation type effects on DMI and feeding waste. The objective of this thesis is to quantify DMI and feeding waste as affected by CS harvest method or supplementation type.

**Feeding system**
Multiple feeding strategies have been employed in the past to utilize CS as a ruminant feedstuff. Grazing models provide efficient CS harvest without added harvest expenses (Klopfenstein et al., 1987). In grazing systems, nutrients are returned to the field maintaining soil quality. Whereas, mechanically harvested CS provides marketing flexibility to export nutrients for use as biomass or feedstuff and can be utilized in total mixed rations as low-cost alternative forage.

*Grazing system management issues*

Grazing corn residue presents three main management issues: soil compaction, water supply, and fencing. Clark et al. (2004) evaluated grazing effects on soil bulk density, penetration resistance, aggregate stability, roughness, and surface cover in a corn-soybean rotation. Paddocks were grazed in 4 wk intervals with a remaining paddock used as a non-grazed control. Prior to soybean planting, paddocks were disked or were managed under no-till practices. Soil bulk density and aggregate stability were not affected by grazing. Paddocks grazed in November every year and paddocks grazed in October in two of three years showed increased soil penetration resistance, however this was decreased as proportion of time soil was frozen increased. Soil surface roughness increased when soil was frozen in December and February. Only one no-till field grazed in November, before soil temperatures were below freezing, resulted in decreased soybean yields the following year. Corn residue grazing in this experiment reduced hay needs by 547 kg/hay per cow (Clark et al., 2004).

Lack of perimeter fencing around dedicated crop production fields may present issues for producers interested in grazing CS. However, cows can easily be trained to
inexpensive single strand electric fencing as long as stocking rate does not limit available forage, depending on yield. After the grazing period, fencing may be removed to allow for easier equipment access. Edwards et al. (2012) estimated single strand polywire fencing costs to total $0.20/ft. At this cost, a 100 acre field would cost approximately $1670 to fence.

Water supply is another challenge producers encounter when considering CS grazing. Most producers must haul water to cattle grazing CS due to lack of existing water source. This increases labor inputs and cost.

At grazing period initiation, excess corn grain left in field increases risk for digestive issues such as acidosis. Corn ear drop can be estimated by counting corn ears in small field portions. Acidosis risk can be reduced by supplementation prior to grazing period allowing for gradual conversion from fibrolytic to amylolytic bacteria in the rumen (Wright and Tjardes, 2004; Rasby et al., 2008). Offering ionophores during grazing can reduce acidosis risk due to effects against *streptococci* and *lactobacilli* (Church, 1988).

_Corn stover utilization and composition in grazing system_

Lamm and Ward (1981) evaluated compositional changes in CS when grazed by gestating beef cows. Sixty Hereford x Angus cows were assigned to six lots and stocked at 1.23 cows/ha for an 86-d grazing period. At grazing period initiation, grain, cobs, stalks, and husks-leaves accounted for 11.2, 9.1, 40.8, and 38.9% total plant DM respectively. At grazing conclusion, grain, cobs, stalks, and husks-leaves accounted for 1.4, 13.1, 54.8, and 30.6% total plant DM respectively. This suggests selection behavior
in which cows consumed grain, husks-leaves, cobs, and stalks in that order. Sample analysis showed reduced quality in final CS samples with increased NDF and ADF suggesting winter weathering effects and sorting (Lamm and Ward, 1981). Fernandez-Rivera and Klopfenstein (1989) observed similar selection order by grazing beef stocker calves when comparing irrigated and dryland corn fields. Leaves and husks were the greatest proportion of total utilized residue ranging from 65 to 72% in all three years. As expected, irrigated corn fields had increased CS yields; however, dryland CS had a greater leaf-husk to stalk ratio suggesting increased CS digestibility in dryland CS fields (Fernandez-Rivera and Klopfenstein, 1989).

Grazing CS is the most economical utilization method; however, harvest efficiencies are considered low in continuous grazing systems (Lamm and Ward, 1981; Klopfenstein et al., 1987). Strip-grazing and altered stocking rates could potentially increase harvest efficiencies compared to continuous grazing. Fernandez-Rivera and Klopfenstein (1989) observed 32 and 47% CS utilization by growing calves stocked at 368 and 590 kg BW/ha respectively. Russell et al. (1993) examined a strip-grazing system and stocking rate effect (384, 768, and 1537 kg BW/ha) in a continuous grazing system. Cows stocked at 384 kg BW/ha showed gained BW while cows stocked at 768 and 1537 kg BW/ha lost BW, with no difference between lesser allowances. Stripstocking system was shown to be highly weather dependent. Cows in this system had increased BW gains compared to continuous grazing systems stocked at the same rate when little snow was encountered. Cow BW were lower in strip-stockling system compared to continuous grazing system during years with harsher weather conditions. Thus, selecting ideal grazing system varies from year to year based on weather conditions.
(Russell et al., 1993). This is further supported by Ward (1978) who stated weather is the most important crop residue utilization factor.

Stalker et al. (2015) evaluated stocking rate effect on cattle performance and subsequent grain yields. Late-gestation cows were allocated to CS paddocks at 1136 or 2272 kg BW/ha. Esophageally fistulated cows were also used to examine OM disappearance between samples taken pre- and post-grazing. At grazing period conclusion, cows stocked at 1136 kg BW/ha had increased BW gains compared to cows stocked at 2272 kg BW/ha. This was due to increased sorting ability in the less dense 1136 kg BW/ha treatment allowing for increased DMI of more digestible fractions. Increased stalk proportion was observed at grazing period conclusion in the 2272 kg BW/ha treatment. These results agree with previous work by Klopfenstein et al. (1987). Both grazing treatments utilized the higher quality husk and leaf portions. Leaf utilization was 42 and 47% for the 1136 kg BW/ha and 2272 kg BW/ha treatments respectively. Husk utilization was 57 and 82% for the 1136 kg BW/ha and 2272 kg BW/ha treatments respectively. No difference was observed in cob or stem mass pre- or post-grazing in both grazing treatments. Baling reduced all components regardless of quality suggesting grazing utilizes high quality portions without removing lower quality portions. There was no difference in IVOMD between 1136 and 2272 kg BW/ha treatments pre-grazing. At grazing period conclusion, 1136 kg BW/ha IVOMD was greater compared to 2272 kg BW/ha. No difference was observed in CP as %OM between stocking rates or between fall and spring samples. Corn grain yields were measured over a 5 year period to determine grazing effect on subsequent grain production. No effect was observed for corn grain yields within any individual year or averaged across the years (Stalker et al., 2015).
Grazed corn stover typically does not meet the nutrient requirements for a gestating cow. Supplementation may be required to prevent BW and body condition loss during the grazing period. Warner et al. (2011) evaluated late gestation protein and energy supplementation during CS grazing effect on cow and subsequent calf performance. Cows were supplemented with a dried distillers grain based cube (25% CP, 7% Crude Fat) at 1 kg/cow/d. No differences in supplemented vs. non-supplemented cows were observed in BW change throughout the grazing period. No differences in subsequent heifer calf progeny performance were observed. Subsequent steer progeny were not different in growth performance or carcass merit (Larson et al., 2009; Warner et al., 2011). These results are likely due to weather conditions and adequate grazing allowance allowing for greater selectivity for high quality portions (Ward, 1978; Russell et al., 1993). Increased supplementation may be required when more intensive stocking rates are used. Russell et al. (1993) observed BW loss in cows grazing CS when stocked at or above 768 kg BW/ha suggesting insufficient nutrient intake. Supplementation must account for nutrient deficiencies caused by over-stocking.

Appropriate CS grazing allowance is poorly defined, likely due to differences in forage utilization rate and yield from year to year. One animal unit month (AUM) is defined as the forage amount required to maintain one 454-kg cow for one month. This is calculated to be approximately 364 kg forage on a DM basis; however, this assumes complete utilization and constant intake. Previous reports have shown CS utilization to be less than 50% (Fernandez-Rivera and Klopfenstein, 1989; Moore, 2013; Stalker et al., 2015). Considering this utilization rate, CS grazing allowance should be calculated to
200% of typical AUM used for other forages. Due to differences in yield, CS stocking rates must be determined on an annual basis.

Grazing results in reduced nutrient removal and increased nutrient cycling through excreta and urine. After ingestion, nutrient return rates to the field range from 70 to 90% (Haynes and Williams, 1993). Nutrient return may not be uniform due to increased excreta in high-frequency feeding or watering areas. However, management techniques such as increased stocking rates or rotational grazing can result in more uniform nutrient distribution (Haynes and Williams, 1993; Dubeux et al., 2006). Grazing CS has been shown to have no effect on subsequent corn grain yields and minimal effect on soybean yields in a corn-soybean rotation (Clark et al., 2004; Tracy and Zhang, 2008).

**Harvested corn stover management issues**

Mechanically harvesting CS allows for increased market flexibility for use as a cellulosic ethanol feedstock or ruminant feedstuff. Harvesting reduces forage quality loss due to weathering compared to grazing as mechanically harvesting removes CS within a short period while grazing harvests CS over a longer period. Corn stover harvested mechanically may be lower quality as baling has been shown to harvest all corn stover components including the most abundant, low-quality stalks and cobs whereas selective harvest occurs in grazing models (Shinners and Binversie, 2007; Stalker et al., 2015).

Producers considering harvesting CS must consider logistical issues. Labor required to harvest CS causes timing issues when grain harvest is the primary concern. Maung and Gustafson (2013) created a mathematical model to compare economics between no CS removal, a one-pass harvest system, and a two-pass harvest system. One-
pass CS harvest systems utilize a cob harvester or CS baler directly behind the combine to harvest CS simultaneous to grain harvest. A two-pass harvest system separates CS and grain harvest and requires separate labor inputs post-harvest. One-pass corn residue harvesting systems reduce post-grain harvest labor inputs. However, these systems have been shown to reduce combine speed and grain harvest rates by up to 50% while doubling fuel use (CVEC, 2009). Based on these results, Maung and Gustafson (2013) reported increased corn grain harvest cost from $70.94/ha to $141.91/ha. Multi-pass systems do not reduce grain harvest rates and allow for CS field drying. However, labor inputs after grain harvest are increased. Grain harvest costs in this system are no different than harvest costs when no CS is harvested, $70.94/ha. Corn stover harvest tractor and baler costs were estimated to be $26.59/ha. Mowing and raking prior to baling costs $29.70/ha resulting in $56.29/ha total CS harvest costs. Maung and Gustafson (2013) also evaluated producer willingness to harvest CS based on grain harvest field time. Grain harvest field time varied greatly from year to year due to weather conditions. As harvest field time increased, farmers were more willing to allocate labor to CS harvest. Based on these cost estimates and issues with labor required during harvest season, it was suggested the most economical CS harvest system was to utilize a third party to bale, transport, and store CS bales (Maung and Gustafson, 2013).

