EFFECTS OF CORN CONDENSED DISTILLERS SOLUBLES SUPPLEMENTATION ON INTAKE, PERFORMANCE, RATE AND SITE OF DIGESTION, AND RUMINAL FERMENTATION IN CATTLE CONSUMING FORAGE-BASED DIETS

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MASTER OF SCIENCE

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ABSTRACT

Two studies were conducted to determine effect of feeding method and level of corn condensed distillers solubles supplementation on performance of beef cows fed forage-based diets and effects on digestibility and ruminal fermentation. Experiment 1 utilized 80 gestating crossbred cows in a randomized complete block design. Treatments were arranged in a 2 × 2 + 1 factorial design; main effects were feeding method (mixed vs. fed separately) and level of CCDS. All treatments were offered ad libitum forage. Experiment 2, utilized 5 ruminally and duodenally cannulated Holstein steers in a 5×5 Latin square to evaluate effects of CCDS supplementation on DM intake, site of digestion, and ruminal fermentation. Exp. 2 utilized similar treatments as experiment 1; and all treatments were offered ad libitum forage. Results of these studies suggest that CCDS supplementation increases intake, performance, and CP digestion and appears to be an effective supplement for cattle eating moderate-quality forages.

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A wise man by the name of Churchill once said, “Kites rise highest against the wind, not with it.”

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LIST OF ACRONYMS

µm	Micrometer
ADF	Acid Detergent Fiber
ADG	Average Daily Gain
AOAC	Association of Official Analytical Chemist
BCS	Body Condition Score
BIF	Beef Improvement Federation
BW	Body Weight
C	Celsius
Ca	Calcium
CCDS	Corn Condensed Distillers Solubles
cm	Centimeter
Co	Cobalt
CP	Crude Protein
Cu	Copper
d	Day
DDGS	Dry Distillers Grains with Solubles
DM	Dry Matter
DMI	Dry Matter Intake
E_2	Estrogen
EE	Ether Extract
FDR	Fluid Dilution Rate
Fe	Iron

g	Gram
h	Hour
I	Iodine
K	Potassium
kg	Kilogram
L	Liter
m	Meter
mg	Milligrams
min	Minute
MIX	CCDS Mixed with Forages Treatment
mL	Milliliter
mm	Millimeter
mM	Mol per Molar
Mn	Manganese
MP	Metabolizable Protein
N	Nitrogen
Na	Sodium
NaCl	Sodium Chloride
NDF	Neutral Detergent Fiber
NH_4	Ammonia
NRC	National Research Council
OM	Organic Matter
OMI	Organic Matter Intake

P	Phosphorus
P	Probability
ppm	Parts per Million
RDP	Rumen Degradable Protein
RFA	Renewable Fuels Association
S	Sulfur
SAS	Statistical Analysis Software
Se	Selenium
SEP	CCDS Separate from Forages Treatment
TMR	Total Mixed Ration
UIP	Undegradable Intake Protein
USDA	United States Department of Agriculture
VFA	Volatile Fatty Acids
vs	Versus
WDGS	Wet Distillers Grains with Solubles
Zn	Zinc

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Introduction

Throughout the Midwest the ethanol industry continues to expand, and with this expansion the amount of feed co-products produced from ethanol manufacturing has increased more than three times in the last decade (RFA, 2013). With the increase in hay and small grain prices (USDA NASS, 2010; 2011), alternative feeds are becoming more popular as supplements or as replacements for other feedstuffs. One of the co-products derived from ethanol production is corn condensed distillers solubles (CCDS), which is relatively high in protein and fat (20 to 30% CP and 4 to 20% fat, DM basis; Gilbery et al., 2006; Rust et al., 1990). Thus, CCDS could be valuable for protein and energy supplementation of lower quality forages.

Low quality forages and crop residues are typically an economical and plentiful resource for cattle producers (NRC, 1983). Forages make up the majority of beef cow diets, however forages alone may not be adequate to meet nutrient requirements at all production stages. Thus, producers are likely to offer supplements to cattle when low quality forages are fed. A variety of supplementation options exist, but major categories include energy or protein supplementation. Both increased cattle performance (Caton and Dhuyvetter, 1997; McCollum and Horn, 1990); however, forage intake is affected in different ways by energy and protein supplementation. In ruminants, forage intake generally decreases with energy supplementation in the form of cereal grains (Sanson et al., 1990) or fat (Kowalczyk et al., 1977). Protein supplementation has resulted in increased forage intake (McCollum and Galyean, 1985; DelCurto et al,. 1990), however according to NRC (1996), crude protein (CP) requirements do not account for the nitrogen (N) needs of the ruminal microbial population. Thus, recent studies have investigated the effects of rumen degradable protein (RDP) and undegradable intake protein (UIP) in meeting the metabolizable protein (MP) requirements of beef cattle and the overall effects of these supplements on forage digestibility.

Rumen degradable protein can be a valuable resource when fed with low quality forages. Numerous studies (Guthrie and Wagner, 1988; Del Curto et al., 1990; Köster et al., 1996) have reported that RDP supplementation of low quality forages increased forage intake, digestibility, and animal performance. Increased forage intake due to protein supplementation is thought to cause increases in rate of passage and forage digestion (McCollum and Galyean, 1985; Köster et al., 1996). Ruminal ammonia N concentrations are low when low quality forages are fed in the absence of protein supplementation (Köster et al., 1996). Without proper ammonia concentrations, ruminal microbial growth is limited (Satter and Slyter, 1974) resulting in negative effects on fiber digestion. With this in mind, RDP provides a source of N for ruminal microbes as well as other nutrients such as branched volatile fatty acids (VFA) to allow for increased microbial efficiency. Moderate levels of protein supplementation result in the greatest levels of ruminal organic matter (OM) fill and fiber digestion; this is likely related to the inherent fermentability of the forage and protein requirements of the animal (Köster et al., 1996; DelCurto et al., 1990).

Gilbery et al. (2006) conducted a study to determine the effects of CCDS supplementation at differing levels on low-quality hay digestion. The results of the two feeding methods (separate vs. mixed) were contrasting and showed no effect on OM digestibility when CCDS was fed separately, however when the supplement was mixed with the forage, ruminal OM digestion increased with increasing levels of CCDS. Ruminal digestion of ADF and NDF increased with CCDS supplementation. The CP in the CCDS utilized in the study was calculated to be 86.7% RDP, and accounted for an increase in CP intake and total tract CP digestibility. Gilbery et al. (2006) concluded that CCDS provided greater nutrient availability and though results for feeding method were conflicting, the data suggests CCDS supplementation can increase low quality forage utilization. Therefore the objectives of the current studies were to determine the benefits of CCDS as a supplement on performance of gestating cows and progeny, forage intake, and digestibility. The studies also took into account different feeding regimes (mixed vs. separate) and levels of CCDS supplementation.

Gestation

Gestation is an important time in an animal's lifecycle. As gestation advances, nutritional requirements increase, the effect on productivity and economics is heightened. Improved nutrition has resulted in greater pregnancy rates, greater or increased body condition score (BCS), and increased percentage of live calves at weaning (Marston et al., 1995; Sletmoen-Olson et al., 2000; Stalker et al., 2006). Not only can malnutrition affect the animal's ability to effectively recover and rebreed, but can also be detrimental to the performance of offspring. Fetal programming is the description used for the effect of maternal nutrition on the subsequent development and physiological composition of progeny. Fetal programming has been shown to affect reproduction, growth, and carcass traits of progeny (Rae et al., 2001; Martin et al., 2007; Wu et al., 2006). Limited data is available to understand whether the effects come predominantly from energy or protein restriction in the dam's diet during gestation. However, protein supplementation has improved many areas of progeny productivity such as increased weaning weight, average daily gain (ADG), and carcass quality (Funston et al., 2010).

Forage intake is complex in ruminants, forage type and animal characteristics can affect the amount of forages consumed. Crampton (1957) found that voluntary intake of forages had very little to do with the nutritive value of the forages fed. Many studies have reported that voluntary intake of forages is mainly due to physical constraints of the animal (Balch and Campling, 1962; Forbes, 1995). Studies have indicated that intake varies inversely with the fiber content of the forages (Balch and Campling, 1962). Thus, with lower forage quality the animal may not be physically able to consume the amount of forage needed to meet their nutritional requirements. The inability to consume the amount of nutrients needed is heightened with progression of gestation and lactation as nutrient requirements increase. As gestation advances and the fetus grows there is a decrease in ruminal volume in sheep offered hay (Forbes, 1969). Though calving has resulted in an immediate increase in DMI, factors such as increased nutrient demand and hormonal levels through gestation and lactation are just as important as ruminal capacity (Stanley et al., 1993). Forbes (1986) indicated that the primary hormones associated with pregnancy can have an adverse effect on voluntary intake (Forbes, 1986). Forbes (1971) showed that with doses of estradiol 17-β similar to concentrations during pregnancy, a dose dependent decrease of voluntary feed intake occurred.

The immense changes in physiology and hormone levels of animals throughout pregnancy causes changes to not only the animal's consumption of nutrients but the digestibility as well. The effect on digestibility becomes more pronounced as pregnancy progresses and hormonal levels change. Weston (1988) indicated pregnancy decreased OM digestion and increased digesta flows through the stomach during late gestation in sheep fed moderate quality forages. This effect continued through lactation. Vanzant et al. (1991) reported conflicting results showing no change in OM digestion when pregnant and lactating heifers were compared to open heifers; however, there was increased indigestible ADF passage rate. Hanks et al. (1993) also reported conflicting results when comparing pregnant cows to a non-pregnant control; there were no differences due to pregnancy status in total tract digestion, rate and extent of NDF disappearance, or ruminal fluid kinetics when fed long-stem fescue hay.

When pregnant ewes were studied, Weston (1988) found that during late gestation ewes had increased absorption rate of VFA and decreased levels of VFA in the reticulorumen. There was continued influence during lactation in these ewes, as ruminal pH was increased while VFA and ammonia levels decreased compared to observed values during gestation. In a study investigating ruminal fill and passage rates, Vanzant et al. (1991) found that pregnant heifers had increased concentrations of propionate while there were decreased levels of acetate as compared to open heifers. While investigating the change in cattle from 58 d prior to calving through 25 d after calving, there was no change in ruminal pH and ammonia concentration. However, total VFA responded with a quadratic increase after calving (Stanley et al., 1993). In studies where sheep were limit-fed during pregnancy, the decrease in ruminal concentration of ammonia were attributed to increases in passage rates of digesta and increased levels of non-ammonia N in the abomasum (Weston 1979, 1988).

