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UTILIZATION OF CORN CONDENSED DISTILLERS SOLUBLES AND FORAGES IN MANAGEMENT SYSTEMS FOR THE COW-CALF ENTERPRISE

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IN MANAGEMENT SYSTEMS FOR THE COW-CALF ENTERPRISE

by

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Of the annual expenses necessary to maintain a beef cow, feed and forage are the greatest and most variable. Thus, nutrition programs for cow-calf operations must be developed using economical feedstuffs that optimize cowherd performance. The corn dry-milling industry provides several feedstuffs that are often the most economical sources of energy and protein, but considerations for storage and handling are necessary. Two experiments evaluated an alternative form of storing corn condensed distillers solubles (CCDS) by applying to grass hay windrows before baling. Round bales were treated with either 0 or 20% (Exp. 1); or 0, 16, and 32% (Exp. 2) CCDS (DM). Bale temperature was monitored and core samples collected. In either study, adding CCDS did not impact DM or the ability of hay to expel heat post-baling. Elevated CP and decreased NDF for CCDS-treated hay indicated within-bale storage occurred. Data suggest pre-baling application is feasible for storing liquid co-products while improving forage quality.

Two related experiments tested the feeding value of grass hay bales treated with CCDS in growing cattle diets. In Exp. 1, replacement heifers were offered ad libitum access to bales treated with 20% CCDS, or fed an equal dietary inclusion of dried distillers grains plus solubles (DDGS) and ad libitum hay. Heifers fed DDGS had increased ADG and BCS with more females cycling before breeding than heifers fed CCDS. Unequal co-product intake or metabolizable protein may have contributed to performance differences. To evaluate these effects, Exp. 2 was conducted as a completely randomized design with a 3 x 2 factorial arrangement of treatments. Factors included CCDS level (0, 15, or 30% of diet, DM) and supplementing to meet metabolizable protein requirements or not (MP or No MP). Steer DMI and performance improved with increasing dietary CCDS. Metabolizable protein improved gain but only for diets with 0% CCDS. Cattle performance data indicate within-bale storage of CCDS occurred, and windrow application before baling is a viable storage technique.

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The Cow-Calf and Backgrounding Segments of the Beef Industry

Sustainable cow-calf operations are fundamental to the beef industry. The global demand for beef is expected to grow concurrent with the human population. Thus, economically viable cow-calf systems will be vital in meeting the demand for beef. To be profitable, cow-calf operations must control costs while optimizing reproduction (Miller et al., 2001). As of January 1, 2012 the cow-calf segment was comprised of 29.9 million mature beef cows (CME Group, 2012). Because the national beef cow herd has been liquidated twelve of the previous fourteen years, this population represents the smallest inventory since the late 1950s (LMIC, 2012). Consequently, feeder calf supply has retracted.

Recently, elevation of cereal grain prices has accompanied contraction within the cattle industry. The demand-driven price increase for corn has inflated feedlot cost of gains. Therefore, forage-based production systems have become competitive alternatives to add weight to cattle prior to feedlot entry. These systems will be integral in sustaining current beef production levels, as they enable cattle to be finished at heavier weights and provide continuous supplies of cattle to feedlots throughout the year (Klopfenstein et al., 2000).

Nebraska ranks fourth in beef cow inventory maintaining over 1.7 million breeding females annually (NE Beef Council, 2012). More than 4.5 million cattle are fed and marketed through feedlots within the state each year. This difference between feeder calf supply and feedlot capacity allows Nebraska to be a net importer of cattle. Thus, opportunities exist to grow cattle prior to feedlot placement using available forage resources including native range and cornstalks.

The Ethanol Industry and Availability of Dry-Milling Co-Products

Foreign and domestic demand for renewable sources of fuel has increased greatly in the last decade. This has spurred the development of the dry-milling ethanol industry (Klopfenstein et al., 2008). Recent data (NE Ethanol Board, 2012) demonstrates the annual production capacity within the United States has escalated from 2 billion gallons in 2000 to over 12 billion in 2010. As of 2012, over one hundred seventy ethanol plants were operating domestically. Twenty-four plants are located in Nebraska. This production volume permits Nebraska to rank second in national ethanol output (NE Ethanol Board, 2012).