Another cost associated with CS harvest is harvest equipment wear and tear. Corn stover physical properties increase equipment wear, especially on equipment not specifically designed for CS harvest (Milhollin et al., 2011). Cook and Shinners (2011) created an economic model to evaluate different CS harvest systems. They estimated baler life can be reduced by 40% when harvesting CS. In addition to increased labor
inputs associated with harvest compared to CS grazing systems, harvested CS also requires proper storage to minimize DM and nutrient loss due to weathering.

Shinners et al. (2007) evaluated harvest method and storage type effect on CS DM loss. Corn stover was harvested with a large round baler or large square baler, wrapped in sisal twine, plastic twine, or net wrap, and stored indoors, outside directly on the ground, or outside on pallets. Dry matter loss was not different between bales types stored indoors, averaged 3.3% over a two year period, and was less than all outdoor stored treatments (18.1%). Sisal twine tied bales (30.4%) had greater DM losses compared to plastic twine (13.9%) and net-wrapped (10.0%) bales. This was reported to be due to sisal twine rotting away at the bale base, causing CS to be sloughed from the bale base when it was removed from storage. Sloughed material was deemed unrecoverable and considered DM storage loss. Moisture was able to drain away from bales stored on pallet, reducing DM losses. Storage DM loss was observed in ensiled high-moisture (60-70% DM) bales. Average DM loss across treatments was 2.9% and no difference was observed between bale type or sisal twine, plastic twine, or net wrap treatments (Shinners et al., 2007).

*Harvest efficiency*

High-moisture CS is a by-product of high-moisture corn grain (HMC) harvest. Producers harvest HMC to reduce field losses, eliminate artificial drying costs, harvest at an earlier date, and harvest a high quality livestock feed. High-moisture corn grain is higher in TDN, RDP, and energy compared to typical corn grain (NRC, 2000). Harvest DM losses can be reduced 3 to 8% compared to dry corn (Mader et al., 1983). Reduced marketing flexibility and increased storage requirements can reduce HMC’s added value.
High-moisture corn is ground, rolled, or stored as whole shelled corn anaerobically in silage bags or bunkers to prevent mold growth (Mader and Rust, 2006).

Harvest efficiencies were observed across a two-year period between high-moisture and dry CS after mowing, raking, and baling (Shinners et al., 2007). High-moisture CS had improved harvest efficiencies compared to dry CS treatments. High-moisture CS was harvested immediately after grain harvest while dry CS remained in field for a drying period. This drying period varied greatly between year 1 and year 2 due to adverse weather conditions. Year 1 dry CS harvest occurred 42 d after grain harvest while year 2 dry CS harvest occurred 7 d after grain harvest. Stover DM loss due to wind and biological degradation was suggested to cause the decrease in harvest efficiency compared to high-moisture CS treatment. High-moisture CS was also observed to increase baler pickup efficiency (Shinners et al., 2007).

Corn stover harvest methods and removal rates affect CS yield and quality (Hoskinson et al., 2007; Shinners et al., 2007; Webster et al., 2010). Hoskinson et al. (2007) evaluated a one-pass CS harvest system with different cutting heights on CS yield. Combine head cutting height was adjusted resulting in low cut, normal cut, and high-cut treatments leaving 10, 40, and 75 cm of stubble respectively. Low-cut, normal cut, and high-cut resulted in 6.68, 5.09, and 4.86 t/ha DM respectively. Normal cut decreased removal rate by 24% compared to low-cut, however, field efficiency was improved due to increased ground speed. Nutrient removal was evaluated among treatments. Low-cut removed 47.1 kg/ha N compared to 42.0 kg/ha N removed by normal cut. Nutrient replacement costs for high-cut and normal cut harvest strategies averaged $54.41/ha.
Low-cut strategies require $67/ha to replace nutrients respectively (Hoskinson et al., 2007).

Producers can use equipment typically used for hay production to harvest CS. Prewitt et al. (2007) evaluated harvest method effect on harvest efficiency using typical hay equipment. In year 1, CS was either baled only \( \textbf{BO} \), raked and baled \( \textbf{RB} \), or mowed, raked and baled \( \textbf{RC} \). In year 2, the three previous treatments were used along with a flail-type mower with windrow-forming shields treatment \( \textbf{RS} \) and a treatment using a disengaged straw chopper and spreader on the combine resulting in a windrow which was then baled directly \( \textbf{BD} \). Two calculations were used each year to calculate total available stover, a 1:1 grain-to-stover ratio and a regression equation using plant components and grain yield based on location within field. Calculated harvest efficiencies were approximately 10% less when calculated using the regression equation however there was no difference in harvest efficiency trends between calculations. In year 1, harvest efficiency was greater for RC compared to BO and RB was. In year 2, harvest efficiency was greater for RS compared to all other treatments. No difference was observed between BO and RB in year 2. In year 1, CS was baled three weeks after grain harvest at less than 20% moisture. Corn stover in year 2 was baled four days after grain harvest with between 25% and 35% moisture. Although this increases the potential for molding or heating during storage, no mold signs were observed. Stover bales harvested in the BD treatment were not individually tracked preventing statistical comparison. However, BD was suggested to be an efficient and easy-to-implement strategy for producers wanting to maximize CS harvest without increasing labor. Harvest efficiencies
for BD ranged from 74.1% to 77.4% across years and did not require additional field traffic for raking or mowing (Prewitt et al., 2007).

**Erosion and nutrient removal**

In order for CS harvest to remain a common production practice, appropriate harvest methods and removal rates must be utilized to prevent long-term effects on soil quality and erosion. Blanco-Canqui and Lal (2009) investigated CS removal rate effect on soil fertility and structural stability. Five removal rates (0, 25, 50, 75, and 100%) were used at three different locations varying in soil type and slope over a 4 year period. Complete CS removal decreased total N and soil organic carbon (SOC) up to 10 cm depths. Higher slope increased total N and SOC losses from 0% to 100% CS removal with no difference at intermediate removal rates. Similar results were observed when measuring P, K+, Ca++, and Mg++. These results suggest negative effects on soil quality and nutrient availability when CS is completely removed (Blanco-Canqui and Lal, 2009).

Johnson et al. (2010) evaluated CS removal effect on nutrient removal in various regions across the United States. Corn plants were sampled from multiple field locations in a 1.0-m² area, separated based on plant part, and cut at 10 cm intervals to examine cutting height effect. All samples above the ear were combined into a single sample for nutrient analysis. Samples were taken at physiological maturity and at grain harvest. As expected, decreasing cutting height resulted in greater nutrient removal and thus less nutrient return to the field. When calculated based on a 5-year nutrient cost average (2005-2009), total N ($0.78/kg), P ($2.78/kg), and K ($0.96/kg) would cost $52.76/ha to return to the field. Harvesting CS below the ear would increases costs $36.23/ha.
Collecting cobs costs the producer $11.66/ha to return to the field. Harvesting CS below the ear also reduced feedstock quality. This suggests harvesting CS above the ear can not only improve feedstock quality, but also reduce nutrient removal and costs associated with fertilizer (Johnson et al., 2010).

Corn stover removal effect on erosion rate must be determined when considering CS harvest. Wind and water erosion have been shown to reduce OM and subsequent corn grain yields (Schertz et al., 1989). Wienhold et al. (2013) evaluated removal rate effect on subsequent corn grain yields and soil erosion. Three experiments compared non-irrigated vs. irrigated corn fields under disk-tilled or no-tillage management. The first experiment showed no difference between 0 and 50% residue removal when averaged among treatments suggesting no detrimental grain yield effects of CS harvest. The second experiment showed increased grain yields with 40 and 80% residue removal compared to no removal. In the third experiment, 53% residue removal resulted in greater sediment loss (30%) (Wienhold et al., 2013) compared with no removal. These experiments suggest CS harvest can be beneficial to both the crop producer and cow-calf producer when proper management techniques are utilized.

Graham et al. (2007) evaluated previous corn grain production to calculate CS availability and cost based on nutrient removal and losses to water and wind erosion. Stover production was calculated using a 1:1 corn grain to stover ratio, a common method in calculating CS availability (Sokhansanj et al., 2002; Shinners and Binversie, 2007). Based on wind and water erosion constraints preventing erosion rates to increase above 0.5 T and current production practices at the time, only 28% of the total available CS could be harvested for less than $33/t. This amount was calculated as the farm gate
cost for the harvested CS. Areas with greater CS production can harvest increased proportions at a lower cost due to adequate remaining nutrients and residue to prevent soil erosion. Universal no-tillage farming practices could double total CS available to be harvested without increased erosion rates or reduced soil quality (Graham et al., 2007).

Wilhelm et al. (2007) suggested SOC was a greater constraint to CS amount available for harvest than water and wind erosion. Soil organic carbon is crucial in soil nutrient recycling and as an energy source for soil microbial population. Corn stover harvest rates when presented as a percentage can be misleading due to differences in grain yield from year to year. These results indicate forage amount required to remain in the field. Using no-tillage farming practices in a continuous corn system, 5.25 t/ha is needed to retain appropriate SOC levels. When using a moldboard plow system, CS needed is increased to 7.5 t/ha. These values are increased when utilizing a corn-soybean rotation. Further research is needed to more accurately assess available CS to maintain SOC levels as CS harvest popularity increases due to increased availability and greater interest for ruminant feedstuff and biomass feedstock (Wilhelm et al., 2007). As grain yields continue to increase, CS availability will also increase due to 1:1 grain to CS ratio (Shinners and Binversie, 2007).

Supplementation

Corn stover can provide an abundant, low-cost forage supply for ruminants; however, supplementation may be required depending on CS quality. Forage quality changes over time as the corn plant matures (Pordesimo et al., 2005). Berger et al. (1979) observed increased ADG in steers fed less mature CS harvested during high-moisture
corn grain harvest compared to more mature CS harvested during typical corn grain harvest. Corn stover typically contains 3.4% to 6.3% CP (Klopfenstein et al., 1987; NRC, 2000). Previous research states 7% CP will supply enough N to meet rumen microbe ammonia requirement (NRC, 1984), suggesting N supplementation may be required. Additionally, supplementation delivery can increase labor inputs, in turn reducing cost savings.

Changes in forage quality over time potentially changes supplemental nutrient requirements. Ward et al. (1979) evaluated supplementation effect on mid-gestation cow performance when grazing corn residues. Cows were provided either 0 or 0.23 kg CP/d from a soybean meal (SBM) range cube. Supplemented cows had greater ADG than non-supplemented cows. Gains were greater for both treatments during the early grazing season, however as the grazing season continued, gains were reduced. This was suggested to be due to CS availability and quality towards grazing period conclusion as CS CP declined as the grazing season continued. Corn stover quality degradation throughout the grazing season was attributed to weathering as well as cow selection behavior for higher quality leaf portion early in the grazing season increasing stalk proportion as grazing season concluded (Ward et al., 1979). These results indicate CS may provide enough nutrients early in the grazing system to prevent BW loss; however, protein supplementation is required later in the grazing season as forage quality declines.