Results for digesta passage rates have been fairly consistent, with the largest increases occurring in late gestation (Hanks et al., 1993; Weston, 1988). This was reported for pregnant sheep fed both ad libitum (Coffey et al., 1989) and limit-fed (Faichney and White, 1988; Gunter et al., 1990). With decreased forage intake reported in gestating ruminants as well as increased particulate passage rate, other possible causes for changing particulate passage rates could be due to increases in circulating levels of hormones. In a review of literature Forbes (1986), found that high concentrations of E_2 could be attributed to decreased voluntary intake and decreased ruminal digesta retention time. It should also be noted that E_2 and progesterone both increased gut motility in non-pregnant cattle and sheep (Forbes, 1986).

Protein and Energy Supplementation

Protein and energy supplementation have been the subject of a vast amount of studies. In a review, McCollum and Horn (1990) stated that the key point is forage availability, when there is an adequate amount of forage available protein supplementation is most effective, otherwise energy supplementation can fill the gap in the livestock's performance needs. Nutrient needs of a ruminant must take into account the nutrient demands of both the ruminal microbial population and the host animal.

Supplementation is vital in many production scenarios to meet livestock's nutritional needs and performance capabilities. However, supplementation has implications on the economics of livestock production (McCollum and Horn, 1990). Increased performance in livestock production is often facilitated through increased voluntary forage intake (McCollum and Galyean, 1985; DelCurto et al., 1990). Furthermore, increases in voluntary forage intake have contributed to increased forage digestibility (Rittenhouse, 1970; Church and Santos, 1981), rate of digestion (Caton et al., 1988), and digesta flow (Redman et al., 1980). Protein supplementation is most often associated with increasing forage intake (McCollum and Horn, 1990; Egan, 1981). When protein supplementation does not result in increased performance, it is most likely due to forage intake not changing. Protein supplementation becomes more important when forage quality decreases during periods of winter dormancy or when crop residues are utilized. Positive responses in forage intake have been noted when forage quality drops below 6% CP (Campling, 1970; Kartchner, 1980). A review of energy supplementation research states that when energy is supplemented there is a decrease in forage intake (Caton and Dhuyvetter, 1997). Sanson et al. (1990) found a correlation between increasing levels of corn and a linear decrease in intake of low-quality meadow hay. Those authors attributed this effect to the amount of starch consumed and subsequent effects on digestion. This effect is also extended to fat supplementation as Kolwalczyk et al. (1977) noted a decrease in forage intake when sheep were fed a chopped grass diet and offered a high-fat supplement. The potential negative effects of energy supplementation also included decreased digestion; while decreases in digestibility related to fat supplementation are generally attributed to antimicrobial effects (Jenkins, 1993), with grain supplements the negative effects are generally correlated with decreasing ruminal pH (Mould et al., 1983).

With a vast quantity of low quality forages available for ruminants, it is important to find effective ways to utilize this resource in livestock production. However, with the lower levels of CP and increased ADF and NDF levels, proper supplementation to maintain acceptable levels of production and digestibility of lower quality forages is crucial. Ruminal effects such as suppressed intake and lowered performance are likely due to ruminal N deficiency (McCollum and Horn, 1990), as improvements in forage digestibility are generally attributed to increasing ruminal N levels (Olson et al., 1999). Total DM digestibility, including digestibility of ADF, cellulose, and lignin, increased linearly with increasing levels of soybean meal supplementation (Guthrie and Wagner, 1988). Specifically, ruminal degradable protein supplementation increased OM and ADF digestibility (Köster et al., 1996; Olson et al., 1999). When undegradable intake protein was supplemented with low-quality forages, there were increases in ruminal OM digestion but no effect on ADF or NDF digestibility (Reed et al., 2007). Starch supplementation is known to decrease ruminal pH; and this decrease can cause a shift in microbial population with an increase in amylolytic and decrease in cellulolytic bacteria. This shift in population could be one of the reasons why decreases in fiber digestion and subsequent reductions in forage intake are noted with energy supplementation (Caton and Dhuyvetter, 1997). Studies have indicated differences in digestion between a high starch energy supplements, such as corn, and fiber based energy supplements such as soyhulls. When corn was supplemented it decreased ruminal DM, ruminal NDF, and total tract digestion (Grigsby et al., 1993). However, when soyhulls were supplemented there were increases in ruminal and total tract DM digestion (Grigsby et al., 1992). When high fat supplements in the form of beef tallow and lecithin were used, there was a significant decrease in digestibility of forages as levels of fat supplementation increased. This effect was only alleviated by use of a rumen bypass fat for supplementation (Kowalczyk et al., 1977).

The ruminal microbial ecosystem and host animal physiology is one of the more complex symbiotic relationships observed in nature. The ruminant host animal cannot live without the microbial population in the rumen; however the feedstuffs that the animal ingests can have a dramatic effect on the microbes. Ruminal pH levels can affect digestibility and DM intake, a decrease in pH can inhibit cellulolysis and impair the microbial population (Mould and Ørskov, 1983). Ruminal pH levels were decreased in steers fed protein supplements when compared to non-supplemented steers, however the pH still remained within acceptable limits for cellulolytic bacteria (Hannah et al., 1991; Köster et al., 1996). Köster (1996) attributed the decrease in ruminal pH to an increase in ruminal fermentation, which increases with added N levels associated with protein supplementation. Energy supplementation can effectively close the performance gap of livestock production, but has negative effects on forage intake and digestion (Caton and Dhuyvetter, 1997). The decrease in forage intake and digestion has been attributed to a decrease in ruminal pH (Mould et al., 1983). Historically, grain supplementation has been thought to decrease ruminal pH, a review of energy supplementation compared many studies with mixed results (Caton and Dhuyvetter, 1997). Ørskov (1982) determined the pH levels where there were no negative effects to cellulolytic bacteria occurred at 6.2 or higher. The studies reviewed by Caton and Dhuyvetter (1997) showed that grain supplementation does not greatly affect ruminal pH, especially at low to moderate inclusion rates (<0.4% BW; Kunkle et al., 2000).

The process of ruminal fermentation breaks down feedstuffs into absorbable products known as volatile fatty acids (VFA). Concentrations and molar proportions of VFA are measured in research assuming that these measurements are a true representation of VFA produced and/or absorbed (Sharp et al., 1982). Protein supplementation resulted in increased levels of total VFA concentration in cattle fed a forage basal diet (DelCurto et al., 1990; Köster et al., 1996; Olson et al., 1999). Molar proportions of acetate and propionate show an inverse relationship when protein is supplemented, with acetate decreasing and propionate increasing (Köster et al., 1996; Olson et al., 1999). Two studies which fed sorghum grain and soyhulls as a supplement to forages, found that there was no effect on total VFA concentration (Krysl et al., 1989; Grigsby et al., 1993).

Ammonia levels are critical for microbial protein synthesis and health of the rumen. Slyter and others (1979) found that when steers were fed a diet of 11.1% CP equivalent or less they had very low ruminal ammonia concentrations, they did not find an accumulation of ammonia until the diet was over 13.3% CP equivalent. These results indicate that once ammonia began accumulating the ruminal microbes had more ammonia than they could utilize. Adding protein to the diet increases microbial N uptake which in turn causes an increase in ammonia levels in the rumen, as Köster and others (1996) noted a linear increase in ammonia levels in the rumen as increasing levels of RDP were fed. In a study comparing steers fed a protein or energy supplement to a forage only diet, both supplemental treatments resulted in an increase in ruminal ammonia concentration (Olson et al., 1999). However, increasing levels of starch supplementation decreased the level of ammonia, while increasing levels of RDP increased the level of ammonia (Olson et al., 1999). In a study by Grigsby and others (1993), when soybean hulls or corn were offered as supplements, the ruminal ammonia concentration decreased with supplemented steers compared to non-supplemented controls. Forage quality has a large effect on supplementation studies, with lower quality forages having low available N and the high demand for N within the rumen, this combination results in low ammonia concentrations in the ruminal fluid (Olson et al., 1999).

Rate of passage has been correlated closely with DM intake levels. However, it is not clear whether increases in rate of passage are attributed to greater DM intake of the animal, or the increased rate of passage stimulates the increased intake. Protein supplementation increases ruminal fill and rate of passage. This increase in rate of passage could also be due in part to increased ruminal and total tract digestibility (McCollum and Horn, 1990). Supplemented cattle have increased particulate passage rates and decreased gastrointestinal mean retention time when fed moderate to low-quality forages (McCollum and Galyean, 1985; Caton et al., 1988; Freeman et al., 1992). Guthrie and Wagner (1988) reported a linear increase in particulate passage rate with increasing levels of soybean meal, which were positively correlated with increased forage intake. When feeding soybean hulls as an energy supplement, Martin and Hibberd (1990) found that fluid passage rate increased with increasing levels of supplement while other research has reported no effect of supplementation on fluid passage rate (Grigsby et al., 1993).

Corn Condensed Distillers Solubles

With a vast supply of corn, ethanol distillery plants have been built throughout the Midwest. This has become an issue within animal feed businesses and producers, as approximately 40% of the corn grain supply has been diverted to the ethanol industry (USDA, 2014). Through the distillation process, many different byproducts are generated as waste that cannot be further utilized by ethanol plants. The two main grains utilized in ethanol production are sorghum and corn, corn being the most important and economical source of starch within the United States (Bothast and Schlicher, 2005).

Ethanol distilling is a very old process, with production of ethanol first being attributed to increasing the alcohol content of beverages through enhancing the distillation process. Ethanol gained popularity through the early 19th century, and an ethanol blend was first used in an internal combustion engine by the late 1830s (Songstad et al., 2011). Within the United States' early automotive industry, the Model T had the capability of using either gasoline or ethanol. Ethanol continued to be used throughout the country until the 1930s, and it was hoped that ethanol would provide revenue back to farmers and rural economies (Kovarik, 1998). However, interest waned with the cheap and readily available supply of gasoline post World War II. Due to conflict and political tension with the Middle East in the 1970s, as well as efforts to remove the lead octane booster out of gasoline, ethanol regained consumer interests (Hunt, 1981). Federal and state tax incentives helped cement the interest in ethanol and has aided in the growth of the industry, which has grown from 17.5×10^7 gallons in 1980 to 13.3×10^9 in 2012 (RFA, 2013).