Corn is comprised of two-thirds starch, which is the component fermented to produce ethanol (Klopfenstein et al., 2008). The remaining nutrients of corn are recovered in co-products. Accordingly, the relative concentrations of crude protein (CP), fiber, fat, and minerals are elevated three-fold in co-products relative to corn grain (Erickson et al., 2010). These nutritional characteristics make co-products attractive for use in ruminant diets (Ham et al., 1994; Cao et al., 2009). Ethanol plants generate varying forms of co-products which can be broadly referred to as distillers grains. However, differences in composition and moisture content warrant differentiation among specific products (Lardy, 2007). Ethanol co-products include wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), dried distillers grains plus solubles (DDGS), and corn condensed distillers solubles (CCDS) (Tjardes and Wright, 2002). Corn condensed distillers solubles will be extensively discussed as the implementation of this co-product into cow-calf production systems is the theme of this

thesis. Due to the growth of Nebraska's ethanol industry, cattle producers within the state have access to approximately 5 million metric tons (as-is) of co-products annually.

Corn Condensed Distillers Solubles

Corn condensed distillers solubles is the result of one of two different production streams in the dry-milling process (Stalker et al., 2010). Rust et al. (1990) noted after yeast fermentation of starch and the subsequent distillation of ethanol, a single product referred to as "whole" stillage remains. Being liquid in form, whole stillage is a combination of solid grain fractions, spent yeast cells, corn oil, and water (Lardy, 2007; Erickson et al., 2010). This product is centrifuged to separate the liquid from the solid fraction, resulting in "thin" stillage and wet distillers grains, respectively (Chen et al., 1977; Cao et al., 2009). Thin stillage is further evaporated to 30-35% dry matter (DM), producing CCDS (Tjardes and Wright, 2002; Lardy, 2007; Cao et al., 2009).

Typically, CCDS is combined with wet distillers grains creating WDGS (Tjardes and Wright, 2002; Sasikala-Appukuttan et al., 2008). This product is most commonly offered for sale by ethanol plants. However, CCDS may be marketed as a separate commodity if production inefficiencies within the ethanol plant or merchandizing opportunities occur. In such an event, CCDS is often priced at a considerable discount relative to other co-products. Researchers (Sasikala-Appukuttan et al., 2008; Cao et al., 2009) have determined wet distillers grains contain more CP and fiber than CCDS. Conversely, CCDS is greater in fat and mineral content. Therefore, the concentration of fat, phosphorus (P), and sulfur (S) in WDGS is directly proportional to the amount of CCDS applied to the grain fraction (Sasikala-Appukuttan et al., 2008; Cao et al., 2009; Corrigan et al., 2009).

Corn condensed distillers solubles contain approximately 22-25% CP DM (Gilbery et al., 2006; Stalker et al., 2010). It has been well documented that zein, the primary protein in corn, is only 35-40% degraded in the rumen (Klopfenstein et al., 2008). Consequently, the protein in WDGS, MDGS, and DDGS is 60-65% rumen undegradable. However, Gilbery et al. (2006) conducted a metabolism experiment in which CCDS was fed to steers consuming low-quality hay. The authors measured ruminal crude protein disappearance and calculated the degradability of CCDS to be 86.7%. These results concur with those of DeHaan et al. (1982), who reported protein in CCDS is almost entirely degraded in the rumen. Therefore, the degradability of crude protein in CCDS is opposite that of distillers grains. This contributes to the attractiveness of the use of CCDS in forage-based diets (Coupe et al., 2007).

Phosphorus and S levels for CCDS have been reported from 1.30-1.72% and 0.37-2.08% DM, respectively (Lardy, 2007; Doran et al., 2008; Stalker et al., 2010). Other investigators (Gilbery et al., 2006; Sasikala-Appukuttan et al., 2008) have reported fat values from 4.2-22.0% DM. Buckner et al. (2011) described the variation of nutrient composition and DM for WDGS and MDGS within and across ethanol plants. Clearly, inherent variation also exists for CCDS. Thus, DM and chemical composition should be monitored when purchasing and feeding CCDS.