In order for CS feeding to be a viable alternative forage, cow performance must not be reduced. Corn stover bales supplemented with corn coproducts can replace hay without sacrificing performance and reduce costs. Braungardt et al. (2010) compared dried distillers grains with solubles (DDGS) supplementation with CS bales to free-
choice alfalfa hay. Lactating cows fed CS bales and supplemented DDGS lost less BW compared to cows given access to free-choice alfalfa. However, no differences were observed for milk production or subsequent calf ADG. Based on costs at time of experiment, feed costs were reduced by approximately $1.00/cow/d when feeding CS bales supplemented with DDGS (Braungardt et al., 2010). Providing supplementation to account for low CS quality can increase labor inputs thus reducing savings associated with feeding CS. Alternate day protein supplementation reduces feeding labor and grazing disruption. Collins and Pritchard (1992) evaluated daily and alternate day supplementation methods and found no difference in CS DMI or animal performance between treatments.

Liquid corn coproducts such as corn condensed distilled solubles (CCDS) are readily available and can be mixed with forage or provided free-choice to supplement protein and reduce labor inputs. Doran et al. (2008) evaluated using lick tanks to provide free-choice CCDS to cows grazing low-quality forages during the summer. As forage quality and thus DMI declined in late summer, CCDS consumption increased. Average CCDS consumption ranged from 1.21 kg to 3.68 kg/cow/d. High CCDS sulfur concentrations may cause sulfur toxicity when offered free-choice. Maximum tolerable Sulfur levels for cattle consuming high forage diets is 0.50% (NRC, 2005). Cows in this experiment consumed 0.43% to 0.62% sulfur depending on CCDS consumption; however, no health issues were observed (Doran et al., 2008).

Further research using lick tanks or mixing liquid protein supplement with forage was conducted by Walker et al. (2013). Two studies were used to evaluate hay waste and cow performance when cows were offered low-quality forages supplemented with a
liquid protein supplement. In the first experiment, cows were offered free-choice liquid protein supplement in lick tanks (TNK), liquid supplement poured onto bales at 10% bale DM weight (POR), or provided 1.25 kg DDGS daily (DRY). The second experiment utilized the same TNK treatment in addition to liquid protein supplement poured on bales at either 10% bale DM weight (POR10) or 15% bale DM weight (POR15). In the first experiment, no difference was observed between treatments for hay DMI. Hay waste was less in the POR treatment compared to TNK; DRY hay waste was not different from POR or TNK. Similar results were observed in the second experiment. No difference was observed in hay DMI between treatments. Hay waste was less for POR10 and POR15 compared to TNK. In the second experiment, cow performance was measured using three different cow BW groups: light, medium, and heavy. Cow BW gain was greater for TNK compared to POR15 in the light and medium groups and not different in the heavy group. Cow BW gain was the least in POR10 for the light and heavy groups and not different in the medium group compared to TNK. This suggests providing liquid protein supplement in free-choice lick tanks or mixed with forages provides an effective supplementation alternative. Mixing liquid supplement with low-quality forage can increase utilization and reduce waste (Walker et al., 2013).

**Chemical treatment**

Chemical treatment can increase low-quality forage utilization efficiency by ruminants. Ammoniation and calcium hydroxide or oxide use are the current common methods to improve crop residue digestibility.

*Ammoniation*
Ammoniation is a practical forage quality improvement strategy using forage in bale form. Anhydrous ammonia treatment partially solubilizes bonds between hemicellulose and lignin increasing digestibility and increases N content in forages through N retained from ammonia (Berger et al., 1994). Ammoniation requires forage to be covered and sealed with six to eight millimeter black plastic sheeting. Anhydrous ammonia is added at 3% forage DM weight. Forage must remain sealed for one to eight weeks depending on external temperature and plastic must be removed three to five days prior to feeding to allow for excess ammonia dissipation (Rasby et al., 1989).

Saenger et al. (1982) investigated CS ammoniation effects on digestibility, intake, and cattle performance. Ammoniation resulted in greater CP content improving low-quality forage nutritive value. Corn stover treated with ammonia retained more nitrogen and was more digestible compared to non-treated CS. Cows fed treated CS had greater DMI resulting in greater weight gains.

Ammoniation is a cost effective method to improve forage utilization. Ammoniation costs were calculated using current cost estimates for plastic sheeting ($174/roll), and anhydrous ammonia ($801/t). Using these estimates, treatment costs were calculated to be $31/t. This cost in addition to current CS cost of $31/t (USDA, 2015) totals $81/t. This total is significantly less than previous 5-year average per ton hay price ($162.8/t) (NASS, 2014).

Strong base treatment

Applying a strong base such as calcium hydroxide or calcium oxide to crop residues can increase digestibility by partially solubilizing hemicellulose, lignin and silica
(Berger et al., 1994). Calcium hydroxide is the hydrated form of calcium oxide. Both are mixed with water to form slurry to be applied to the forage. Calcium oxide undergoes a chemical reaction with water producing heat. Maintaining forage at 50% moisture can reduce handling and storage issues caused by heat from the reaction. The hydrated form, calcium hydroxide, has already undergone chemical reaction with water and thus does not produce heat when applied to CS. Calcium hydroxide and calcium oxide are typically added at 7 and 5% forage DM weight, respectively. The calcium hydroxide or oxide slurry can be applied to CS directly behind the combine using a sprayer over the windrows. The slurry can also be sprayed on the CS as it is exiting the forage processor or mixed with processed CS immediately prior to anaerobic storage. Unlike ammoniation, forage treatment with calcium hydroxide or oxide does not increase forage N content; thus, N supplementation is necessary to meet requirements. Both Ca methods increase CS calcium content helping to maintain proper calcium to phosphorus ratio when providing a corn coproduct supplement high in phosphorus such as DDGS (NRC, 2000).

Shreck et al. (2015) evaluated calcium oxide treatment effect on CS digestibility and subsequent steer performance. The first study utilized treated or untreated CS at 10% inclusion. Diets were fed to 366 crossbred steers through the finishing phase. Calcium oxide treatment decreased CS NDF 13.1% compared to untreated CS. No difference in DMI was observed between treatments. Calves on treated CS diet had greater ADG and thus improved feed efficiency. A second experiment was a metabolism study fed treated or untreated CS in the diet at 15% inclusion. Fiber digestibility was greater for treated CS compared to untreated CS. Treating CS increased diet DM and OM total tract
digestibility 11.3% and 12.1% respectively. Neutral detergent fiber total tract digestibility was greater for treated CS compared to untreated. These results suggest using treated CS as a 10-15% dry-rolled corn replacement can provide increased performance and NDF digestibility.

Costs associated with calcium oxide treatment will depend on equipment availability and storage capability. Corn stover is typically processed and then mixed with calcium oxide and water. If CS is not planned to be used immediately, it must be stored anaerobically to prevent mold. Based on 5% DM treatment levels and $260/t cost for calcium oxide, one dry t CS treatment would cost $13/t. This cost does not include processing costs or cost needed for added N supplementation.

**Forage feeding losses**

Corn stover can be fed using multiple delivery methods including free-choice bales or bunk-feeding. Feeding processed forages in bunks reduces waste compared to feeding intact large round bales but requires processing equipment and increased feeding infrastructure (Landblom et al., 2007). Feeding processed forages can also increase DMI due to reduced sorting ability and increased passage rate (Osafo et al., 1997; NRC, 2000; Kononoff et al., 2003). Grass hay baled by a conventional baler or a baler fitted with a forage processor was used to investigate processing and feeder effect on hay waste by Sexten and Lalman (2011). Processing hay resulted in greater waste compared to unprocessed hay when fed to gestating cows. No difference was observed in DMI between treatments.
Large round bale feeder design has been shown to impact forage waste (Buskirk et al., 2003; Moore and Sexten, 2015). Cone feeders or ring feeders with sheeting are the most effective in reducing large round bale hay waste (Buskirk et al., 2003; Moore and Sexten, 2015; Tomczak and Sexten, 2015). However, increased forage waste has been observed when feeding CS bales in large round bales compared to waste typically associated with low-quality forages (Moore, 2013).

Moore (2013) evaluated feeder design and ammoniation effect on CS waste and sorting. In the first experiment, large round bale CS was fed in open bottom feeders with no sheeting, tapered side feeders with sheeted bottom, or a cone feeder with sheeting on the top and bottom. Waste tended to be greater in ring feeders compared to cone feeders. In a second experiment, ammoniated large round bale CS was fed in feeders used in the first study. Waste as a percent of bale was greater for open ring feeder compared to tapered and cone feeders. Greater CS digestibility from ammoniation was expected to reduce waste values compared to untreated CS however no difference was observed. Sorting for higher quality components was evident in both studies (Moore, 2013).

**Summary**

As corn grain yields continue to rise due to advancements in technology, CS continues to become a greater management concern to prevent any reduction in grain yields. Feed costs are highly variable from year to year and are highly influential on profitability. Corn stover provides a viable, low-quality alternative forage for cow-calf producers when hay prices become expensive due to drought or low availability. Mechanically harvesting CS might be inefficient as baled CS is primarily stalk, the
lowest quality portion typically refused due to sorting ability. Baled CS may only be 50% usable CS as total refusal for intact CS has been previously documented as 50%. More efficient methods must be determined to account for costs associated with harvest, transportation, and storage. Processing or mixing CS with supplement can potentially reduce sorting and increase stalk consumption and utilization. Producers must be able to adapt to changes in forage costs and maximize forage utilization to remain profitable.
Chapter 2

Harvest method and feeder type effects on corn stover intake and waste in gestating beef cows

Abstract

Thirty non-lactating, mid-gestation crossbred cows (575 ± 59 kg) were used in a 5 x 5 Latin square to evaluate corn stover (CS) harvest method and feeding strategy on DMI and waste in gestating beef cows. Dry CS (90% DM) was mowed and raked (DMR) or raked only (DR) then baled and barn stored. High-moisture CS (58% DM) was mowed, raked then baled and wrapped to exclude oxygen (WMR). Corn stover bales were offered in a conventional open bottom ring feeder (RING) or processed through 20-cm screen and offered in fence-line bunks (BUNK). Processed high-moisture CS feeding was hypothesized to increase DMI and reduce waste. Stover harvest by raking only was hypothesized to result in greater quality forage and increase DMI. A distillers grain-based supplement containing monensin at 200 mg•cow⁻¹•day⁻¹ was offered separate from CS at 1.58 kg•cow⁻¹•day⁻¹. Stover DMI was calculated by subtracting ORTs and collected waste from DM on offer then dividing by number of cows per pen. Daily CS DMI was greater (P < 0.05) for DR-RING (9.2 kg, 1.56% BW) and WMR-BUNK (9.0 kg, 1.53% BW) compared to DMR-BUNK (7.2 kg, 1.22% BW) and DR-BUNK (7.5 kg, 1.28% BW); DMR-RING (8.3 kg, 1.41% BW) was not different (P > 0.05) from all other treatments.
Daily waste was greater ($P < 0.05$) for ring-fed treatments compared to processed, bunk-fed treatments. Fiber was lower ($P < 0.05$) for WMR-BUNK initial (65.1% NDF, 37.4% ADF) and waste (65.4% NDF, 38.2% ADF) than all other treatments. Initial CS NDF was greater ($P < 0.05$) in DMR-RING (81.9%) compared to DMR-BUNK (79.3%) and DR-BUNK (78.6%); DR-RING (79.9%) was not different ($P > 0.05$) from all other dry treatments. NDF in CS waste was less ($P < 0.05$) in DMR-BUNK (72.7%) compared to DMR-RING (79.6%) and DR-RING (78.3%); DR-BUNK (75.0%) was not different ($P > 0.05$) from all other dry treatments. Offering unprocessed CS in ring feeders allows for selection behavior and resulted in greater DMI and waste. Bunk feeding dry, processed CS at 10% above expected intake was effective at reducing waste but reduced DMI due to reduced sorting ability. Increased amount on offer may prevent DMI reduction but increase refusal. Feeding processed high moisture, lower fiber CS in fence-line bunks resulted in the greatest DMI and least waste.