Ethanol can be produced by three different manufacturing processes, either by dry grind, dry milling, or wet milling. Through the wet milling process, the following co-products are created: corn gluten feed/meal, germ meal, and steep water. While dry milling produces hominy feed, flaking grits, and brewer’s grits. Dry grind processes produce the by-product CCDS (Figure 1.1), as well as others such as wet distillers grains plus solubles (WDGS), dried distillers grains plus solubles (DDGS), and thin stillage (Rausch and Belyea, 2006). Through the dry grind process, corn is ground with hammer mills or roller mills to increase surface area and allow more water penetration. The ground corn is then mixed with water and amylase is added to the slurry, to prepare for fermentation amylase breaks down starch into simple sugars. The slurry is then cooked to the point where it is

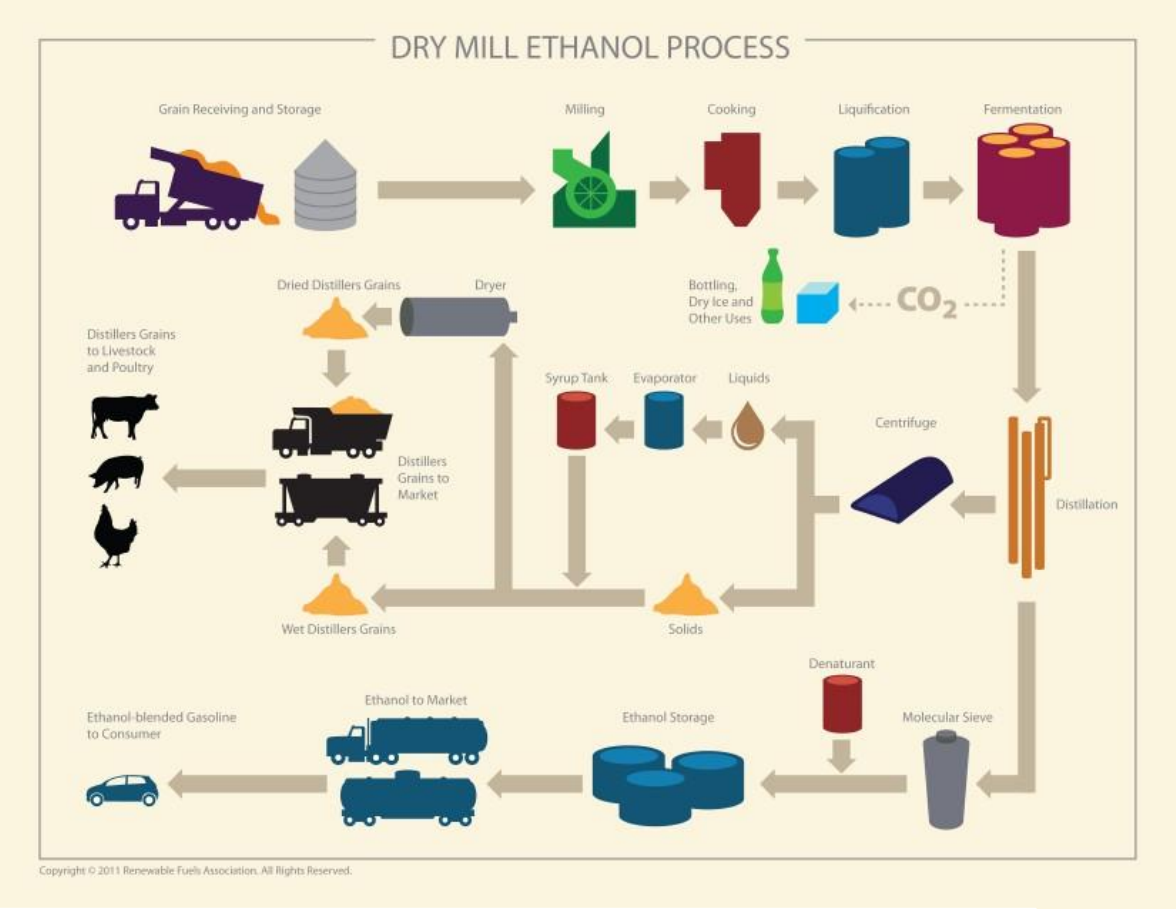

Figure 1.1: Dry Mill Ethanol Process Chart (RFA, 2013)

liquefied, and glucoamylase and yeast are added to begin the fermentation process. Glucoamylase continues breaking down the liquefied starch down into glucose which is readily utilized in the fermentation process. Once fermentation is complete, the beer is a combination of ethanol, water, and unfermented solids. The beer then proceeds through a recovery system, where the water-ethanol is separated and goes through a molecular sieve to absorb the remaining water. Ethanol is then mixed with gasoline to provide the proper octane level. When the ethanol-water mixture is separated, the remaining solids then are further processed to produce two different co-products. Whole stillage settles to the bottom of the distillation unit, and is then syphoned off to be centrifuged. The solids from the centrifuge can be used as wet grains and the liquid is thin stillage. Thin stillage can be evaporated and concentrated into corn condensed distillers syrup. This can be combined with the wet grains and then dried to produce DDGS (Rausch and Belyea, 2006).

Many different factors can alter the nutrient profile of CCDS. The two largest variations come from the nutritive value of the corn and the fermentation process. Many things can contaminate the process and cause reduced ethanol yields and reduced value of co-products, such as moldy grain, improper storage of grain, faulty equipment, re-introduced stillage, and air (Bothast and Shlicher, 2005). Typical nutrient content of CCDS (DM basis) range from 15 to 30% CP and 4 to 20% fat (Gilbery et al., 2006; Rust et al., 1990), with the greatest concentrations of minerals being K, Na, and P. The variation in CP content can be extensive and results in the byproducts being marketed conservatively, for example the CP content of DDGS can range from 25-35%. When marketed, DDGS often has a minimum CP guarantee of 25% to meet state requirements for feed labeling. Corn condensed distillers solubles has high concentrations of K, Na, and P, if left unmonitored this can cause an imbalance of Ca:K and could have possible long term physiological effects (Rausch and Belyea, 2006). One other item of note is the tendency of CCDS to separate over time, this causes some issues to producers and increases investment in equipment needed to effectively feed these byproducts on the farm. Tanks with agitators are needed to store CCDS for longer periods of time.

Corn Condensed Distillers Solubles as a Supplement

Limited research is available where CCDS was used as a supplement; this is mainly due to the limited availability of this co-product. Due to the separation and shelf life of the wet co-products, many dry grinding ethanol manufacturers combine the wet grain and solubles and dry them to produce DDGS. The varying levels of nutrients also make interpretation of research data with ethanol co-products difficult, with protein and fat levels varying by as much as 10%, different batches of CCDS can cause mixed results. Recent studies have also focused on establishing the most optimal feeding practice and rate of CCDS supplementation.

With such high levels of both protein and energy, CCDS should be of value in many different production settings for ruminants. In two experiments Gilbery et al. (2006) used CCDS, with moderate nutritive values of 15-21% CP and 4-17% fat (DM basis), as a supplement for steers fed low-quality hay (3-5% CP, 40-43% ADF, DM basis). For the first experiment, steers were fed increasing levels of CCDS (5%, 10%, and 15% CCDS) separate from the low-quality hay and were compared to a control fed only hay. The second experiment also fed the different levels of CCDS; however, CCDS was blended with the forage using a forage mixer. With CCDS fed separately, there was no effect on forage DMI. Forage DMI increased quadratically in the second study when CCDS was mixed with the forages, with the greatest forage DMI occurring at 10% CCDS inclusion. Da Cruz et al. (2005) used CCDS in a total mixed ration (TMR) at 0, 5, and 10% with higher quality forages fed to dairy cows, and noted a tendency for increased DMI at 5% level. Though protein supplementation has resulted in increased forage DMI (DelCurto et al., 1990; Köster et al., 1996), the added levels of fat in CCDS could be the reason for a limited response in DMI at greater levels of supplementation. In a literature review, Hess et al. (2008) found that different types of fat supplementation at higher levels (> 2% DMI) can decrease forage DMI.

While energy deficiency is normally the main cause of poor performance in livestock, inadequate protein can limit forage digestion and intake (McCollum and Horn, 1990). When Gilbery et al. (2006) fed CCDS separately from forages, he reported there were no effects of supplementation on ruminal, postruminal or total tract digestibility. Once the CCDS was mixed with low quality forages, there was a linear increase in apparent and true ruminal digestion with increasing levels of supplementation. Postruminal and total tract digestion was not affected by CCDS supplementation. In an earlier in vitro study, Chen et al. (1977), using screened and centrifuged processed distiller solubles at varying levels found increased cellulose digestion with supplementation.

Many researchers have attributed grain supplementation to decreased pH levels in the rumen, once pH falls below 6.2-6.7 this can cause decreased fiber and forage digestion (Mertens, 1977; Ørskov, 1982; Mould and Ørskov, 1983). Supplementation of ethanol co-products produced conflicting results on ruminal pH. Loy et al. (2007) found that heifers offered supplemental DDGS had decreased average pH vs. heifers only fed grass hay, other research indicated decreased ruminal pH when RDP was supplemented (Guthrie and

Wagner, 1988; Köster et al., 1996). However, Gilbery et al. (2006) found no effect on ruminal pH and total VFA concentration with supplemental CCDS. Other studies have found increased concentration of VFA with supplementation of RDP (Olson et al., 1999). Supplementation of DDGS increased ammonia levels (Loy et al., 2007). However, feeding CCDS separately did not have any effect on ammonia level, but when CCDS was mixed with forages, levels of ruminal ammonia increased (Gilbery et al., 2006).

A number of research studies have attributed increased rate of passage to an increase in voluntary intake of forages (Ellis, 1978; McCollum and Galyean, 1985). As protein supplementation results in increases in voluntary forage intake (McCollum and Horn, 1990), increased DMI and resulting increased rate of passage would be anticipated from CCDS supplementation. When CCDS is fed as part of a TMR, increases in hay DMI and overall OM intake occurred as increasing levels of CCDS were supplemented. Though there was no effect on fluid dilution rate (FDR) there was a linear increase in ruminal passage rate of OM as CCDS supplementation increased. This aligns with the linear increase in ruminal digestibility of the TMR (Gilbery et al., 2006).