Factors Impacting the Use of Harvested Forages

Season of Calving

It was determined by Adams et al. (1996) that the quantity of harvested feeds required to maintain a cowherd is strongly correlated with calving date. As such, selecting a calving period is a critical decision affecting production efficiency and

profitability. Cow nutrient requirements are cyclical and greatest during peak lactation (NRC, 1996). Forage nutrient density is dynamic and seasonal. Therefore, the ability of grazed forages to meet the nutrient requirements of the cow is dictated by when lactation begins. In the northern Great Plains, the quality of native range peaks in early summer and declines thereafter (Adams et al., 1996; Grings et al., 2005). Consequently, late-winter or early-spring calving results in peak nutrient requirements of the cow occurring well prior to maximum forage quality (Adams et al., 1996). This biological imbalance results in the need for supplemental protein and/or energy, which can often be supplied through harvested forages.

Researchers have investigated the production (Grings et al., 2005; Stockton et al., 2007) and economic (Stockton et al., 2007) impact of aligning peak nutrient requirements of the cow to the period of highest forage quality. Results from Grings et al. (2005) demonstrate the need for harvested forages is reduced for cows calving in June compared to February or April. In agreement, Stockton et al. (2007) reported altering the season of calving from March to June resulted in feeding 1.7 fewer metric tons of hay/cow/yr. These savings in harvested forages contributed to the increased net returns realized by the June calving system.

Certainly, a calving date allowing for an increase in cow nutrient demand with a concomitant increase in quantity and quality of forage for grazing is effective in reducing the need for harvested forages. However, Sprott et al. (2001) noted vast differences in production environments across the United States prevent the adoption of a universal calving season. In the author's review, it was reported that time of calving is heavily influenced by the seasonal growth pattern of critical forage species. Accordingly,

producers with abundant warm-season forages prefer to calve in spring or summer; locations with adequate cool-season plant growth favor fall or winter calving provided grazing is not limited.

Synchronization of forage quality and cow nutrient demand is one of multiple factors to contemplate when choosing a calving date. Economic implications such as market timing, calf size at marketing, price seasonality, and annual production costs are pertinent to consider when selecting a date to calve (Reisenauer et al., 2001; Sprott et al., 2001; Stockton et al., 2007). Prior research has documented the reduction in weaning weight for June born calves compared to those born in March (Stockton et al., 2007) or February and April (Grings et al., 2005) when weaned at an equal age. This reduction in calf performance is chiefly due to lowering forage quality with seasonal advancement resulting in reduced forage intake and cow milk production (Grings et al., 2005). Therefore, management systems designed to add weight and economic value to the calf post-weaning may be necessary for later-calving operations. These management systems may require the use of harvested forages provided grazed resources are unavailable.

Adams et al. (1994) evaluated grazing subirrigated Sandhills meadows during May as an alternative to feeding hay for March calving cows grazing upland range. Grazing meadows rather than dormant upland range during May improved economic returns. It was noted that Sandhills ranches can face resource constraints pertaining to meadow or winter range availability. Similarly, Reisenauer et al. (2001) suggested late-calving will not depress feeding costs without sufficient standing forage available for winter grazing. Therefore, in situations where grazing is limited, harvested forages are still necessary for the cowherd regardless of calving date.

Wintering Systems for Growing Cattle

Most beef cows are bred to calve in late-winter or-early spring (Klopfenstein et al., 2000; Martin, 2004). Accordingly, the greatest supply of weaned calves occurs in autumn. Klopfenstein et al. (2000) further described that within this population of feeder calves, 30% enter feedlots directly post-weaning. These calf-feds are comprised of the heaviest cattle from within a larger supply of animals. Therefore, the remaining 70% of the yearly feeder cattle supply is comprised of lighter-weight calves available to enter yearling or backgrounding programs. Cattle in such programs are fed primarily forage-based diets designed to increase skeletal growth and protein deposition prior to finishing (McCurdy et al., 2010; Stalker et al., 2010). Previous research has identified the importance to the beef industry of placing cattle into forage-based growing systems from a supply/demand (Klopfenstein et al., 2000) and economic (Janovick Guretzky et al., 2005) standpoint. Additionally, replacement heifer development systems require the use of either grazed or harvested forage resources during the winter prior to breeding (Martin et al., 2007; Stalker et al., 2010; Funston and Larson, 2011). Therefore, depending on the availability of forage resources for grazing, harvested forages can present a significant investment for operations retaining calves following weaning.