**Introduction**

According to the USDA, feed costs account for 70% of the total cow-calf production operating costs (ERS, 2014). In the last decade, hay production decreased 6% and price received for hay increased 85% (NASS, 2014). Concurrently, corn acres planted increased 12% and yield per acre increased 7% (NASS, 2014). Corn stover (CS) accounts for approximately 50% of the total corn plant (Shinners and Binversie, 2007). Therefore, as corn grain yields increase, so does corn stover availability. Excess corn residue can interfere with planting and decrease potential grain yields (Mann et al., 2002). Wiebold (2010) observed increased grain yields and stand density when 50% of the total
available stover was removed. Harvested CS can provide a cost effective forage source in years of exaggerated hay prices.

Feeding CS in large round bale feeders increases waste compared to reports typically associated with low-quality forages. Moore (2013) reported 38.7% CS waste as a percent of bale when fed in open, non-sheeted ring feeders. Waste could be reduced through further processing and bunk-feeding (Landblom et al., 2007). Reducing corn silage particle size has been shown to reduce sorting and increase DMI in lactating dairy cattle (Kononoff et al., 2003). Osafo et al. (1997) observed reduced sorting ability and increased stem consumption in cattle consuming chopped sorghum stover compared to whole sorghum stover.

Moore and Sexten (2015) measured DMI and waste using different quality forages. Low-quality fescue hay had increased waste in tapered and open ring feeders (Moore and Sexten, 2015). Higher moisture forages lower in NDF and higher in CP used by Moore and Sexten (2015) resulted in reduced forage waste. Corn plant quality declines as plant matures (Pordesimo et al., 2005); therefore, harvesting less mature CS should result in higher quality forage, potentially reducing waste.

Raking and baling removes 57.2% CS while mowing, raking, and baling has resulted in 65.7% CS removal (Prewitt et al., 2007). Mowing and raking increases yield due to increased harvest efficiency; however, this could potentially increase harvested stalk proportion and decrease quality. The less digestible stalk fraction accounts for the largest CS fraction (50%) at typical CS harvest (Shinners and Binversie, 2007). Raking
alone may decrease stover yield, however forage quality can potentially be increased due to decreased stalk harvest.

Experimental objective was to quantify corn stover waste and intake by gestating beef cows as affected by harvest method and feeding strategy. Processing CS and feeding in bunks was hypothesized to reduce waste and increase DMI compared to unprocessed CS offered in ring feeders. Processed, high-moisture CS feeding was hypothesized to increase DMI and reduce waste. Dry stover harvested by raking only was hypothesized to increase DMI and reduce waste in both feeding strategies compared to dry mowed and raked CS due to greater forage quality.

Materials and methods

Cows, supplements, and facilities

All animal use procedures were approved by the University of Missouri Animal Care and Use Committee.

Thirty non-lactating, mid-gestation crossbred cows were used in a 2 X 2 + 1 factorial treatment arrangement within a 5 X 5 Latin square design. Three forage types and two feeding strategies were used to evaluate harvest method and feeding strategy effects on corn stover DMI and waste. Cows were stratified by 24-h shrunk weight (575 ± 59 kg), BCS (4.6 ± 0.1 units), and stage of gestation into 5 replicates with 6 cows per replicate. Replicates were randomly assigned to one of five, 18 x 61 m dry lots with lime floors containing a south-facing barn and 9.8 m of bunk space adjacent to the barn along the north pen edge. Stover was offered and waste was collected in ring-fed treatments on a 9.1 x 9.1m concrete pad located at each pen’s center. A dried distillers grain-based
supplement (Table 2.1) containing vitamin and mineral mix and 400 g/909 kg monensin (Rumensin, Elanco Animal Health, Greenfield, IN) was offered daily at 1.58 kg DM •cow•day•1 immediately after forage remaining in feeder (ORT) was collected.

Forage and feeding strategies

High-moisture (58% DM, 6.5% CP, 69.8% NDF, 40.2% ADF) CS of the same variety (MC4134 RIB VT2P, MFA Inc., Columbia, MO) was mowed, raked (WMR), then baled in October of 2013. High-moisture CS bales were wrapped in a row immediately after harvest using an inline bale wrapper (NWS 660; Anderson Group Co., Chesterville, QC) to exclude oxygen and stored until feeding. Dry (90% DM) CS of the same variety (MC4124 RIB VT2P, MFA Inc., Columbia, MO) was mowed using a discbine mower-conditioner (H4750; New Holland Agriculture, New Holland, PA) and raked using a twin bar rake (R2300 TwinRake; Vermeer, Pella, IA) (DMR)(5.0% CP, 76.7% NDF, 44.9% ADF) or raked only (DR)(5.2% CP, 75.2% NDF, 43.8% ADF) then baled and barn stored. All dry CS was harvested from the same field in November of 2013. Dry CS was offered in bale form on flat end in open steel ring feeders (RING). Ring feeders were 1.2 m in height and 2.4 m in diameter with no sheeting and 0.6 m tall angled feeding spaces (Hay Ring; Hatton Vermeer Sales, LLC, Auxvasse, MO). Dry and high-moisture CS were processed through a 20-cm screen and stored under roof in lime floored bays with concrete dividers. Processed CS was offered in concrete fence-line bunks (BUNK) providing 1.6 m of bunk space per cow. Bunks were 38 cm tall on the interior of the pen with a 53 cm tall backing. High-moisture bales were processed on alternating days to prevent spoilage. Each bale was individually sampled by taking 3 cores per bale (Hayprobe, Hart Machine Co. Madras, OR) and weighed immediately
prior to feeding or processing. Random grab samples were taken from processed CS offered in bunks immediately after feeding.

**Waste collection**

During CS feeding period, 48 h were allowed for acclimation to feeder and CS type. At 48 h, ORTs and debris were cleaned from each bunk or feeding pad and new CS was offered providing *ad libitum* intake. Stover remaining in feeder and waste were collected at 24 and 48 h from bunks following collection period initiation. Waste was collected at 24 and 48 h and ORTs were collected at 48 h from ring feeders. Waste was considered forage outside the bale feeder or bunk and was sorted to remove manure contamination. Forage remaining in the bale feeder or bunk was considered ORTs. Three to five grab samples were randomly collected from ORTs and waste and were weighed for DM determination and analyzed for NDF, ADF, and ash. At each collection period end, bunks and sampling pads were cleaned and forage and feeding strategy combinations were rotated through pens. Cow replicates remained within pen throughout the entire experiment.

**Sample analysis**

Corn stover samples were immediately dried at 55° C for 96 h, ground through a 5-mm screen using a Wiley Mill (Model 4, Thomas Scientific; Swedesboro, NJ), subsampled, and ground through a 1-mm screen using a 1093 Cyclotech Mill (Tecator; Eden Prairie, MN). Wet chemistry methods were used for DM (dried 12 h at 105° C),
NDF and ADF (Ankom Tech Corp; Fairport, NY) and ash (combusted 12 h in a muffle furnace at 500º C) for all samples.

**Statistical analysis and calculations**

Stover DMI was calculated by subtracting ORTs and collected waste from DM on offer then divided by number of cows per pen. Forage waste is expressed as average DM waste per cow per day (kg/ (cow·d)) or as a percent of DMI. Percent of DMI calculation was used as DMI was the most consistent measure across treatments. Amount on offer was greater in ring-fed treatments as a whole bale was offered every other day while processed CS was offered daily.

Due to differences in collection times between treatments and alternating ORTs collection for ring-fed treatments, daily estimates were combined and averaged within period for statistical analysis. Means were analyzed using the MIXED procedure of SAS 9.4 (SAS Inst. Inc.; Cary, NC). Forage type and feeding strategy were included in the model as fixed effects. Pen, period, and their interaction were included as random effects and pen was experimental unit. When fixed effect $P \leq 0.05$, means were separated using the Least-square means statement with the PDIF option. Differences were considered to be significant at $P \leq 0.05$.

**Results and Discussion**

Corn stover NDF results are presented in Table 2.2. Initial bale NDF was less ($P < 0.05$) for WMR-BUNK compared to all other treatments. Offered CS NDF was less ($P < 0.05$) for WMR-BUNK than all other treatments. Initial bale core samples for dry CS treatments prior to feeding or processing were not different ($P > 0.05$) in NDF suggesting
no difference between harvest methods. After processing and feeding, grab sample variation resulted in NDF differences between harvest methods. Offered CS NDF was greater ($P < 0.05$) in DMR-RING compared to DMR-BUNK and DR-BUNK; DR-RING was not different ($P > 0.05$) from all other dry treatments. Increased CS quality in WMR can be attributed to plant maturity at time of harvest. Pordesimo et al. (2005) found soluble solids fractions in husk, leaf, and stalk fractions decrease as plant matures.

Variation in offered CS NDF in ring-fed and bunk-fed treatments within the same harvest method could be attributed to sampling error as two different sampling techniques were used. Bale core samples taken prior to processing or feeding show no difference ($P > 0.05$) in quality between harvest methods. This suggests harvest method had no effect on CS quality and sampling variation occurred between bale cores and grab samples. No differences in CS quality between harvest methods allows for harvest method selection based on desired yield and labor input.