Summary

Due to the need to lower cost of production and to enhance livestock performance, proper supplementation has been key to producer profitability. The ability of ruminants to breakdown and digest forages high in lignin and cellulose has allowed them to utilize low quality forages and crop residues. During a ruminant’s life cycle, times such as gestation and lactation are critical to not only the animal’s health but also her progeny. Fetal programming has resulted in long-term effects and is minimally reversed with better nutrition in the offspring after they are born. Thus, it is important to meet the animal’s nutrient requirements through these different life stages to fully enhance livestock production.

Forms of supplementation can greatly affect the animal, and perhaps more importantly the ruminal environment. The animal's voluntary intake and digestion of feedstuffs can be affected by physiological state and nutrient profile, specifically its effect on ruminal pH and microbial efficiency. The type of supplementation can cause disruption or promotion of ruminal environment and thus, microbial efficiency. Ruminal pH and ammonia levels are important to forage fermentation in the rumen and under certain conditions enhance cellulotyic bacteria synthesis. Forage fermentation and digestion are the foundation of ruminant animal performance, and end products of ruminal fermentation (VFA) provide the major source of energy for ruminants.

Though CCDS and other ethanol co-products have varying nutrient profiles, the levels of protein and fat make it a valuable resource for supplementation. The decreased cost of these co-products has created a demand for use in livestock production. With current research showing conflicting results, further research is needed on feeding practices and level of CCDS addition to the diet in order to help producers better utilize CCDS as a supplement.

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CHAPTER 2: EFFECTS OF CORN CONDENSED DISTILLERS SOLUBLES SUPPLEMENTATION ON PERFORMANCE AND DRY MATTER INTAKE OF BEEF COWS CONSUMING FORAGE-BASED DIETS

Abstract

Eighty crossbred cows (avg initial BW = 607 kg ± 10 kg; BCS = 5.0 ± 0.1) in mid to late gestation were used in a randomized complete block design to determine effect of feeding method and level of corn condensed distillers solubles (CCDS) supplementation on performance of beef cows fed forage-based diets. Cows were housed in a drylot, blocked by BW and projected calving date, and allocated to 1 of 5 treatments (4 replicates per treatment). Treatments were arranged in a 2 × 2 + 1 factorial design; main effects were feeding method (mixed vs. fed separately) and level of CCDS (0.2 vs. 0.4% BW; 29.7% CP, 24.3% EE, DM basis). The resulting 5 treatments were a negative control (no supplement), 0.2% BW CCDS (DM basis) mixed with the forage, 0.4% BW CCDS (DM basis) mixed with the forage, 0.2% CCDS (DM basis) supplement fed separately, and 0.4% BW CCDS (DM basis) fed separately. All treatments were offered ad libitum forage (7.9% CP, 65.3% NDF, 41.6% ADF; DM basis) which consisted of a mixture of 40% grass hay and 60% corn stover. The trial lasted for 48 d, cows were weighed every 14 d and BCS was evaluated at the beginning and end of the trial. Supplemented cows had greater ($P < 0.001$) BW gains than non-supplemented cows. Cows supplemented 0.4% CCDS had greater ($P = 0.005$) weight gains than cows fed 0.2% CCDS. There was no treatment effect ($P = 0.87$) on BCS change. Non-supplemented cows had greater ($P = 0.006$) forage DMI than all supplemented treatments. Mixing CCDS with the forage resulted in lower ($P = 0.004$) forage DMI compared to diets where CCDS was fed separately. Total (forage and CCDS)

DMI was increased (*P* < 0.001) in treatments with CCDS fed separately compared to those treatments where CCDS was mixed with forage. Corn condensed distillers solubles appear to be an effective supplement for cows fed forage-based diets.

Introduction

With the expansion of the ethanol industry and elevated feed costs, alternative feeds are becoming more important. The ethanol industry is expanding, and consequently producers have the option to utilize the associated byproducts, such as corn condensed distillers solubles. Corn condensed distillers solubles (CCDS) an ethanol byproduct, is relatively high in CP and fat, which makes this product appealing for supplementing beef cows. Low-quality forages and crop residues are usually plentiful and represent an important economical asset in ruminant production systems (NRC, 1983). However, to achieve an acceptable level of animal production from low to moderate quality forages, energy and/or protein supplementation often must be provided. Research has indicated that grain supplementation may cause a decrease in forage intake but increase livestock performance (Caton and Dhuyvetter, 1997). Protein supplementation can increase forage intake, utilization, and consequently cattle performance (Sanson et al., 1990; Bodine et al., 2001). Specifically, rumen degradable protein supplements have been reported to improve forage intake and animal performance when low-quality forages represent the basal diet (Guthrie and Wagner, 1988; Del Curto et al., 1990; Köster et al., 1996).

Corn condensed distillers solubles are high in both protein and fat (20 to 30% CP and 4 to 20% fat, DM basis; Gilbery et al., 2006; Rust et al., 1990). Gilbery et al. (2006) reported forage DMI in steers was not affected by increasing levels of CCDS when fed separately from forage. However, when CCDS was mixed with forage, DMI increased quadratically with the greatest DMI at 10% CCDS. Little published work exists which examines the use of CCDS as a supplement. This byproduct could be used to enhance livestock production or as an inexpensive alternative to other high protein and/or high energy supplements. The objectives of this study were to evaluate the effects of CCDS supplementation on cow performance, BCS, and DM intake.

Materials and Methods

Animals and Diets. All animal care and handling techniques were approved by the North Dakota State University Animal Care and Use Committee prior to initiation of research. Eighty crossbred cows, in their third trimester of gestation, were used in a randomized complete block design. Cows were weighed and assigned a body condition score (BCS range 1=emaciated, 9=obese; Wagner et al., 1988) on two consecutive days at the initiation and conclusion of the trial. Cows were housed in a drylot and assigned to 1 of 20 pens by BW and projected calving date. Cows were weighed every 14 d. Cows were offered ad libitum access to a basal diet consisting of 40% grass hay and 60% corn stover, which was chopped and mixed (Table 2.1). Cows had free access to water, mineral (minimum 9.0% of Ca, 21,120 ppm of Zn, 7,000 ppm of Cu, 28,000 ppm of Mn, 75 ppm of Co, 350 ppm of I, and 175 ppm of Se; Interstate Vet Clinic, Mandan, ND), and trace mineralized salt (minimum 93.0% of NaCl, 0.008% of Co, 0.039% of Cu, 0.008% of I, 0.2% of Fe, 0.19% of Mn, 0.38% of Zn, and 0.0053% of Se; Trouw Nutrition, Highland, IL). Orts were collected twice weekly, weighed, subsampled, and analyzed.

Treatments were arranged in a 2 × 2 + 1 factorial design with main effects of CCDS level (0.2% BW vs. 0.4% BW CCDS, DM basis) and feeding method (either mixed with the forage or fed separately). This resulted in the following treatments: negative control (no supplement), 0.2% BW CCDS mixed with the forage (0.2 % MIX, DM basis), 0.4% BW CCDS mixed with the forage (0.4% MIX, DM basis), 0.2% CCDS supplement fed separately in tanks (0.2% SEP, DM basis), and 0.4% BW CCDS fed separately (0.4% SEP, DM basis).

Table 2.1: Analyzed nutrient content of forage and corn condensed distillers solubles (CCDS)

Item, %	Forage[1]	CCDS[2]
DM		24.6
	%, DM Basis	
Fat	ND[3]	24.3
Ash	12.1	7.4
CP	7.9	29.7
NDF	65.3	ND
ADF	41.6	0.5
Ca	0.6	0.1
P	0.1	1.3
S	ND	1.7

[1] Forage consisted of 40% grass hay and 60% corn stover.
[2] CCDS = corn condensed distillers solubles
[3] ND = not determined.

Laboratory Analysis. Diet and ort samples were dried using a forced-air oven (55° C; The Grieve Corporation, Round Lake, IL) for 48 h. Dried samples were ground in a Wiley mill to pass through a 2-mm screen. Samples were then analyzed for DM, ash, and CP (Procedure numbers: 930.15, 942.05, 4.2.10, respectively; AOAC, 1990). Concentrations of NDF and ADF were determined using an Ankom 200 Fiber Analyzer (Ankom Technology, Fairport, NY). Corn condensed distillers solubles were analyzed for nutrient content at Midwest Laboratories (Omaha, NE).

Calculations and Statistical Analysis. Adjusted weaning weight was calculated by taking actual weaning weight – birth weight / days of age, then taking the result + birth weight × 205 for 205 d adjusted weaning weight (BIF, 1990). Data were analyzed as a 2 ×

2 + 1 factorial using MIXED procedures of SAS. The model included treatment and stage of gestation. Pen was used as the experimental unit. Orthogonal contrasts included control vs. supplemented treatments, MIX vs. SEP, 0.4% level vs. 0.2% level, and the interaction of method of feeding × level of CCDS. When the overall F-test for treatment was significant ($P \leq 0.10$) means were separated using least significant difference, and were considered significant at $P < 0.10$.

Results and Discussion

Cow performance and BCS data are reported in Table 2.2. There were no significant CCDS level × feeding method interactions for any variable measured ($P > 0.54$). By design, there was no effect ($P = 0.66$) of treatment on initial BW. Cows supplemented with CCDS had greater ($P < 0.01$) weight gain than non-supplemented controls, which resulted in supplemented cows having greater BW change ($P < 0.01$) compared to control. This agrees with a previous study by Sanson et al. (1990) that indicated protein and energy supplementation resulted in increased weight gain in cows grazing winter range or fed grass hay. Additionally, Larson et al. (2009) reported that protein supplementation increased cow BW prepartum compared to non-supplemented cows. At the conclusion of the trial, CCDS supplemented cows weighed more ($P = 0.05$) than the non-supplemented controls. Furthermore, cows supplemented with 0.4% BW CCDS had greater weight gains ($P = 0.01$) than cows supplemented with 0.2% BW CCDS, which resulted in 0.4% level CCDS weighing more ($P = 0.04$) than cows supplemented 0.2% level CCDS at the conclusion of the study. This was expected due to greater amounts of nutrients available to the supplemented cows vs. non-supplemented control. A study by Beaty et al. (1994), resulted in decreased BW loss during late gestation in cows fed

Table 2.2: Effects of corn condensed distillers solubles (CCDS) supplementation on cow performance while consuming a forage-based diet.