Nutrient profiles for grazed forage-based diets during the dormant season are generally low (Adams et al., 1996). In the Nebraska Sandhills, autumn forage regrowth on subirrigated meadows provides a higher quality diet for cattle than upland range. Lamb et al. (1996) reported diet samples collected from cattle grazing meadow regrowth during October contained approximately 11% versus 6% to 8% CP DM for upland range diets collected during the same time period. The same authors evaluated the effects of

grazing either native upland range or subirrigated meadow regrowth during the fall combined with weaning September 7 or November 7 on two year-old females. Calf body weight (BW) gains for weaned calves grazing subirrigated meadow were similar to those nursing cows on upland range. It was concluded subirrigated meadow regrowth can support calf BW gains post-weaning without supplementation. Depending on location, subirrigated meadows may not be readily accessible for some cow-calf operations. Grazing weaned calves on dormant upland range during winter may prove necessary for these operations provided calves are retained post-weaning. As described by Adams et al. (1996) and Ward (1978), additional opportunities for extending the grazing season include crop residues following harvest. Early in the grazing period, the in vitro DM disappearance (IVDMD) for cornstalk diets has been measured near 70% (Wilson et al., 2004). However, diet quality of grazed, dormant forage resources deteriorates with seasonal advancement regardless of the resource. Therefore protein supplementation is necessary to support desired calf BW gains (Fernandez-Rivera et al., 1989; Wilson et al., 2004).

The difference between the nutrient demands of the growing calf and that supplied by the basal diet is mediated by feeding hay or commercial supplements (Adams et al., 1996). Typically, purchased supplements contain higher concentrations of protein and energy relative to hays. However, instances do exist when the cost per unit of delivered nutrient DM for harvested forages is less than or similar to that of other supplements. It was determined by Reece et al. (1994) that manipulation of harvest date can impact costs associated with harvesting hay. Forages harvested in immature growth stages have increased nutrient concentrations including CP and total digestible nutrients

(TDN). The authors suggested feeding hays with increased nutrient densities during times of elevated nutrient demand to reduce the need for additional supplementation. Moreover, lower-quality hay harvested at an advanced maturity should be fed when animal nutrient demands are less. Thus, manipulating forage quality through harvest maturity is effective in reducing the total amount of hay fed.

Factors Affecting Forage Intake

Quality as Influenced by Maturity

Forage nutrient composition is highly variable within and across plant species (Bohnert et al., 2011). Plant variety, growing conditions, and management practices all impact nutrient parameters. However, plant physiological and morphological development has the greatest impact on nutrient composition (Blaser et al., 1964). The same authors reported a decreasing plant leaf/stem ratio is accompanied by advancement in maturity. Further, nitrogen (N) compounds comprise less of the DM as plants mature. These changes in nutrient composition are concurrent with increases in structural carbohydrates contributing to the fibrous constituents of forages (Van Soest, 1965). Therefore, it is well recognized that plant maturity impacts the fiber component of forages, and through its negative association with digestibility and passage rate, effects intake (Peterson et al., 1974).

The impact of alfalfa plant parts on dietary cell wall content, nutrient digestibility, and voluntary intake in sheep was evaluated in a metabolism experiment by Robles et al. (1981). Wethers were fed leaves, leaves plus stems, and stems in amounts sufficient for a 10 to 15% daily refusal DM. The cell wall content of diets comprised of leaves, leaves plus stems, and stems measured 48, 56, and 64% DM, respectively. Dry matter, energy,

and CP digestibility were significantly different among dietary treatments. Digestible energy (DE) was not statistically different between leaves (57%) and leaves plus stems (53%). However, these diets differed from those of stems (45%). Crude protein digestibility measured 62% (DM) for diets comprised solely of stems compared to 71% and 74% for diets of leaves plus stems and leaves, respectively. Dry matter intake (DMI) decreased from 1,739 g/d for diets comprised of leaves to 1,155 g/d for stem-based diets. It was concluded feeding diets entirely of alfalfa leaves resulted in increased diet DE concentration and intake. Further, the correlation of leaf diets with decreased cell wall intake and increased rate of passage contributed to a greater total DMI. This trial classically demonstrates the effect of forage quality, as impacted by plant maturity at harvest, on forage DMI and digestibility.