Corn stover NDF was lesser ($P < 0.05$) for WMR-BUNK than all other treatments. Stover NDF was greater ($P < 0.05$) for DMR-RING ORTs compared to all processed treatments. Stover NDF for ORTs in DR-R was greater ($P < 0.05$) than DR-BUNK and not different ($P > 0.05$) from DMR-RING and DR-BUNK. There was no difference ($P > 0.05$) in ORTs NDF between dry, processed CS treatments. Waste stover NDF was lesser ($P < 0.05$) for WMR-BUNK than all other treatments. Neutral detergent fiber in CS waste was less ($P < 0.05$) in DMR-BUNK compared to DMR-RING and DR-RING; DR-BUNK was not different ($P > 0.05$) from all other dry treatments. Neutral detergent fiber was expected to be greater in CS ORTs and waste compared to initial offered CS indicating sorting for higher quality fractions. However, across treatments, CS
ORTs and waste NDF was equal to or less than initial CS offered. Processing CS increases bulk density (Mani et al., 2004). Greater bulk density for processed CS resulted in minimal remaining bunk space allowing for lighter CS fractions to be easily pushed from bunks immediately after feeding while heavier portions such as the stalk remained within bunk for consumption.

Waste and ORTs NDF for ring-fed treatments remained consistent with initial CS. Despite no difference in NDF between offered and ORTs, sorting for higher quality fractions was hypothesized to have occurred based on previous research utilizing *ad libitum* CS (Methu et al., 2001; Moore, 2013). Forage offered amount was calculated to result in 10% ORTs. Actual ORTs were higher than expected (≥ 24%). Methu et al. (2001) observed increased leaf and husk selection as amount on offer increased. Greater amount on offer in this experiment may have allowed for increased higher quality fraction consumption without significant decreased forage quality as a whole. These results agree with previous research by Wahed et al. (1990) who increased forage amount on offer to sheep and goats and observed increased ORTs forage quality compared to treatments with less offered.

Corn stover DMI, ORTs, and waste results are presented in Table 2.3. Daily CS DMI was greater (*P* < 0.05) for DR-RING and WMR-BUNK compared to DMR-BUNK and DR-BUNK; DMR-RING was not different (*P* > 0.05) from all other treatments. Forage DMI as a percent of BW averaged 1.4% across treatments; less than suggested 2% (NRC, 2000). Moore (2013) fed CS in bale ring feeders resulting in 1.98% of BW DMI. Decreased DMI across treatments was thought to be due to increased NDF; however, WMR NDF (65.1%) was significantly less than CS used by Moore (2013).
Forage was offered at 10% above expected DMI to prevent limiting intake. Actual ORTs were at minimum 24% of amount offered across treatments suggesting forage was not limiting. Forage remaining in feeder was greater ($P < 0.05$) in DR-Ring compared to DMR-Bunk, DR-Bunk, and WMR-Bunk; DMR-Ring was not different ($P > 0.05$) from all other treatments. Among dry CS treatments there was no difference in DMI within feeding system suggesting no harvest method effect.

Supplement was balanced relative to analysis of bale core samples taken from randomly selected bales from entire CS lot immediately prior to experiment initiation. Protein supplement amounts were based on this analysis and assumption of 2.0% BW total DMI (NRC, 2000) to provide adequate RDP. As mentioned above, actual forage DMI was 1.4% BW; however, even at lower intake, diet provided adequate RDP to prevent limiting forage intake across all treatments. Reduction in DMI compared to suggested levels (NRC, 2000) can partially be attributed to confinement. Confined cattle expend less energy on a daily basis compared to grazing cattle due to grazing behavior, distance to water and shelter, and time spent eating (NRC, 2001). Limited research has estimated a 10-50% reduction in maintenance requirements in confined cows compared to grazing cows depending on pasture size and terrain (CSIRO, 1990). Reduction in DMI was mostly attributed to physical fill. Previous research has shown NDF intake to be approximately 1.2% BW (Mertens, 1987). Greater CS NDF prevents typical DMI due to ruminal fill.

Increased DMI among ring-fed treatments compared to dry bunk-fed treatments was hypothesized to be caused by sorting opportunity for intact leaf and husk CS fractions (Fernandez-Rivera and Klopfenstein, 1989). Increased DMI among dry CS
treatments can also be attributed to amount on offer. Methu et al. (2001) reported increased non-processed CS DMI as amount on offer increased. Increased amount on offer in unprocessed forage diets has been shown to increase DMI in sheep and goats due to increased sorting ability and refusal rate (Wahed et al., 1990). Osafo et al. (1997) observed similar results with increased amount on offer in sheep and cattle. High-moisture CS resulted in increased DMI compared to dry, bunk-fed CS but showed no difference compared to ring-fed CS. This suggests increased moisture and lower fiber results in greatest intake. Decreased DMI among dry CS bunk-fed treatments is hypothesized to be due to reduced ability to sort for higher quality CS fractions due to particle size.

Daily waste was greater \((P < 0.05)\) for DMR-RING and DR-RING compared to DMR-BUNK, DR-BUNK, and WMR-BUNK. Calculated daily waste as a percent of DMI was greater \((P < 0.05)\) for DMR-RING and DR-RING compared to DMR-BUNK, DR-BUNK, and WMR-BUNK. Both ring-fed treatments resulted in greater CS waste. Immediately after being offered, CS bales began to lose integrity. Open, non-sheeted ring feeders did not contain CS, thus increasing waste. Increased ability to sort CS bales also resulted in greater waste. Feeding processed CS in fence-line bunks reduced waste. Bunk design better contained CS due to solid sidewalls and bottom compared to open ring, reducing waste and reduced particle size decreased sorting ability resulting in decreased waste.

**Implications**
As hypothesized, feeding high-moisture, lower fiber CS both increased DMI and reduced waste. Further processing and bunk feeding dry stover decreased waste but showed no effect on DMI. We suggest this to be due to lesser ability to sort for higher quality corn stover fractions. Contrary to our hypothesis, no harvest method effect was observed within dry stover feeding strategies. In opposition to our hypothesis, processing and feeding CS in bunks was not effective at increasing DMI; however, waste was reduced. As hypothesized, waste was increased in ring feeders due to feeder design and increased sorting ability.
## Table 2.1 DM supplement composition

<table>
<thead>
<tr>
<th>Item</th>
<th>Supplement</th>
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<tbody>
<tr>
<td>Soybean Meal</td>
<td>38.4</td>
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<tr>
<td>Ground Corn</td>
<td>18.5</td>
</tr>
<tr>
<td>Wheat Middlings</td>
<td>6.2</td>
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<tr>
<td>Dicalcium Phosphate</td>
<td>8.6</td>
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<tr>
<td>Vitamin and Mineral Premix¹</td>
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<tr>
<td>Magnesium Oxide</td>
<td>8.0</td>
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<tr>
<td>Limestone</td>
<td>6.4</td>
</tr>
<tr>
<td>Salt</td>
<td>5.4</td>
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<tr>
<td>Monensin, g/909 kg</td>
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<td>CP</td>
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<td>ADF</td>
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<td>Ash</td>
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</table>

¹ Vitamin and Mineral Premix= 26.0% trace mineral premix (3.0% Zn, 2.5% Fe, 2.0% Mn, 1.0% Cu, 100 ppm Co, 500 ppm I, 100 ppm Se), 9.1% vitamin premix (8,800,000 IU/kg vitamin A, 1,760,000 IU/kg vitamin D, 1,100 IU/kg vitamin E) and 64.9% vitamin E premix (4,400 IU/kg)
Table 2.2 Harvest method and processing effects on corn stover NDF

<table>
<thead>
<tr>
<th>Item</th>
<th>Unprocessed Stover in Ring</th>
<th>Processed Stover in Bunk</th>
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<tr>
<td>Bale wt., kg DM</td>
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<td>323</td>
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<td></td>
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<tr>
<td>BNR</td>
<td>308</td>
<td>328</td>
<td>634</td>
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<tr>
<td>DM</td>
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<td>79.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>81.7&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>79.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>75.8&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>74.7&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>Waste</td>
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<td>78.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.7&lt;sup&gt;h&lt;/sup&gt;</td>
<td>75.0&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

abcd Means within the same row with different superscripts are different (P < 0.05)

1DMR: Dry, mowed and raked, DR: Dry, raked only, WMR: High-moisture, mowed and raked
2Largest standard error of least squared means
3Observed significance levels for main effect of treatment
4Samples taken for all treatments immediately prior to feeding or processing
5Samples taken immediately post-feeding in processed treatments
<table>
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<th>Item</th>
<th>Unprocessed CS in Ring</th>
<th>Processed CS in Bunk</th>
<th>DMR</th>
<th>DR</th>
<th>DMR</th>
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<td>1.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.53&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>0.0383</td>
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<sup>abc</sup>Means within the same row with different superscripts are different (P < 0.05)
<sup>1</sup>DMR: Dry, mowed and raked, DR: Dry, raked only, WMR: High-moisture, mowed and raked
<sup>2</sup>Largest standard error of least squared means
<sup>3</sup>Observed significance levels for main effect of treatment
<sup>4</sup>Calculated forage DMI (offered – waste – ORTs)
<sup>5</sup>Calculated average daily forage DMI expressed as a percent of calculated midpoint body weight
<sup>6</sup>Forage remaining within feeder

38
Figure 2.1 (a) Large round bale feeder design (b) Concrete fence-line bunk
Chapter 3

Supplementation method and moisture level effect on cow-calf pair corn stover intake and waste

Abstract

Two experiments were conducted to evaluate supplementation method, moisture addition, and treatment acclimation method effect on corn stover (CS) DMI and waste. Water and protein supplement addition were hypothesized to increase CS DMI. Prior acclimation to all treatments or acclimation to each treatment between periods was hypothesized to have no effect on DMI. In Exp. 1, 40 spring calving cow-calf pairs, 58 d post-partum, were used in a 5x5 Latin square design. Five periods contained 4-d diet acclimation periods followed by a 3-d collection period. Dry CS (90% DM) was processed through a 13-cm screen and mixed with: 3.1 kg condensed distilled solubles (CDS), water and 3.1 kg DDGS (H2O-DDGS), water and 3.1 kg DDGS offered separately (H2O); or stover (as-is) fed with 3.1 kg DDGS offered separately (DRY), or fed with CDS offered ad libitum in lick-tank feeder (TNK). In Exp. 2, 24 spring-calving cow-calf pairs, 93 d post-partum, were used in a 3x3 Latin square. Cow-calf pairs were acclimated to all diets prior to the experiment and no acclimation period was provided between collection periods. Dry CS (90% DM) was processed through a 13-cm screen and mixed with water to target 50% DM and 3.1 kg DDGS (H2O-DDGS), mixed with water with 3.1 kg DDGS offered separately (H2O), or fed as-is with 3.1 kg DDGS...
offered separately (**DRY**). A vitamin and mineral supplement containing monensin at 200 mg•cow⁻¹•day⁻¹ was offered separate from CS at 0.45 kg•cow⁻¹•day⁻¹. In Exp. 1, daily CS DMI was greatest (**P < 0.05**) for CDS (8.23 kg) compared to DRY (7.36 kg) and TNK (6.86 kg). Stover DMI was greater (**P < 0.05**) for H2O-DDGS (8.14 kg) compared to TNK but not different (**P > 0.05**) from all other treatments; no difference (**P > 0.05**) was observed in CS DMI between H2O and all other treatments. Corn stover ORTs and waste were not different (**P > 0.05**) between treatments. Fiber was less and CP was greater (**P < 0.05**) in offered compared to ORTs in CDS, H2O-DDGS, and H2O indicating sorting. Sorting was not observed in DRY or TNK treatments. Crude protein was greater (**P < 0.05**) for CDS and H2O-DDGS on offer compared to all other treatments. In Exp. 2, no differences were observed in CS DMI, ORTs, or waste among treatments. Fiber was greater and CP was lower (**P < 0.05**) in ORTs compared to CS on offer for H2O and H2O-DDGS indicating sorting. Mixing CS with water and protein supplement was not effective at increasing CS DMI compared to CS fed protein supplement separately. Acclimation period timing did not appear to affect DMI or waste.