	Treatment[1]							Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	*P*-value[4]	CON vs. SUP	MIX vs. SEP	HIGH vs. LOW	METH × LEV
BW, kg											
Initial	608.4	612.8	613.6	594.4	607.4	10.41	0.659	0.900	0.220	0.490	0.539
Final	674.6	698.3	716.9	677.9	706.7	12.01	0.047	0.050	0.188	0.042	0.655
Change	66.1	85.5	103.3	83.5	99.3	5.85	<0.001	<0.001	0.612	0.005	0.865
BCS											
Initial	4.84	5.03	4.99	5.05	5.02	0.12	0.701	0.157	0.808	0.772	0.990
Final	5.35	5.63	5.61	5.63	5.47	0.12	0.326	0.068	0.450	0.551	0.551
Change	0.51	0.45	0.61	0.57	0.60	0.13	0.871	0.719	0.653	0.437	0.594

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 4 observations per treatment.

[4] Probability value for the *F*-test of overall treatment.

increasing levels of CP. Also in this study, cows fed greater levels of soybean meal gained weight before parturition. There was no effect ($P > 0.33$) of treatment on initial or final BCS. This conflicts with a study by Stalker et al. (2006) who reported an increase in BCS in prepartum cows that were supplemented with protein.

Tennant et al. (2002) investigated the relationship between cow BW and BCS change and concluded that an average of 47.4 kg of cow BW was needed for an increase or decrease of one BCS (BCS scale 1-9). Our study lasted 48 d which may not have been long enough for differences in BCS to manifest themselves under the present feeding conditions. Cow BW and BCS at parturition are very important because of their effects on re-breeding interval and subsequent pregnancy rates (Randel, 1990). Nutrient intake is important in gestation and lactation when demand for nutrients are greater, as reproductive performance traits are not as high of a priority in nutrient partitioning as weight gain (Short and Adams, 1988). Energy deficiency, particularly glucose, has resulted in delayed estrous cycles and even anestrous; this effect is mainly due to energy deficiency affecting hormonal levels (Short and Adams, 1988). In a study by Sasser and others (1988), when primigravid heifers were fed adequate vs. deficient amounts of CP the last 150 d of gestation and into lactation, there were pronounced effects including delayed estrous, decreased first-service conception, and decreased overall pregnancy rates.

Several studies have documented the effects of energy and protein supplementation on forage intake. While protein supplementation has resulted in increased forage intake and utilization (McCollum and Horn, 1990; Egan, 1981), energy supplementation, generally decreases forage intake (Caton and Dhuyvetter, 1997). In the current study, non-supplemented cows had greater forage DMI compared to CCDS supplemented cows (Table 2.3), when expressed as kg/d (*P* = 0.01) or % BW (*P* < 0.01). Other researchers (Guthrie and Wagner, 1988; McCollum and Galyean, 1985) reported forage intake increases in response to protein supplementation with low-quality forages. Köster et al. (1997) evaluated RDP supplementation specifically and reported no effects on DMI when supplementing low-quality forages, while Arroquy et al. (2004) found a linear increase in low-quality grass hay consumption with increasing levels of RDP supplementation. A possible cause for decreased forage intake in this study is the high fat content in the CCDS used, as Kowalczyk et al. (1977) found decreased forage intake in sheep when fed a high-fat supplement. In Kowalczyk's experiment, sheep were fed levels ranging from 0.25-0.75% BW of the high fat supplement which was a combination of beef tallow and lecithin. The supplement offered in the current study was not fed at the higher levels of the Kowalczyk study; however, the fat concentration may have caused a decrease in DMI. Cows fed CCDS separately from forage had greater (*P* < 0.01) forage DMI than cows fed CCDS mixed with forage. This conflicts with the results of Gilbery et al. (2006) who conducted two studies investigating the use of CCDS as a forage supplement. In one study, CCDS was fed separately from the forage while in the other, CCDS was mixed with the forage. When steers were fed CCDS separately from forage there were no effects of increasing CCDS levels on DMI. However, when steers were fed CCDS and forage mixed this resulted in an increase of DMI with increasing levels of CCDS until the 15% of diet inclusion of CCDS which decreased DMI. Cows fed 0.2% BW CCDS had greater (*P* = 0.08) forage DMI than cows fed 0.4% BW CCDS. This decrease in DMI for the cows fed 0.4% BW CCDS may be the result of a substitution effect. However, Stafford et al. (1996)

Table 2.3: Effects of corn condensed distillers solubles (CCDS) on DMI on cows consuming forage-based diet.

	Treatment[1]							Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	*P*-value[4]	CON vs. SUP	MIX vs. SEP	HIGH vs. LOW	METH × LEV
Intake, kg/d											
Forage	14.02	11.73	11.30	13.55	12.67	0.55	0.002	0.006	0.004	0.232	0.680
CCDS[5]	0.00	1.12	2.22	1.20	2.35	0.02	<0.001	<0.001	<0.001	<0.001	0.165
Total	14.02	12.84	13.51	14.74	15.02	0.55	0.037	0.986	0.002	0.392	0.723
Intake, % BW											
Forage	2.24	1.85	1.75	2.19	1.98	0.09	<0.001	0.003	0.001	0.084	0.501
CCDS[4]	0.00	0.18	0.34	0.19	0.36	0.004	<0.001	<0.001	<0.001	<0.001	0.410
Total	2.24	2.02	2.10	2.38	2.35	0.09	0.016	0.803	<0.001	0.829	0.532

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 4 observations per treatment.

[4] Probability value for the *F*-test of overall treatment.

reported no effect on DMI due to a substitution effect with up to 0.44% BW (DM basis) inclusion of a high protein supplement (32.7% CP). With CCDS being fed once daily in the current study, substitution effect may have occurred due to supplementation frequency rather than being fed ad libitum throughout the day.

By design there was an effect of treatment on CCDS DMI ($P < 0.01$). Cows fed 0.4% CCDS had greater CCDS intake ($P < 0.01$) than cows fed 0.2% BW CCDS. There was also a treatment effect on total DMI, when expressed on a kg/d ($P < 0.03$) and % BW basis ($P < 0.02$). Cows fed CCDS supplement mixed with forage had lower ($P < 0.01$) total DMI than cows fed CCDS separately. This data conflicts with a previous study by Gilbery (2006), which resulted in increased total DMI when CCDS was fed either as a TMR or separately from low quality forages. In Gilbery's study an important note is the composition of CCDS used, both studies had levels of both CP and fat (15.4-21.6% CP and 4.2-17.4% fat) that were lower than the CCDS used in the cow study. Also, while still considered low quality forage, the forage used in the cow study was higher in CP (7.9%) than both of Gilbery's studies (5.1% CP fed separately and 3.3% CP fed as TMR). These key differences may partially explain differences in results found between Gilbery's study and the cow study reported here.

Many studies have evaluated the effect of nutritional deficiencies during gestation on progeny development. Nutritional demands of the dam are increased tremendously during late gestation and early lactation (NRC, 1996). This increase in nutrient demand in the dam can alter the nutrient transfer and availability for fetal development and growth (Bauer et al., 1998). Dam nutrition, during gestation affects progeny performance and number of live calves at weaning (Larson et al., 2009; Stalker et al., 2006), CP supplementation of dams has also resulted in earlier conception and greater pregnancy rates in heifer progeny. Supplementation of CCDS resulted in no effects of treatment on calf birthdate or sex (*P* > 0.56). There were no differences in birth weight or 205-d adjusted weaning weight (*P* > 0.17; Table 2.4) of the progeny, likely due to the short time dams were offered CCDS supplementation. Martin et al. (2007) also reported no effects of prepartum protein supplementation on calf birth weight. However, some studies (Larson et al., 2009; Beaty et al., 1994) have reported increased progeny birth weight with protein supplementation. Additional research (Martin et al., 2007; Stalker et al., 2006) indicates progeny from dams supplemented with protein prepartum have increased calf BW at weaning. Larson et al. (2009) reported no effects of prepartum protein supplementation on calf BW at weaning. Effects passed onto progeny from dam nutrition are an important consideration in cattle production, the economic impact from decreased progeny performance as well as subsequent reproductive performance and impact on carcass traits can lower productivity and profitability.

Results of this study suggest that CCDS supplementation increases cow performance, however there were minimal effects on DMI during this study. While no effect occurred in DMI, cow performance was improved with CCDS supplementation. More importantly the fact that supplemented cows gained more BW and maintained initial BCS could result in an advantage during the high nutritional demand of early lactation. This may be advantageous to calves postnatally. Increased BW at weaning may increase calves ability to stay healthy and adapt more quickly to the stresses associated with

Table 2.4: Effects of corn condensed distillers solubles (CCDS) supplementation on progeny performance.

	Treatment[1]							Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	*P*-value[4]	CON vs. SUP	MIX vs. SEP	HIGH vs. LOW	METH × LEV
Birth weight, kg	41.5	42.2	45.6	41.2	42.1	1.43	0.169	0.400	0.092	0.104	0.350
Adjusted Weaning weight, kg	276.0	278.0	278.3	269.6	275.5	4.72	0.659	0.900	0.220	0.490	0.539

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 4 observations per treatment.

[4] Probability value for the *F*-test of overall treatment.

weaning. The results of this study also indicate CCDS is a viable source of protein and energy and can increase plane of nutrition in gestating cows fed moderate-quality forages.

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CHAPTER 3: EFFECTS OF CORN CONDENSED DISTILLERS SOLUBLES SUPPLEMENTATION ON DRY MATTER INTAKE, RATE AND SITE OF DIGESTION, AND RUMINAL FERMENTATION IN STEERS FED MODERATE QUALITY FORAGES

Abstract

Five ruminally and duodenally cannulated steers (755 ± 68 kg of initial BW) were used in a 5 × 5 Latin square to evaluate the effects of corn condensed distillers solubles (CCDS; 20.4% CP, 15.6% EE, 1.2% P, 1.2% S; DM basis) supplementation on intake, site of digestion, and ruminal fermentation when fed moderate-quality forage. Steers were offered forage ad libitum (8.2% CP, 73.6% NDF, 47.6% ADF, DM basis; mixture of 40% mature bluestem hay and 60% mixed grass alfalfa hay). Steers were individually penned during each 7-d adaptation period then placed in individual metabolism stalls during each 7-d collection period. Treatments were arranged in a 2 × 2 + 1 factorial design; main effects were CCDS feeding method (mixed vs. fed separately) and level of CCDS (0.2 vs. 0.4% BW). The resulting 5 treatments were a negative control (no supplement), 0.2% BW CCDS mixed with the forage, 0.4% BW CCDS mixed with the forage, 0.2% BW CCDS fed separately, and 0.4% BW CCDS (DM basis) fed separately. Supplementation with CCDS increased (kg/d; $P = 0.04$) total DM and OM intake compared to control. Steers fed 0.4% BW CCDS had increased (kg/d; $P = 0.04$) total DM and OM intake compared with steers fed 0.2% BW CCDS. Total tract OM digestion increased ($P = 0.01$) in steers fed 0.4% BW CCDS compared to 0.2% BW CCDS. Apparent and true ruminal CP digestion was increased ($P < 0.01$) in supplemented steers, whereas apparent ruminal CP digestion was increased ($P < 0.01$) and true ruminal CP digestion tended ($P = 0.09$) to increase in steers fed 0.4% BW CCDS. Microbial efficiency was increased ($P = 0.02$) in control steers compared to supplemented steers, and tended ($P = 0.12$) to increase in steers fed mixed diets compared to CCDS fed separately. Non-supplemented steers had increased ($P < 0.03$) total tract NDF and ADF digestion compared to supplemented steers. Steers fed CCDS separately had increased ($P < 0.03$) total tract NDF and ADF digestion compared to steers fed mixed diets. Steers fed 0.4% BW CCDS had decreased ($P = 0.04$) ruminal pH compared to steers fed 0.2% BW CCDS. No treatment effects were observed for ruminal fill or fluid dilution rate ($P \geq 0.17$). Results of this study suggest that CCDS supplementation increases total DM and OM intake as well as CP digestion while decreasing fiber utilization and microbial efficiency in steers fed moderate-quality forages.