Cline et al. (2010) examined the influence of seasonal advancement and grazing treatment (season-long or twice-over rotation) on dietary composition, intake, site of digestion, and microbial efficiency in beef steers grazing native range. In a two-year study, ruminally and duodenally cannulated steers sampled pastures from early June to mid-November. Diet in vitro organic matter disappearance (IVOMD) declined in both years and both grazing treatments with progressing season. Intuitively, dietary N decreased concurrent with an increase in fiber across both years. Interestingly, OM intake (g/kg of BW) was not impacted by grazing treatment or seasonal advancement. Total tract and apparent ruminal OM digestion decreased with advancing season and were similar between treatments. However, microbial efficiency (g of microbial N/kg of OM truly fermented) was elevated for season-long compared to the twice-over rotation treatment (15.1 vs. 10.8 ± 1.6 g, respectively). The investigators concluded forage

quality and intake decline with progressing season. Although rate of passage was not measured, it is likely the depression in digestibility was related to retention time thereby impacting rumen volume and forage intake.

Protein Supplementation

The rate and extent of forage digestion is a function of protein and energy availability to the rumen microbial population (Mertens and Ely, 1982). As plant maturity advances, fiber components increase concurrent with reductions in soluble component concentrations (Merchen, 1988). Consequently, N supplied to rumen microbes is limited for cattle consuming low-quality forages. Therefore, reductions in digestibility, rate of passage, and ultimately DMI are often attributed to diet protein deficiencies (Kunkle et al., 2000). Accordingly, previous reports have consistently documented the improvement in forage intake (McCollum and Galyean, 1985; Petersen et al., 1985) and performance (Beaty et al., 1994; Schauer et al., 2005) from protein supplementation to cattle consuming low-quality forages.

The metabolizable protein (MP) system segregates feedstuff proteins into two forms (NRC, 1996). Klopfenstein et al. (2001) described degradable intake protein (DIP) as that which is necessary for rumen microbial function. Bacteria and protozoa have the synthetic capacity of converting N supplied from DIP to bacterial crude protein (BCP) (Owens and Zinn, 1988). Bacterial crude protein is passed from the rumen and absorbed at the small intestine. Undegraded intake protein (UIP) resists rumen degradation and is metabolized in a similar manner. Hence, MP is the sum of BCP and UIP (Lardy et al., 2004). Information on effects of DIP and UIP on forage intake is varying. Therefore, a review of current literature is warranted.

Adams et al. (1996) and Köster et al. (1996) reported DIP as first limiting to the utilization of poor-quality forages. The latter authors conducted a metabolism experiment evaluating the effect of increasing DIP levels on forage intake and digestion in beef cows. Cows were given ad libitum access to low-quality (1.9% CP, 77% neutral detergent fiber (NDF)) native tallgrass-hay. Supplemental DIP (sodium caseinate, 90% CP) levels ranged from 0 to 720 g/d in 180 g intervals. Significant quadratic increases in forage OM intake up to 540 g/d were reported. Total volatile fatty acid (VFA) and ammonia concentrations increased in response to supplemental DIP. Microbial N flow and efficiency increased linearly with increasing DIP levels. It was concluded supplemental DIP enhances rumen fermentation thereby directly impacting rate of passage and stimulating forage intake. Further, the investigators calculated the DIP requirement of nonpregnant, mature cows to be 11.1% of digestible OM.

Similar results were observed in a study conducted by Del Curto et al. (1990). Steers grazed dormant tallgrass-prairie forage and were fed one of three supplements at 0.50% BW (DM). Containing varying proportions of soybean meal and sorghum grain, supplements were formulated to contain 13.5, 24.5, and 39.6% CP DM supplying 40, 79, or 120% of animal requirements, respectively. Quadratic responses to protein supplementation were reported for forage and total OM intake. There was a tendency for total tract OM digestibility to respond in a comparable fashion to protein supplementation. Total VFA tended to increase as protein level increased.

Two grazing trials were conducted by Hollingsworth-Jenkins et al. (1996) to determine the DIP requirement of late-gestation beef cows grazing winter Sandhills range. In both experiments, cows were supplemented DIP at four levels: 50, 75, 100, and

125% (trial 1); or 29, 65, 100, or 139% (trial 2) of the estimated requirement. Degradable intake protein was supplied through combinations of corn steep liquor and soyhulls. In vivo OM digestibility responded to increasing supplemental DIP in trial 1, but not trial 2. The DIP requirement of gestating beef cows was calculated to be 7.1% of digestible OM. Contrary to the previous two studies, forage intake was not impacted by treatment in either experiment. The authors postulated diet OM digestibility was not increased sufficiently by supplementation to elicit an intake response.