**Introduction**

According to the USDA, feed costs account for 70% total cow-calf production operating costs (ERS, 2014). In the last decade, hay production decreased 6% and price received for hay increased 85% (NASS, 2014). Concurrently, corn acres planted increased 12% and yield per acre increased 7% (NASS, 2014). Corn stover (CS) accounts for approximately 50% of the total corn plant (Shinners and Binversie, 2007). Therefore, as corn grain yields increase, so does corn stover availability. Excess corn residue can interfere with planting and decrease potential grain yields (Mann et al., 2002). Wiebold
(2010) observed increased grain yields and stand density when 50% of the total available stover was removed. Harvested CS can provide a cost effective forage source in years of exaggerated hay prices.

Feeding CS in large round bale feeders has been shown to result in higher waste than typically associated with low-quality forages. Moore (2013) reported 38.7% CS waste as a percent of bale when fed in open, non-sheeted ring feeders. Waste could be reduced through further processing and bunk-feeding (Landblom et al., 2007). Reducing corn silage particle size has been shown to reduce sorting and increase DMI in lactating dairy cattle (Kononoff et al., 2003). Osafo et al. (1997) observed reduced sorting ability and increased stem consumption in cattle consuming chopped sorghum stover vs. whole sorghum stover.

Supplement addition or increased moisture levels can potentially increase low-quality forage DMI and reduce forage waste. Walker et al. (2013) measured DMI and waste when mixing low-quality forage with liquid supplement. Mixing supplement with forage was effective at reducing waste; however no effect was observed for DMI. Leonardi et al. (2005) observed reduced sorting and a tendency to increase NDF intake when water was added to diets fed to dairy cows.

The experimental objective was to quantify corn stover intake and waste by lactating cows as affected by supplementation strategy and CS moisture. Mixing processed CS with condensed distilled solubles or with water and DDGS was hypothesized to increase DMI and reduce sorting compared to CS treatments with protein
supplement fed separately. Mixing CS with water was hypothesized to increase DMI and reduce sorting compared to treatments fed as-is CS.

**Materials and methods**

All animal use procedures were approved by the University of Missouri Animal Care and Use Committee.

**Experiment 1**

Forty cow-calf pairs were selected from a spring-calving crossbred herd and used in a 5 x 5 Latin square design in a 35-d study. Cow-calf pairs were stratified by cow BW (572 ± 54 kg), BCS (5.1 ± 0.2 units), calf BW (96 ± 17 kg), calf age (58 ± 10 d) and calf sex into five replicates with eight cow-calf pairs per replicate. Corn stover (MC4234 RIB VT2P, MFA Inc., Columbia, MO) (90% DM, 5.2% CP, 78% NDF, 49% ADF) processed through a 13-cm screen was mixed with: condensed distilled solubles (CDS), water and DDGS (H2O-DDGS), water with the DDGS offered separately (H2O), fed as-is with DDGS offered separately (DRY), or fed as-is with CDS offered ad libitum in a lick-tank feeder (TNK). Corn condensed distilled solubles (Table 3.2) were stored anaerobically in a 24,600 L above ground tank to prevent mold. All treatments were mixed in a truck mounted feed delivery box (Kuhn 3020, Kuhn North America; Brodhead, WI) for 10 minutes prior to feeding. Water was added to CS for H2O-DDGS and H2O targeting 50% CS DM. Dried distillers grains plus solubles (3.1 kg/cow) were added to H2O-DDGS after water was added to prevent diet separation and ensure even distribution of DDGS within diet. A lick-tank feeder was filled with CDS and weighed at the beginning and end of each collection period to calculate intake. Samples were taken daily during collection
period from three locations within lick-tank feeder and composited for analysis. During each 7-d period, 4 d were allowed for diet acclimation followed by a 3-d collection period. At conclusion of each collection period, bunks and pens were cleaned and forage and feeding strategy combinations were rotated through pens. Cow replicates remained within pen throughout the experiment.

*Experiment 2*

Twenty-four cow-calf pairs were selected from a spring-calving, crossbred herd and used in a 3 x 3 Latin square design in a 9-d study. Cow-calf pairs were stratified by cow BW (575 ± 60 kg), BCS (5.0 ± 0.3 units), calf BW (123 ± 21 kg), calf age (93 ± 11 d) and calf sex into three replicates with eight cow-calf pairs per replicate. Corn stover (MC4234 RIB VT2P, MFA Inc., Columbia, MO) (90% DM, 5.2% CP, 78% NDF, 49% ADF) processed through a 13-cm screen was mixed with: water and 3.1 kg DDGS (H2O-DDGS), water while 3.1 kg DDGS was offered separately (H2O), or fed as-is with 3.1 kg DDGS offered separately (DRY). Water was added to CS to target 50% DM for H2O-DDGS and H2O treatments. Stover and water were mixed for 10 minutes in a truck mounted feed delivery box (Kuhn 3020, Kuhn North America; Brodhead, WI). Dried distillers grains plus solubles were added to H2O-DDGS after water was added to prevent diet separation and allow for proper mixing. At each collection period end, bunks and pens were cleaned and forage and feeding strategy combinations were rotated through pens. Cow replicates remained within pen throughout the entire experiment. Exp. 1 was used as acclimation to all treatments prior to Exp. 2 initiation. No diet acclimation period was provided between collection periods.
Cow measures, facilities, and supplementation

In Exp. 1 and 2, BCS were assigned by three experienced evaluators on a 1 to 9 scale (Wagner et al., 1988) and 2-d full BW were measured at trial initiation and conclusion. Cows were fed a common CS and CDS diet for 3 d prior each weigh period. Treatment groups were randomly assigned to one of five, 18 x 61 m dry lots with lime floors containing a south-facing barn and 9.8 m of bunk space adjacent to the barn along the north pen edge. A dried distillers grain based supplement (Table 3.1) containing vitamin and mineral mix and 400 g/909 kg monensin (Rumensin, Elanco Animal Health, Greenfield, IN) was offered at 0.45 kg DM •cow⁻¹•day⁻¹ separate from CS and protein supplement feeding in 3.1 m portable feed bunks (Heavy-Duty Bunk Feeder, Tarter Farm & Ranch, Dunnville, KY) to ensure equal vitamin and mineral consumption.

Sample collection

Immediately prior to each collection period, ORTs and debris were cleaned from bunks and feeding apron and new CS was offered. Forage remaining within the bunk was considered ORTs. Waste was considered forage outside the bunk and was sorted to minimize manure contamination. Waste was separated into two sub-categories, waste-in and waste-out. Waste-in was any CS within the pen still able to be consumed on the apron in front of the bunk. Waste-out was any CS outside of the pen along feeding alleyway that cows were unable to reach and consume. Waste within pen, still able to be consumed, was considered Waste-In and waste outside of the pen, unable to be consumed, was considered Waste-Out. Waste and ORTs were collected daily during
collection periods. Three to five random grab samples were taken from ORTs and waste and were weighed for DM determination and analyzed for CP, NDF, ADF, and ash.

Sample analysis

Grab samples were immediately dried at 55°C for one week, ground through a 5-mm screen in a Wiley Mill (Model 4, Thomas Scientific; Swedesboro, NJ), subsampled, and ground through a 1-mm screen using a 1093 Cyclotech Mill (Tecator; Eden Prairie, MN). Offered, ORTs, and waste samples were analyzed for DM (dried 12 h at 105°C) and ash (combusted 12 h in a muffle furnace at 500°C) using wet chemistry methods. Near-infrared spectroscopy with Westerhaus et al. (2004) scan, calibrate, and validation methods was used to measure CP, NDF, and ADF. Prediction equations were generated using 70 validation samples for NDF and ADF (Ankom Tech Corp; Fairport, NY) and CP (% N x 6.25; Vario MACRO cube CN, Elementar Americas Inc.; Mt. Laurel, NJ). Validation sample correlation coefficients were 0.94, 0.90, and 0.99 for CP, NDF, and ADF respectively.

Statistical analysis and calculations

Corn stover DMI was calculated by subtracting ORTs and collected waste, (waste-in and waste-out), from DM on offer then divided by number of cows per pen. In order to calculate CS DMI, ORTs, and waste in treatments mixed with protein supplement, a consistent supplement to CS ratio was used based on amount of protein supplement added. Protein supplement to CS ratio was assumed to be consistent across offered, ORTs, and waste due to inability to sort supplement from CS. Forage waste and ORTs are presented as average DM per cow per day (kg/ cow·d).
Means were analyzed using the MIXED procedure of SAS 9.4 (SAS Inst. Inc.; Cary, NC). Diet was included in the model as a fixed effect. Pen, period, and their interaction were included as random effects, and pen was experimental unit. When fixed effect $P \leq 0.05$, means were separated using the Least-square means statement with the PDIFF option. Differences were considered to be significant at $P \leq 0.05$. Tendencies were discussed when $P < 0.1$.

**Results and Discussion**

*Experiment 1*

Corn stover DMI, ORTs and waste results are presented in Table 3.3. Daily CS DMI was greater ($P < 0.05$) for CDS compared to DRY and TNK. Stover DMI was greater ($P < 0.05$) in H2O-DDGS compared to TNK and not different ($P > 0.05$) from all other treatments; H2O was not different ($P > 0.05$) in CS DMI from all other treatments. Stover DMI tended ($P = 0.06$) to be greater for H2O-DDGS compared to DRY. Stover DMI tended ($P = 0.06$) to be greater for H2O compared to TNK. A greater difference in forage DMI was expected between treatments fed CS mixed with water or CDS versus treatments fed as-is CS. Tendencies suggest numerical difference however lack of statistical difference was due to large variation in forage DMI among periods causing a period effect ($P = 0.03$). The period effect was attributed to above average rainfall during May and June increasing ORTs and waste contamination and reducing moisture differences among treatments. Daily and total period rainfall amounts during collection periods are reported in Table 3.5 (USCD, 2015). Variation in DMI may only be partly attributed to rainfall due to feeding behavior. Cows were observed to spend the largest
proportion of their daily feeding time immediately after feed delivery reducing rainfall effect on treatment.