Introduction

The ethanol industry is expanding throughout the Midwest, and consequently producers have the option to utilize these byproducts (RFA, 2008). Corn condensed distillers solubles (CCDS) is becoming more popular as a protein supplement. Corn condensed distillers solubles are relatively high in CP and fat, which makes this product appealing for supplementing beef cows.

Low quality forages and crop residues are a plentiful and economical resource that can be an important asset in beef cattle production systems (NRC, 1983). When these resources are utilized, energy or protein supplementation may be necessary to achieve an acceptable level of animal productivity. Starch or fat supplementation may cause a decrease in forage intake but improves livestock productivity by reducing weight loss, reducing BCS loss, and/or increasing weight gain (Caton and Dhuyvetter, 1997; Kowalczyk, 1977). Protein supplementation can increase forage intake and utilization

(McCollum and Horn, 1990; Hannah et al., 1991). As a result, increased cattle performance has been documented in some studies (Sanson et al., 1990; Bodine et al., 2001). Specifically, rumen degradable protein improved forage intake, digestibility, and animal performance when animals are fed low-quality forages (Guthrie and Wagner, 1988; Del Curto et al., 1990; Köster et al., 1996).

Corn condensed distillers solubles are high in both protein and fat (15 to 25% CP and 4 to 22% fat, DM basis; Gilbery et al., 2006; Da Cruz et al., 2005). Gilbery et al. (2006) reported two studies that used CCDS as a supplement for low quality forages which gave conflicting results. In the first study, forage DMI was not affected by increasing CCDS levels when fed separately from forage. In addition, total tract ADF and NDF digestibilities were not affected by increasing levels of CCDS. However, in a second study when CCDS was mixed with forage, forage DMI increased quadratically with the greatest DMI at 10% CCDS. There was also a linear increase of ruminal ADF and NDF digestion when increasing levels of CCDS were mixed with forage. One explanation for the differences between the studies could be that feeding CCDS and forage together results in improved synchrony and release of nutrients (Gilbery et al., 2006). However, more research is needed to better understand the differences in DMI and digestibility that occurs when CCDS is fed mixed vs. separately. Thus, the objectives of this study were to evaluate the effects of level and form of CCDS supplementation on DMI, site of digestion, and ruminal fermentation in cannulated steers fed low quality forage.

Materials and Methods

Animals and Diets. Five ruminally and duodenally cannulated Holstein steers were used in a 5 × 5 Latin square. Steers were weighed at the initiation of the trial and housed in a climate-controlled room in individual pens (3.0 × 3.7 m) during each 7-d adaptation period and stalled in individual metabolism crates (1.0 × 2.2 m) during each 7-d collection period. Steers were offered ad libitum quantities of a basal diet consisting of a mixture of 40% mature bluestem hay and 60% chopped mixed grass alfalfa hay (Table 3.1), and allowed access ad libitum to water. Treatments consisted of a negative control (CON, no supplement), 0.2% BW CCDS mixed with the forage (DM basis), 0.4% BW CCDS mixed with the forage, 0.2% BW CCDS supplement fed separately, and 0.4% BW CCDS fed separately. Mixed rations consisted of 1:0.55 forage to CCDS for the 0.2% mixed diet and 1:1.1 for the 0.4% mixed diet (as-fed basis). Steers fed CCDS separate from forages were given 1 h to consume CCDS after which any remaining CCDS was immediately dosed intra-ruminally. A trace mineral supplement block (NaCl 96.0%, Mn 0.2%, Fe 0.2%, Cu 0.03%, Co 0.01%, I 0.007%, Zn 0.005%; Cutler Magner Company, Duluth, MN) was provided during the study.

Table 3.1: Analyzed nutrient content of forage and corn condensed distillers solubles (CCDS)

Item, %	Forage[1]	CCDS[2]
DM	87.7	33.6
	%, DM Basis	
Fat	ND[3]	15.6
Ash	6.5	6.9
CP	8.2	20.4
NDF	73.6	ND
ADF	47.6	ND
Ca	0.6	0.1
P	0.1	1.2
S	ND	1.2

[1] Forage consisted of 40% mature bluestem hay and 60% mixed grass alfalfa hay.
[2] CCDS = corn condensed distillers solubles
[3] ND = not determined.

Sampling and Collections. Individual ingredient samples were taken daily (approximately 200 g) and composited within period. Ort samples were taken daily, prior to morning feeding (0700), throughout the 7-d collection period. Five d prior to and throughout collections, 8 g of chromic oxide was dosed ruminally twice daily at 0700 and 1900 via gelatin capsule (Torpac, Inc., Fairfield, NJ) for use as a digesta flow marker. Total fecal collections were performed using stainless steel pans placed directly behind the stalls and total fecal output determined daily. Fecal sub-samples (10% of output; wet weight basis) were composited within steer during each period. Sub-samples were stored (4˚C) until mixed with a rotary mixer (Model: H-600; Hobart Manufacturing Co., Troy, OH) at the end of each period, where another sub-sample was taken and frozen (-20˚ C) until analysis. Duodenal samples (200 mL) were collected over 4 d in a manner that allows for every other hour in a 24-h period to be sampled. Samples were taken on d 3 at 0800, 1400, and 2000; d 4 at 0200, 1000, 1600, and 2200; d5 at 0400, 1200, 1800, and 2400; and d 6 at 0600 of each collection period. Samples were composited by steer within period and stored (-20˚ C) until analyses.

Liquid dilution rate was estimated using Co-EDTA as a liquid flow marker. Two hundred mL of Co-EDTA (1734 mg Co; Uden et al., 1980) was dosed intraruminally 2 h prior to feeding on d 6 of each collection period. Ruminal fluid samples (200 mL) were collected with a suction strainer at 0, 2, 4, 6, 8, 10, and 12 h post feeding, and pH immediately determined with a combination electrode (Model 2000 pH/ temperature meter; VWR Scientific Products, West Chester, PA). Samples (200 mL) were acidified with 2 mL, 6.0 *N* HCl. A sub-sample (3 mL) of the initial, non-acidified ruminal fluid sample was collected and added to 0.75 mL metaphosphoric acid and frozen (-20˚ C) until VFA analysis.

On d 7 of each collection period, prior to morning feeding, ruminal evacuations were conducted to determine ruminal fill. Ruminal contents were removed, weighed, and sub-sampled. Sub-samples were obtained by hand mixing ruminal contents in 208 L tubs and taking samples from various locations. A grab sample was taken for DM, OM, ADF, and NDF analyses. A second ruminal content sample (4 kg) was taken and 2 L of formalin/ saline solution (3.7% formaldehyde/ 0.9% NaCl) was added (Zinn and Owens, 1986) for isolation of bacterial cells which later was analyzed for DM, ash, N, and purine. Samples were stored frozen (-20˚ C) until analyses.

Laboratory Analyses. Diet, ort, and fecal samples were dried using a forced-air oven (55˚ C; The Grieve Corporation, Round Lake, IL) for 48 h. Dried samples were ground in a Wiley mill to pass through a 2-mm screen. Duodenal samples were lyophilized (Virtis Genesis 25LL; The Virtis Company, Inc., Gardiner, NY) and ground with a Wiley mill to pass through a 1-mm screen.

Diet, ort, duodenal, and fecal samples were analyzed for DM, ash, and N (Procedure numbers: 930.15, 942.05, 984.13, respectively; AOAC, 1997). Concentrations of NDF (Robertson and Van Soest, 1991, as modified by Ankom Technology, Fairport, NY) and ADF (Goering and Van Soest, 1970, as modified by Ankom Technology, Fairport, NY) were determined using an Ankom 200 Fiber Analyzer (Ankom Technology, Fairport, NY) without sodium sulfite, with amylase, and without ash correction as sequentials. Chromic oxide concentrations were analyzed in duodenal samples by the spectrophotometric method (Fenton and Fenton, 1979). In situ residue from duplicate bags was composited and analyzed for DM, NDF, and ADF.

Ruminal fluid samples were thawed for 12 h at 4˚C prior to analysis. Ruminal fluid samples were centrifuged at 20,000 × g for 20 min and supernatant taken for analysis of ammonia (Broderick and Kang, 1980). Ruminal VFA concentrations (Goetsch and Galyean, 1983) was quantified by gas chromatography (Hewlett Packard 5890A Series II GC, Wilmington, DE) using a capillary column. Cobalt was analyzed by methods described by Uden et al. (1980) with an air-plus-acetylene flame using atomic absorption spectroscopy (Model: 3030B; PerkinElmer, Inc., Wellesley, MA).

Ruminal content samples from total evacuations were analyzed for DM and ash (AOAC, 1997). A Waring blender (Model: 37BL19 CB6; Waring Products, New Hartford, CT) was used to blend ruminal contents. Samples were blended on high speed for 1 minute and mixture strained through four layers of cheesecloth. Liquid was then placed in 250 mL centrifuge bottle and centrifuged at 500 × g for 20 min to remove feed particles and protozoa. Supernatant was removed and re-spun at 500 × g for 20 min. Bacteria were separated from supernatant by centrifuging at 30,000 × g for 20 min. Isolated bacterial cells and duodenal contents were analyzed for purines (Zinn and Owens, 1986) as a microbial marker.