Forage proteins are promptly degraded in the rumen (Klopfenstein et al., 2001). This observation renders them excellent and poor sources of DIP and UIP, respectively. Blasi et al. (1991) found an increase in cow milk production and calf gain in response to UIP supplementation (0.23 kg/hd/d). This suggests MP may be limiting for cattle consuming forage-based diets; particularly those with increased requirements such as early-lactation females or rapidly growing calves. However, cow forage intake across treatments was similar. Sletmoen-Olson et al. (2000) evaluated effects of UIP on forage utilization and performance of beef cows during late-gestation and early-lactation. Undegraded intake protein, supplied through corn gluten meal and blood meal, was fed at three levels (53, 223, or 412 g UIP/kg supplement DM). No response to UIP supplementation was observed for forage OM intake during gestation. Independent of treatment, forage OM intake quadratically decreased and increased during gestation and early-lactation, respectively. Interestingly, non-supplemented cows had greater forage intakes than supplemented counterparts postpartum. These data suggest supplemental UIP minimally impacts forage utilization provided DIP is adequate in the diet.

Increasing amounts of UIP fed to beef cows during early-lactation had no impact on total DMI (Lents et al., 2000). Loy et al. (2008) evaluated the influence of supplement type, concentration, and frequency on intake of heifers fed high-forage diets. Dry-rolled corn, dry-rolled corn plus corn gluten meal, and DDGS were fed at 0.21 or 0.81% BW DM and were offered daily or 3 times weekly. Forage DMI was similar among supplements. Regardless of source, a substitution effect was realized as hay DMI was less for the high than for the low concentration level. Supplementing 3 times weekly depressed hay DMI compared to daily feeding. Independent of supplementation frequency or concentration, UIP supplied from DDGS did not alter forage DMI. The impact of supplemental UIP on forage intake is further discounted by data from Fernandez-Rivera et al. (1989).

Collectively, results suggest forage DMI is influenced to a greater degree by DIP rather than UIP. Sufficient rumen microbial function requires adequate DIP. Through mechanisms controlling digestibility and passage rate, DIP appears to govern forage consumption.

Factors Influencing Replacement Heifer Development and Reproduction

Nutrition

A replacement heifer represents a significant investment to the cow-calf enterprise. Unless additional heifers are kept above the required replacement rate, the mature cowherd must be credited for the investment cost of the females. Lesmeister et al. (1973) determined that yearling heifers conceiving early in their initial breeding season and calving early as 2-yr-olds have heightened lifetime productivity than those bred later in the first breeding season. They reported nutrition and breeding season length in

yearling heifers as two critical management factors influencing future cow productivity. It is well recognized (Dunn and Moss, 1992) that nutrition has a profound impact on reproduction. The cow-calf producer has the ability to control nutritional inputs. Consequently, emphasis should be placed on developing nutrition programs for replacement heifers that minimize expenses while optimizing reproductive success (Hess et al., 2005). Thus, a review of the impact of three primary nutrients on replacement heifer development and reproduction is warranted.

Energy

Early research (Wiltbank et al., 1962) clearly demonstrates the negative impact of insufficient dietary energy on reproduction in the lactating mature beef cow. While reproduction was most severely impacted in Hereford cows fed one-half the recommended level of energy pre- and postpartum, treatment differences based upon the timing of energy restriction indicate biological interactions exist. Cows deficient in energy prepartum but fed adequate energy postpartum had extended postpartum intervals (PPI). However, sufficient dietary energy prepartum followed by energy restriction after calving resulted in lower conception rates. Nutrient requirements of yearling heifers differ from those of multiparous females. Regardless, this work demonstrates the influence of energy on reproduction. Rate and time of gain post-weaning is a direct function of dietary energy. Therefore, for the purposes of this discussion, energy in conjunction with rate and timing of gain will be reviewed.

Early work by Short and Bellows (1971) evaluated the effect of rate of gain between weaning and breeding on reproduction in heifers. Females developed in drylots were fed to gain 0.23, 0.45, or 0.68 kg/d. This difference in growth rate was designed by

feeding 0.0, 0.87, or 2.02 kg/d of grain, thus providing increasing levels of dietary energy. Following the 153 d growing period, heifers were managed similarly on summer range. As expected, varying levels of feed produced significant differences in BW by the end of the feeding period. Body weight at the start of the summer grazing period was greatest and least for heifers fed to gain 0.68 and 0.23 kg/d, respectively. Heifers fed to gain less during post-weaning development experienced compensatory growth while on summer range. However, the relative ranking among groups for final BW remained unchanged from the end of the initial feeding period. Age at puberty declined as feed level increased. Further, heifers fed to gain less conceived later in the breeding season and had lower pregnancy rates. The investigators summarized feeding heifers to gain at reduced rates prior to initial breeding delays puberty and hinders reproduction.