Supplements were balanced using bale core samples taken from entire CS lot prior to experiment initiation. Protein supplement formulations were based on analysis and predicted 2.4% BW total DMI (NRC, 2000) to provide adequate RDP. Post-experiment sample analysis indicated offered CS was approximately 4 percentage points lower in CP compared to pre-experiment analysis and total DMI was reduced to 1.8% BW across treatments. Lower than expected CP in CS and CDS resulted in insufficient RDP in CDS treatment potentially limiting forage intake. Treatments fed distillers grains, mixed or separately, had adequate RDP intake. Reduction in DMI observed compared to predicted (NRC, 2000) can partially be attributed to confinement. Confined cattle expend less energy on a daily basis compared to grazing cattle due to grazing behavior, distance to water and shelter, and time spent eating (NRC, 2001). Limited research has estimated a 10 to 50% reduction in maintenance requirements in confined cows compared to grazing cows depending on pasture size and terrain (CSIRO, 1990). Intake in this experiment was 25% lower than expected and within the range estimated by CSIRO (1990). Reduction in DMI was mostly attributed to physical fill. Previous research has shown NDF intake to be approximately 1.2% BW (Mertens, 1987). Greater CS NDF prevents typical DMI due to ruminal fill.

Corn stover ORTs, waste within pen, and waste outside of pen were not different \((P > 0.05)\) between treatments. Forage ORTs were expected to be lesser for CDS, H2O-DDGS, and H2O treatments compared to DRY and TNK treatments due to increased DMI; however no difference was observed. This was attributed to above average rainfall
minimizing treatment differences in CS moisture. Forage waste differences were not expected among treatments. Previous research has shown no difference in CS waste due to DM % when processed and fed in bunks (Mertz et al., 2014). Providing DDGS in bunks separate from forage resulted in complete supplement consumption and no waste. Mixing supplement with CS resulted in increased supplement waste and refusal compared to when offered separately as supplement could not be sorted from CS. Due to greater supplement cost compared to CS, this can reduce potential mixing advantages associated with CDS, H2O-DDGS, and H2O treatments if CS intake differences are not observed.

Bunk sample CP and NDF composition are presented in Table 3.4. Supplement addition lowered fiber and increased CP and thus increased quality. Crude protein was greater ($P < 0.05$) for CDS and H2O-DDGS on offer compared to all other treatments. This was expected due to high-protein supplement addition to the diet mixture. Neutral detergent fiber was less and CP was greater ($P < 0.05$) in offered compared to ORTs in CDS, H2O-DDGS, and H2O indicating sorting. No difference ($P > 0.05$) was observed in offered versus ORTs for DRY or TNK treatments fed as-is CS with no supplement addition. Increased moisture and supplement addition was expected to decrease sorting ability; however, moisture-added and supplement-mixed treatments showed increased sorting ability. Water addition has increased (Miller-Cushon and DeVries, 2009) and reduced sorting ability (Leonardi et al., 2005) in corn silage and alfalfa haylage based diets. DeVries and Gill (2012) observed reduced sorting ability with liquid feed addition. These experiments utilized different forages and smaller forage particle size than the 13-cm particles used in this experiment.
Increased sorting ability in moisture-added treatments in this experiment was attributed to moisture content in leaf and husk fractions after mixing. Leaf and husk fractions have been shown to have increased water sorption rates compared to stalks due to increased surface area and soluble fiber content (Igathinathane et al., 2009). The stalk’s thick outer rind and decreased surface area reduce water absorption (Igathinathane et al., 2009). In this experiment, leaves and husks were hypothesized to uptake the majority of the water added to the CS with a smaller proportion absorbed by the stalk. This would increase leaf and husk palatability without improving stalk palatability leading to sorting. An increased proportion of stalks were observed in ORTs compared to offered further suggesting CS fraction sorting in high-moisture diets.

Waste inside and outside the pen was of equal or greater quality compared to CS on offer. This indicates waste CS was pushed out of the bunks due to animal feeding behavior preventing further intake and not sorted and refused. Increased bulk density in processed CS (Mani et al., 2004) minimize remained bunk space allowing for lighter leaf and husk fractions to be easily pushed from bunks immediately after feeding while heavier stalk portions remained within bunk. These results are similar to previous waste measures observed when feeding processed CS in bunks (Mertz et al., 2014).

Experiment 2

Corn stover DMI, ORTs and waste results are presented in Table 3.6. No differences (\(P > 0.05\)) were observed for CS DMI, ORTs, or waste between treatments. Supplement intake was greater (\(P < 0.05\)) for DRY and H2O treatments compared to H2O-DDGS. These treatments were fed DDGS separate from CS in portable bunks.
resulting in complete DDGS consumption. Protein supplement in the H2O-DDGS treatment was mixed with water and CS. Any ORTs or waste was assumed to have the same protein supplement to CS ratio as initially offered. Therefore, H2O-DDGS treatment refused and wasted a larger supplement proportion reducing protein supplement DMI confirmed by greater CP in ORTs and waste.

Diets were balanced using bale core samples taken from entire CS lot prior to Exp. 1 initiation. Protein supplement formulations were based on CS analysis and predicted 2.4% BW total DMI (NRC, 2000) to provide adequate RDP. Actual DMI averaged 2.05% BW across treatments; however, RPD intake was calculated to be sufficient and not limiting forage intake. Similar to Exp. 1, reduction in DMI was mostly attributed to physical fill.

Bunk sample CP and NDF composition are presented in Table 3.7. Quality on offer was greater ($P < 0.05$) for H2O-DDGS compared to DRY and H2O due to supplement addition to diet mixture. No differences ($P > 0.05$) were observed for CP or NDF in ORTs or waste across treatments. Similar to Exp. 1, sorting was evident in moisture-added treatments. Fiber was greater ($P < 0.05$) in ORTs compared to CS on offer for H2O and H2O-DDGS and not different ($P > 0.05$) in DRY. Crude protein was greater ($P < 0.05$) in offered compared to ORTs for all treatments further indicating sorting. These results agree with results from Exp. 1 suggesting sorting ability is increased with water addition or water and supplement addition.
Observed DMI, ORTs, and waste were consistent among collection days within period. This suggests complete prior acclimation to CS diets did not affect measurements taken in this study when no acclimation between collection periods was used.

Overall

Observed forage DMI across treatments was at minimum 1 kg greater in Exp. 2 compared to Exp. 1. This can be attributed to increased calf age and size. As calf age increased, greater CS consumption was observed. Calves were not observed consuming protein supplement when fed separately due to cow behavior and competition at the bunk. Sorting was evident in both Exp. when water was added to CS. No reduction in DMI, increase in waste, or variation between treatments compared to previous results were observed when acclimation periods were not provided between collection periods. In these experiments, few treatment effects were observed. Acclimating to all treatments prior to experiment initiation could potentially result in greater variation in DMI and waste measures compared to acclimation periods prior to each collection period when greater treatment effects are observed. Further research is needed to compare diet acclimation methods when greater differences are observed across treatments compared to this experiment.

Implications

Mixing CS with water and protein supplement was not effective at increasing CS DMI compared to CS fed protein supplement separately. Mixing liquid protein supplement with CS increased supplement waste and ability to sort CS for higher quality fractions. Liquid supplements are highly variable in nutrient composition and DM and
can cause storage issues due to settling and freezing. This may require large, costly alterations to producer’s current facility to add storage tanks equipped with heaters and agitation pumps to prevent settling and freezing (Lardy, 2009). Increased potential for sulfur toxicity due to CDS sulfur content suggests limit-feeding is a more viable option compared to lick-tank feeders due to ability to control intake. Feeding CS mixed with water and DDGS can achieve similar DMI compared to mixing with a liquid protein supplement such as CDS and reduce storage requirements. Dried distillers grains do not need to be stored anaerobically and can more easily be stored in producers’ current facilities. Supplement cost must be analyzed to ensure supplement lost in waste does not offset economic incentives to utilize low-cost CS. Increasing moisture levels through water addition or liquid supplement addition reduces transport efficiency as a greater proportion of the available weight that can be hauled is consumed by water.
Table 3.1 DM vitamin and mineral supplement composition in Exp. 1 and 2

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<tr>
<td>NaCl</td>
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<td>Vitamin E</td>
<td>7.7</td>
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<tr>
<td>Vitamin and Mineral Premix(^1)</td>
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<tr>
<td>ADE Nutra Mix</td>
<td>0.96</td>
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<tr>
<td>Monensin, g/909 kg</td>
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\(^1\) Vitamin and Mineral Premix = 26.0% trace mineral premix (3.0% Zn, 2.5% Fe, 2.0% Mn, 1.0% Cu, 100 ppm Co, 500 ppm I, 100 ppm Se), 9.1% vitamin premix (8,800,000 IU/kg vitamin A, 1,760,000 IU/kg vitamin D, 1,100 IU/kg vitamin E) and 64.9% vitamin E premix (4,400 IU/kg)
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<th>Protein supplement¹</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CDS</td>
<td>DDGS</td>
</tr>
<tr>
<td>DM</td>
<td>32.4</td>
<td>91.0</td>
</tr>
<tr>
<td>CP</td>
<td>16.3</td>
<td>31.0</td>
</tr>
<tr>
<td>Ash</td>
<td>15.7</td>
<td>4.7</td>
</tr>
<tr>
<td>TDN</td>
<td>73.1</td>
<td>83.8</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1.42</td>
<td>0.65</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>2.59</td>
<td>0.83</td>
</tr>
</tbody>
</table>

¹CDS: Condensed distilled solubles, DDGS: dried distillers grains plus solubles
Table 3.3 Supplementation method and moisture addition effect on DMI, refusal, and waste (Exp. 1)

<table>
<thead>
<tr>
<th>Item, kg/hd/d</th>
<th>Treatment</th>
<th>H2O-DDGS</th>
<th>H2O</th>
<th>SEM²</th>
<th>P-value³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CDS</td>
<td>DRY</td>
<td>TNK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forage</td>
<td>8.23ᵃ</td>
<td>7.36ᵇᶜ</td>
<td>6.86ᶜ</td>
<td>8.14ᵃᵇ</td>
<td>7.64ᵃᵇᶜ</td>
</tr>
<tr>
<td>Supplement</td>
<td>2.07</td>
<td>3.05</td>
<td>2.31</td>
<td>2.27</td>
<td>3.05</td>
</tr>
<tr>
<td>ORTs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forage</td>
<td>0.72</td>
<td>0.80</td>
<td>1.38</td>
<td>0.62</td>
<td>1.07</td>
</tr>
<tr>
<td>Supplement</td>
<td>0.22</td>
<td>-</td>
<td>-</td>
<td>0.19</td>
<td>-</td>
</tr>
<tr>
<td>Waste-In⁴</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forage</td>
<td>0.58</td>
<td>1.09</td>
<td>0.91</td>
<td>0.45</td>
<td>0.66</td>
</tr>
<tr>
<td>Supplement</td>
<td>0.17</td>
<td>-</td>
<td>-</td>
<td>0.14</td>
<td>-</td>
</tr>
<tr>
<td>Waste-Out⁵</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forage</td>
<td>0.81</td>
<td>1.06</td>
<td>0.75</td>
<td>0.91</td>
<td>0.82</td>
</tr>
<tr>
<td>Supplement</td>
<td>0.24</td>
<td>-</td>
<td>-</td>
<td>0.28</td>
<td>-</td>
</tr>
</tbody>
</table>