Statistical Analysis. Data were analyzed as a 5 × 5 Latin square using the MIXED procedures of SAS (SAS Inst., Cary, NC). The model included diet and period as fixed effects and animal as the random effect. Data over time was analyzed as a repeated measures design using the MIXED procedures of SAS (SAS Inst., Cary, NC). The model included period, animal, diet, time, diet × time, and animal × period × diet with the random variable being animal. When the overall F-test for treatment was significant ($P \leq 0.10$) means were separated using orthogonal contrasts which included control vs. supplemented treatments, mixed diets vs. CCDS fed separately, 0.4% CCDS vs. 0.2% CCDS, and the interaction of method of feeding × CCDS level.

Results and Discussion

Forage DMI (Table 3.2) was not affected (*P* > 0.13) by treatments, which is similar to the results reported by Köster and others (1997) which indicated that RDP supplementation had no effect on low-quality (1.9% CP) forage DMI. However, RDP supplementation has increased forage intake in many studies (Mathis et al., 1999; Olson et al., 1999; Bodine et al., 2001). By design, CCDS intake was increased (*P* < 0.01) in both control vs. supplemented steers and high vs. low treatments. Increased CCDS intake in steers fed CCDS separately (*P* < 0.01) compared to those fed mixed diets, was due to our study protocol in which any remaining CCDS was dosed intraruminally after feeding. Total intake was increased (*P* = 0.04) in supplemented steers compared to control steers, intake was also increased (*P* = 0.04) in steers fed 0.4% BW CCDS compared to 0.2% BW CCDS. No treatment effects for ruminal DM fill were observed (*P* = 0.32). This is similar to Olson et al. (1999) who observed no affects when steers were fed low-quality hay (4.9% CP) with RDP supplementation. However, researchers (DelCurto et al., 1990; Sunvold et al., 1991) have reported increased ruminal DM fill with protein supplementation. Since differences detected in DMI were minimal with CCDS supplementation, no differences in DM fill were expected.

Fluid dilution rate (FDR; 10.8 ± 1.2%/h) was not affected (*P* = 0.17) by treatments (Table 3.2). Results in FDR have been conflicting in other studies where protein supplementation was used with a forage-based diet. Gilbery et al. (2006) reported no

Table 3.2: Effects of corn condensed distillers solubles (CCDS) supplementation on DMI, ruminal fill, and fluid dilution rate in dairy steers consuming a forage-based diet.

	Treatment[1]							Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	*P*-value[4]	CON vs. SUP	HIGH vs. LOW	MIX vs. SEP	METH × LEV
Forage DM intake											
kg/d	6.75	5.99	6.43	6.28	5.03	0.66	0.130	0.123	0.381	0.232	0.081
% of BW	0.80	0.77	0.95	0.70	0.57	0.14	0.349	0.689	0.847	0.104	0.242
CCDS DM intake kg/d	0.00	0.93	2.38	1.61	3.14	0.20	<0.001	<0.001	<0.001	0.003	0.828
Total intake											
kg/d	6.75	6.92	8.81	7.89	8.17	0.76	0.043	0.041	0.038	0.736	0.111
% of BW	0.81	0.89	1.31	0.93	0.98	0.20	0.422	0.312	0.238	0.469	0.347
Ruminal DM fill, % of BW	16.36	11.25	11.96	9.29	9.98	2.73	0.315	0.052	0.778	0.431	0.997
Fluid dilution rate, %/h	9.17	12.04	12.01	9.51	11.42	1.18	0.173	0.089	0.372	0.148	0.361

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 5 observations.

[4] Probability value for the *F*-test of overall treatment.

effects of increasing CCDS level on FDR, and other researchers (Köster et al., 1997; Bandyk et al., 2001) reported no increase in FDR with RDP supplementation. However, some research has shown an increase in FDR (Freeman et al., 1992; Hannah et al. 1991)with protein supplementation. Hannah et al. (1991) associated increases in FDR with increased forage intake. In our research, CCDS supplementation had only minimal effects on DMI which could explain why no responses were noted in FDR.

Supplemented steers had a greater (*P* = 0.04) OM intake than control steers (Table 3.3). Organic matter intake was also increased (*P* = 0.04) in steers fed 0.4% BW CCDS compared to 0.2% BW CCDS. Total OM, nonmicrobial OM, and fecal OM flows were not affected (*P* > 0.40) by treatment; however microbial OM flow was increased (*P* < 0.01) in supplemented steers and those fed 0.4% BW CCDS. Intestinal OM digestion was not affected by treatments (*P* = 0.95), whereas true ruminal OM digestion increased (*P* = 0.02) and apparent ruminal OM digestion tended to increase (*P* = 0.13) in supplemented steers. Total tract OM digestion was increased (*P* = 0.01) in steers fed 0.4% BW CCDS and tended (*P* = 0.11) to increase in supplemented steers. Gilbery et al. (2006) reported no effects of increasing levels of CCDS when CCDS fed separately on OM intake, flow, and digestion. Freeman et al. (1992) also reported no effect on OM intake when steers were fed a cottonseed meal supplement. However, in a second study, Gilbery et al. (2006) reported increased forage OM intake, duodenal OM flow, and ruminal digestibilities when increasing levels of CCDS were mixed and fed together with forage. Increased OM intake is consistent with other research which investigated protein supplementation of low-quality hay (<4% CP; Guthrie and Wagner, 1988; Köster et al., 1996).

Table 3.3: Effects of corn condensed distillers solubles (CCDS) supplementation on OM digestion in dairy steers consuming a forage-based diet.

	Treatment[1]							Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	*P*-value[4]	CON vs. SUP	HIGH vs. LOW	MIX vs. SEP	METH × LEV
OMI, kg/d	6.31	6.43	8.15	7.36	7.63	0.71	0.046	0.044	0.040	0.643	0.117
Duodenal OM flow											
Total, kg/d	4.18	4.59	4.73	4.49	4.90	0.35	0.178	0.049	0.174	0.841	0.520
Microbial, kg/d	0.95	1.16	1.39	1.17	1.29	0.12	0.004	0.001	0.012	0.449	0.384
Nonmicrobial, kg/d	4.19	4.37	4.35	4.28	4.58	0.35	0.699	0.380	0.494	0.719	0.443
Fecal OM flow, kg/d	3.13	3.06	3.48	3.85	2.81	0.62	0.397	0.708	0.434	0.880	0.082
Digestion, % of intake											
Apparent ruminal	24.44	28.18	32.97	32.57	36.21	3.95	0.125	0.044	0.188	0.230	0.855
True ruminal	41.00	46.54	51.98	49.50	53.09	3.86	0.108	0.024	0.161	0.510	0.768
Intestinal	26.43	23.78	25.19	24.15	28.04	5.55	0.955	0.837	0.576	0.732	0.791
Total tract	49.88	51.95	57.29	50.50	64.25	5.93	0.036	0.110	0.011	0.402	0.209

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 5 observations.

[4] Probability value for the *F*-test of overall treatment.

By design, total CP intake was increased (*P* < 0.01) in supplemented steers, and in steers fed 0.4% BW CCDS compared to 0.2% BW CCDS (Table 3.4). Forage CP intake was increased (*P* < 0.01) in steers fed mixed diets compared to CCDS fed separately, as a result of increased forage DMI in these treatments. Total, microbial, and nonmicrobial CP flow were all increased (*P* < 0.03) in supplemented vs. non-supplemented steers and steers fed 0.4% BW CCDS vs. 0.2% BW CCDS, whereas fecal CP flow was not affected (*P* = 0.26) by treatments. Apparent ruminal, true ruminal, and total tract digestion of CP was increased (*P* < 0.01) in supplemented steers compared to control fed steers; whereas intestinal CP digestion was decreased in supplemented steers compared to control steers. Steers fed 0.4% BW CCDS had increased apparent ruminal (*P* = 0.01) and total tract (*P* < 0.01) CP digestion; and tended to have increased (*P* = 0.09) true ruminal CP digestion compared to steers fed 0.2% BW CCDS. Gilbery et al. (2006) reported conflicting results with two different forms of feeding CCDS. The negative apparent ruminal CP digestibilities found in this study are consistent with other researchers feeding low quality forages with no supplemental CP (Hannah et al., 1991; Köster et al., 1996) and is attributed to N recycling in the rumen (Bunting et al., 1989).

Microbial efficiency was decreased (*P* = 0.02) in supplemented steers compared to the non-supplemented control, and tended to increase (*P* = 0.11) in steers fed mixed diets compared to those fed CCDS separately. Gilbery et al. (2006) reported no effects on microbial efficiency (*P* > 0.38) in both studies they conducted using CCDS as a protein supplement. Other research (Caton et al., 1994; Reed et al., 2004) indicated no effect on microbial efficiency when cattle were fed a protein supplement with low to moderate-quality forages (6.2-8.0% CP).

Table 3.4: Effects of corn condensed distillers solubles (CCDS) supplementation on CP digestion in dairy steers consuming a forage-based diet.

	Treatment[1]							Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	*P*-value[4]	CON vs. SUP	HIGH vs. LOW	MIX vs. SEP	METH × LEV
CP intake											
Hay, kg/d	0.57	0.64	0.79	0.52	0.42	0.07	0.003	0.618	0.646	<0.001	0.027
CCDS, kg/d	0.00	0.19	0.49	0.33	0.64	0.04	<0.001	<0.001	<0.001	0.002	0.827
Total, kg/d	0.57	0.83	1.27	0.85	1.06	0.10	<0.001	<0.001	<0.001	0.219	0.135
Duodenal CP flow											
Total, kg/d	0.96	1.13	1.33	1.16	1.32	0.17	0.005	0.002	0.009	0.914	0.667
Microbial, kg/d	0.50	0.58	0.68	0.59	0.64	0.06	0.013	0.004	0.027	0.546	0.360
Nonmicrobial, kg/d	0.46	0.55	0.65	0.57	0.68	0.06	0.008	0.004	0.009	0.513	0.988
Fecal CP output, kg/d	0.32	0.35	0.43	0.43	0.36	0.07	0.263	0.143	0.865	0.910	0.086
CP digestion, % intake											
Apparent ruminal	-91.8	-36.7	-22.1	-44.5	-23.2	9.60	<0.001	<0.001	0.010	0.451	0.572
True ruminal	7.50	34.3	40.2	29.4	36.6	4.87	<0.001	<0.001	0.086	0.248	0.841
Intestinal	137.8	94.5	89.2	100.9	90.2	8.48	0.003	<0.001	0.265	0.599	0.702
Total tract	43.8	57.8	66.7	51.8	67.0	5.65	<0.001	<0.001	0.002	0.364	0.323
Microbial efficiency[5]	22.5	20.0	18.7	18.2	15.9	2.00	0.052	0.019	0.199	0.111	0.748

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 5 observations.