ᵃᵇᶜMeans within the same row with different superscripts are different (P < 0.05)

¹CDS: Dry corn stover mixed with condensed distilled solubles, DRY: Dry corn stover fed with DDGS supplementation fed separately, TNK: Dry corn stover fed with condensed distilled solubles offered in lick-tank, H2O-DDGS: Corn stover mixed with water and DDGS, H2O: Corn stover mixed with water, DDGS fed separately
²Largest standard error of least squared means
³Observed significance levels for main effect of treatment
⁴Forage waste inside pen in front of bunk
⁵Forage waste outside pen behind bunk
Table 3.4 Supplementation method and moisture addition effect on mixed corn stover ration quality (Exp. 1)

<table>
<thead>
<tr>
<th>Item</th>
<th>CDS</th>
<th>DRY</th>
<th>TNK</th>
<th>H2O-DDGS</th>
<th>H2O</th>
<th>SEM^2</th>
<th>P-value^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offered CS Mix</td>
<td>5.99^a</td>
<td>3.42^h</td>
<td>3.76^h</td>
<td>5.2^y</td>
<td>3.63^by</td>
<td>0.40</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>ORTs</td>
<td>4.24^az</td>
<td>3.40^k</td>
<td>3.36^b</td>
<td>3.23^bz</td>
<td>3.15^bz</td>
<td>0.32</td>
<td>0.03</td>
</tr>
<tr>
<td>Waste-In^4</td>
<td>5.18^aby</td>
<td>3.81^c</td>
<td>4.11^b^c</td>
<td>5.23^y</td>
<td>4.45^bcx</td>
<td>0.47</td>
<td>0.04</td>
</tr>
<tr>
<td>Waste-Out^5</td>
<td>5.47^axy</td>
<td>3.68^h</td>
<td>3.79^b</td>
<td>5.16^y</td>
<td>4.03^bxy</td>
<td>0.33</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>SEM^6</td>
<td>0.35</td>
<td>0.31</td>
<td>0.36</td>
<td>0.38</td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-Value^7</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDF, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offered CS Mix</td>
<td>68.5^y</td>
<td>79.4^ax</td>
<td>77.6^abs</td>
<td>74.7^by</td>
<td>77.3^abx</td>
<td>1.7</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>ORTs</td>
<td>76.2^bx</td>
<td>79.4^abx</td>
<td>79.7^asy</td>
<td>81.1^ax</td>
<td>82.2^aw</td>
<td>1.6</td>
<td>0.03</td>
</tr>
<tr>
<td>Waste-In</td>
<td>68.3^y</td>
<td>70.8^y</td>
<td>67.9^e</td>
<td>67.2^e</td>
<td>68.4^f</td>
<td>3.5</td>
<td>0.64</td>
</tr>
<tr>
<td>Waste-Out</td>
<td>67.6^by</td>
<td>74.5^ay</td>
<td>74.4^ay</td>
<td>71.0^abyx</td>
<td>73.2^ay</td>
<td>1.8</td>
<td>0.01</td>
</tr>
<tr>
<td>SEM</td>
<td>2.2</td>
<td>2.0</td>
<td>2.4</td>
<td>2.0</td>
<td>1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-Value^7</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^a,b,c Means within the same row with different superscripts are different (P < 0.05)

^x,y,z Means within the same column with different superscripts are different (P < 0.05)

^1CDS: Dry corn stover mixed with condensed distilled solubles, DRY: Dry corn stover fed with DDGS supplementation fed separately, TNK: Dry corn stover fed with condensed distilled solubles offered in lick-tank, H2O-DDGS: Corn stover mixed with water and DDGS, H2O: Corn stover mixed with water, DDGS fed separately

^2Largest standard error of least squared means for treatment

^3Observed significance levels for main effect of treatment

^4Forage waste inside pen in front of bunk

^5Forage waste outside pen behind bunk

^6Largest standard error of least squared means within column

^7Observed significance levels within column
<table>
<thead>
<tr>
<th>Item</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 4</th>
<th>Period 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>d 1 2</td>
<td>2.2</td>
<td>1.3</td>
<td>1.2</td>
<td>0.1</td>
<td>2.4</td>
</tr>
<tr>
<td>d 2</td>
<td>0.8</td>
<td>0.0</td>
<td>1.5</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>d 3</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
<td>0.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Total period 3</td>
<td>3.0</td>
<td>1.3</td>
<td>3.7</td>
<td>1.0</td>
<td>4.5</td>
</tr>
</tbody>
</table>

1Period 1: May 14-16, Period 2: May 21-23, Period 3: May 28-30, Period 4: June 4-6, Period 5: June 11-13
2Day within collection period
3Sum of total rainfall for 3 collection period days
<table>
<thead>
<tr>
<th>Item, kg</th>
<th>Treatment</th>
<th>DRY</th>
<th>H2O</th>
<th>H2O- DDGS</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI</td>
<td>Forage</td>
<td>8.68</td>
<td>8.85</td>
<td>9.22</td>
<td>0.68</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Supplement</td>
<td>3.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.68&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.12</td>
<td>0.03</td>
</tr>
<tr>
<td>ORTs</td>
<td>Forage</td>
<td>0.58</td>
<td>0.37</td>
<td>0.52</td>
<td>0.25</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Supplement</td>
<td>-</td>
<td>-</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste-In&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Forage</td>
<td>0.25</td>
<td>0.19</td>
<td>0.11</td>
<td>0.32</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Supplement</td>
<td>-</td>
<td>-</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste-Out&lt;sup&gt;5&lt;/sup&gt;</td>
<td>Forage</td>
<td>0.58</td>
<td>0.71</td>
<td>0.75</td>
<td>0.28</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Supplement</td>
<td>-</td>
<td>-</td>
<td>0.22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Means within the same row with different superscripts are different (*P* < 0.05)

<sup>1</sup>DRY: Dry corn stover fed with DDGS supplementation fed separately, H2O: Corn stover mixed with water, DDGS fed separately, H2O-DDGS: Corn stover mixed with water and DDGS

<sup>2</sup>Largest standard error of least squared means

<sup>3</sup>Observed significance levels for main effect of treatment

<sup>4</sup>Forage waste inside pen in front of bunk

<sup>5</sup>Forage waste outside pen behind bunk
Table 3.7 Supplementation method and moisture addition effect on mixed corn stover ration quality (Exp. 2)

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DRY</td>
<td>H2O</td>
<td>H2O-DDGS</td>
</tr>
<tr>
<td>CP, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offered CS Mix</td>
<td>3.15&lt;sub&gt;by&lt;/sub&gt;</td>
<td>3.38&lt;sub&gt;by&lt;/sub&gt;</td>
<td>4.9&lt;sup&gt;ax&lt;/sup&gt;</td>
</tr>
<tr>
<td>ORTs</td>
<td>2.78&lt;sup&gt;z&lt;/sup&gt;</td>
<td>2.82&lt;sup&gt;z&lt;/sup&gt;</td>
<td>2.84&lt;sup&gt;z&lt;/sup&gt;</td>
</tr>
<tr>
<td>Waste-In&lt;sup&gt;4&lt;/sup&gt;</td>
<td>4.55&lt;sup&gt;w&lt;/sup&gt;</td>
<td>4.03&lt;sup&gt;x&lt;/sup&gt;</td>
<td>4.49&lt;sup&gt;xy&lt;/sup&gt;</td>
</tr>
<tr>
<td>Waste-Out&lt;sup&gt;5&lt;/sup&gt;</td>
<td>3.68&lt;sup&gt;x&lt;/sup&gt;</td>
<td>3.64&lt;sup&gt;y&lt;/sup&gt;</td>
<td>4.16&lt;sup&gt;y&lt;/sup&gt;</td>
</tr>
<tr>
<td>SEM</td>
<td>0.23</td>
<td>0.19</td>
<td>0.50</td>
</tr>
<tr>
<td>P-value&lt;sup&gt;7&lt;/sup&gt;</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>NDF, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offered CS Mix</td>
<td>80.88&lt;sup&gt;ax&lt;/sup&gt;</td>
<td>79.08&lt;sup&gt;ay&lt;/sup&gt;</td>
<td>75.22&lt;sub&gt;by&lt;/sub&gt;</td>
</tr>
<tr>
<td>ORTs</td>
<td>82.55&lt;sup&gt;x&lt;/sup&gt;</td>
<td>82.49&lt;sup&gt;xy&lt;/sup&gt;</td>
<td>82.90&lt;sup&gt;y&lt;/sup&gt;</td>
</tr>
<tr>
<td>Waste-In</td>
<td>69.21&lt;sup&gt;x&lt;/sup&gt;</td>
<td>71.20&lt;sup&gt;x&lt;/sup&gt;</td>
<td>70.92&lt;sup&gt;z&lt;/sup&gt;</td>
</tr>
<tr>
<td>Waste-Out</td>
<td>77.81&lt;sup&gt;y&lt;/sup&gt;</td>
<td>77.92&lt;sup&gt;y&lt;/sup&gt;</td>
<td>77.26&lt;sup&gt;y&lt;/sup&gt;</td>
</tr>
<tr>
<td>SEM</td>
<td>1.40</td>
<td>1.18</td>
<td>1.71</td>
</tr>
<tr>
<td>P-value&lt;sup&gt;7&lt;/sup&gt;</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

<sup>a</sup>x<sup>y</sup>Means within the same row with different superscripts are different ($P < 0.05$)

<sup>w</sup>x<sup>y</sup>Means within the same column with different superscripts are different ($P < 0.05$)

<sup>1</sup>DRY: Dry corn stover fed with DDGS supplementation fed separately, H2O: Corn stover mixed with water, DDGS fed separately, H2O-DDGS: Corn stover mixed with water and DDGS

<sup>2</sup>Largest standard error of least squared means for treatment

<sup>3</sup>Observed significance levels for main effect of treatment

<sup>4</sup>Forage waste inside pen in front of bunk

<sup>5</sup>Forage waste outside pen behind bunk

<sup>6</sup>Largest standard error of least squared means within column

<sup>7</sup>Observed significance levels within column
Literature cited


Lardy, G. 2009. Feeding coproducts of the ethanol industry to beef cattle.


Mader, T., and S. Rust. 2006. High moisture grain: harvesting, processing and storage. Cattle Grain Processing Symposium, Oklahoma State University, Stillwater, OK.