[4] Probability value for the *F*-test of overall treatment.

[5] Grams of microbial N per kilogram of OM truly fermented.

Intake of NDF and ADF was increased ($P < 0.02$) in control steers compared to supplemented steers (Table 3.5). Total tract digestion of NDF and ADF decreased ($P < 0.03$) in supplemented steers; however, digestion of NDF and ADF increased ($P < 0.03$) in steers fed CCDS separately compared to those fed mixed diets. Several studies (Caton et al., 1988; Guthrie and Wagner, 1988; DelCurto et al., 1990) reported increased NDF and ADF digestion with protein supplementation, specifically rumen degradable intake protein (Köster et al., 1996). It is possible that the high fat content of CCDS may have played a role in depressing digestion in supplemented steers. Hess et al. (2001) fed increasing levels of soybean meal and soybean oil to heifers, which resulted in decreased NDF digestion with soybean oil inclusion; which they attributed to depressed NDF digestion in the rumen. Furthermore, Gould et al. (2000) reported a decrease in NDF digestion post-ruminally and in the total tract digestion. Ruminal and intestinal digestion of NDF and ADF were not affected ($P > 0.26$) by CCDS treatments.

Feeding steers 0.4% BW CCDS resulted in decreased ruminal pH (6.74 ± 0.09) compared to feeding 0.2% BW CCDS ($P = 0.04$; Table 3.6). Supplementation of CCDS did not affect ($P = 0.12$) ruminal pH compared to controls. Both protein and energy supplementation have resulted in decreased ruminal pH (Hannah et al., 1991; Köster et al., 1996; Caton and Dhuyvetter, 1997). Decreased ruminal pH has been attributed to decreased forage intake and digestion (Mould et al., 1983), however Ørskov (1982) determined that cellulolytic bacteria were not affected at pH levels 6.2 or greater. At all levels of CCDS supplementation, pH remained above 6.2 thus we did not expect any adverse effects on digestion.

Table 3.5: Effects of corn condensed distillers solubles (CCDS) supplementation on ADF and NDF digestion in dairy steers consuming a forage-based diet.

	Treatment[1]							Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	*P*-value[4]	CON vs. SUP	HIGH vs. LOW	MIX vs. SEP	METH × LEV
NDF											
Intake, kg/d	4.95	3.74	3.64	4.57	3.65	0.429	0.037	0.012	0.136	0.220	0.228
Duodenal, kg/d	2.11	2.15	2.04	1.97	2.03	0.23	0.958	0.779	0.899	0.595	0.664
Fecal, kg/d	2.37	2.31	2.65	2.93	2.10	0.46	0.353	0.709	0.414	0.911	0.069
Digestion, % intake											
Ruminal	52.1	42.3	35.8	47.8	45.7	5.65	0.258	0.123	0.373	0.132	0.656
Intestinal	-0.43	-4.61	-6.35	-4.15	-1.50	8.90	0.972	0.647	0.947	0.702	0.750
Total tract	51.1	37.7	27.7	39.6	44.2	7.37	0.011	0.006	0.479	0.031	0.075
ADF											
Intake, kg/d	3.19	2.44	2.40	2.97	2.41	0.29	0.047	0.017	0.162	0.206	0.228
Duodenal, kg/d	1.40	1.46	1.32	1.34	1.34	0.16	0.928	0.840	0.584	0.710	0.613
Fecal, kg/d	1.61	1.52	1.75	1.91	1.36	0.30	0.410	0.930	0.432	0.989	0.081
Digestion, % intake											
Ruminal	51.1	40.0	35.3	46.0	45.2	6.08	0.292	0.126	0.583	0.131	0.692
Intestinal	-1.23	-3.48	-6.88	-2.32	0.26	9.21	0.952	0.814	0.952	0.542	0.657
Total tract	48.6	36.6	27.1	39.3	45.5	7.42	0.022	0.026	0.694	0.023	0.078

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 5 observations.

[4] Probability value for the *F*-test of overall treatment.

Table 3.6: Effects of corn condensed distillers solubles (CCDS) supplementation on ruminal pH, NH_4 concentration, and VF concentration in dairy steers consuming a forage-based diet.

	Treatment[1]						*P*-value[4]			Contrast[2]			
Item	CON	0.2% MIX	0.4% MIX	0.2% SEP	0.4% SEP	SEM[3]	Trt	Time	Trt × Time	CON vs. SUP	HIGH vs. LOW	MIX vs. SEP	METH × LEV
pH	6.80	6.77	6.64	6.77	6.72	0.09	0.092	0.010	0.168	0.120	0.042	0.407	0.343
NH_4, mM	3.08	4.66	4.20	3.27	4.26	0.72	0.173	<0.001	0.019	0.093	0.207	0.611	0.172
VFA													
Total, mM	73.2	70.4	75.5	69.7	67.7	6.18	0.231	0.0171	0.047	0.388	0.529	0.102	0.168
Acetate	57.7	53.7	51.6	53.7	49.7	6.63	0.078	<0.001	0.947	0.016	0.117	0.602	0.590
Propionate	12.7	13.0	14.0	14.2	15.90	1.93	0.048	<0.001	<0.001	0.062	0.070	0.048	0.666
Butyrate	4.12	6.89	8.96	6.95	8.62	0.97	<0.001	<0.001	0.002	<0.001	0.007	0.819	0.733
Acetate: Proprionate[5]	4.59	4.14	3.77	3.83	3.31	0.12	<0.001	<0.001	0.006	<0.001	0.001	0.003	0.495

[1] CON = forage only, 0.2% MIX = forage mixed with 0.2% BW corn condensed distillers solubles supplement, 0.4% MIX = forage mixed with 0.4% BW corn condensed distillers solubles supplement, 0.2% SEP = forage with 0.2% BW corn condensed distillers solubles supplement fed separately, 0.4% MIX = forage with 0.4% BW corn condensed distillers solubles supplement fed separately.

[2] CON vs. SUP = control treatment vs. all supplemented treatments, MIX vs. SEP = forage and corn condensed distillers solubles mixed vs. forage and corn condensed distillers solubles fed separately, HIGH vs. LOW = 0.4% BW corn condensed distillers solubles level vs. 0.2% BW corn condensed distillers solubles level, METH × LEV = method of feeding (mixed and fed separately) and corn condensed distillers solubles supplementation level interaction.

[3] n = 5 observations.

[4] Probability value for the *F*-test of overall treatment.

[5] Ratio of Acetate to Propionate.

Total VFA concentration was not affected by CCDS supplementation (71.3 ± 6.2 mM; $P = 0.23$). Protein supplementation has increased total VFA concentration in cattle fed a forage based diet (DelCurto et al., 1990; Köster et al., 1996). Molar proportion of acetate was increased ($P = 0.02$) in CCDS supplemented steers compared to control fed steers, whereas molar proportion of butyrate increased in supplemented steers ($P < 0.01$) and those fed 0.4% BW CCDS ($P = 0.01$). Molar proportion of propionate increased in supplemented steers ($P = 0.02$), steers fed CCDS separately ($P = 0.05$), and steers fed high level of CCDS ($P = 0.07$). However, the acetate to propionate ratio was decreased ($P < 0.01$) in supplemented steers, increased ($P < 0.01$) in steers fed mixed diets, and decreased in steers fed high level of CCDS ($P < 0.01$). There was a time × treatment interaction for propionate ($P < 0.01$), butyrate ($P < 0.01$), and acetate to propionate ratio ($P = 0.01$). This was due to a magnitude response and was not thought to be biologically significant.

Concentration of NH_4 (3.89 ± 0.72 mM) was not affected ($P = 0.17$) by treatments. Gilbery's (2006) two studies had conflicting results, when CCDS was fed separately it did not have any effect on ruminal NH_4 concentrations. However, when CCDS was fed as a TMR, steers had increased levels of ruminal NH_4 compared to non-supplemented steers.

Results of this study suggest that CCDS supplementation increases OM, total and forage CP intake. Though this study did not show increases in forage DMI, ADF, and NDF digestion when CCDS was supplemented, results show increased nutrient availability to steers. It is important to consider the variability of CCDS CP and fat content when formulating rations for ruminants. Though CP supplementation increases digestibility of forages in most cases, high amounts of fat in CCDS may cause slight decreases in forage digestibility. Supplementation of CCDS is beneficial as it is a source of energy and protein, however further research is necessary to fully determine its effects on forage utilization and to make reliable feeding recommendations.

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CHAPTER 4: CONCLUSIONS AND FUTURE DIRECTIONS

The high concentration of protein and fat within CCDS makes it a viable supplementation option for forage fed beef cattle. With the continued growth of the ethanol industry, by products such as CCDS are economical and readily available in most regions. In the past 10 years, Ethanol production has increased almost five times in volume and with over a third of the corn used being diverted back to livestock feed as ethanol co-products. Regionally ethanol co-products are becoming more readily available as well; there are now ethanol production facilities in 24 states.

Data suggests that the high levels of nutrients in CCDS increase performance and can provide a valuable resource for cattle utilizing low to moderate quality forages. In comparison with two of the highest usage feedstuffs, corn and soybean meal, CCDS offers both high energy and protein levels. Corn has historically been used as an energy supplement with approximately 61% starch, 3.8% oil, 8% CP, 11.2% fiber and 16% moisture. While soybean meal is predominately used for protein supplementation, 48% CP, 1% fat, 3% fiber, and 10% moisture. Not only is CCDS a great source of both protein and energy, but it is also much more economical than other supplements.

While CCDS offers greater nutrient availability to ruminants, further research is needed to fully understand its effects on forage utilization. The variability of fat content may be the reason that research studies using CCDS as a supplement report conflicting effects on forage intake and digestibility. For producers, the important item of consideration is availability of forage, if forage is not a limiting factor then a moderate to high protein supplement would be most beneficial. However, as is often the case through the winter, when forage is not readily available, CCDS with both high energy and protein levels would provide a resource that will help maintain BCS and maintain acceptable performance levels. At both levels, CCDS supplementation provided increased performance in cattle; however, there are conflicting results on the best method of feeding CCDS.

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