Work by Clanton et al. (1983) suggests developing heifers to a certain BW is necessary for attainment of puberty and reproduction. Weaned heifers were fed for no gain the first half of the period followed by increased gains the second half; fed to gain at an even rate throughout the trial, or fed to gain rapidly the first half followed by no gain the latter half. Heifers were fed common diets from weaning to breeding, but intake was varied to manipulate gain. Body weight was similar among treatment groups at the end of the growing period. Neither age at initial estrus nor pregnancy rate was impacted by timing of gain. Cow and calf weights at weaning the following year were not different implying heifer development programs have little impact on subsequent production given females weigh similarly at the onset of breeding. However, Marston et al. (1995) evaluated effects of level of supplementation and short-term feeding of concentrate diets on age and weight at puberty and milk production of heifers. Females were wintered on a

40% CP soybean meal-based supplement; fed either a low (1.8 kg/d) or high (2.7 kg/d) level of a 20% CP soybean hull-based supplement, or fed a 40% CP supplement then limit-fed a corn-based diet for the final 75 d prior to breeding. Heifers fed either the high or low levels of the 20% CP supplement or those fed a corn-based diet weighed more prior to breeding than those fed a 40% CP supplement. Age at puberty was similar for females fed the 20% CP supplement regardless of level and the 40% CP diet, but was less for those fed a corn-based diet. Percentage of females cycling prior to breeding and final pregnancy rates were reduced for heifers fed a 40% CP supplement compared to those fed greater levels of energy. Milk production during the first lactation was not impacted by development regimen. The researchers concluded dietary energy level post-weaning impacts reproduction as a yearling independent of BW without affecting subsequent production.

Research conducted by Ciccioli et al. (2005) examined the impact of high- (53.1%, DM) or low-starch (36.6%, DM) diets prior to breeding on reproduction in yearling heifers. Heifers either grazed native dormant tallgrass range supplemented with a soybean meal-based pellet, or were developed in a drylot and fed a high-starch diet for 30 or 60 d, or a low-starch diet for 30 d. Diets were formulated to contain similar levels of energy, yet differed in the amount of dietary energy supplied from starch. Feeding a high-starch diet for 60 d or a low-starch diet for 30 d increased BW and body condition score (BCS) by the initiation of breeding. Control heifers and those fed a high-starch diet for 30 d weighed less at breeding but gained more during the breeding season while grazing vegetative range. Age and BW at puberty were decreased for heifers fed high-starch diets for 60 d compared to heifers offered low-starch diets for 30 d. Age at puberty

was similar for heifers given control, or high- or low-starch diets for 30 d. Pregnancy rate was not impacted by treatment. Changes in BW gain, as influenced by treatment, precipitated differences in puberty. It was concluded isocaloric diets containing greater levels of starch may hasten puberty compared to diets containing less starch.

Data from these studies demonstrate dietary energy has a profound impact on reproduction in the developing female. Further, effects of post-weaning energy on reproduction interact with breed type (Wiltbank et al., 1969; Patterson et al., 1991). Energy density of the diet during development influences rate of BW gain prior to breeding. It has been previously accepted that BW is a major factor determining the onset of puberty. Therefore, management strategies designed to grow heifers to certain weights prior to breeding have been widely adopted (Patterson et al., 1992). However, genetics and the economic constraints in which beef cattle are produced have changed significantly since the original work evaluating heifer development systems was conducted. Current data suggest development systems incorporating grazed forage resources (Funston and Larson, 2011; Larson et al., 2011) and developing heifers on low-energy diets (Funston and Deutscher, 2004) effectively reduces development costs without impairing reproduction. Perhaps breed type interacts with dietary energy more now than in previous years.

Protein

In the Midwest, most replacement heifers are weaned in the fall and enter development programs during the winter prior to their first breeding season. This period of growth and maturation occurs at a time when grazed forages are dormant and of low-quality. Protein is the first-limiting nutrient in low-quality forage diets, and has been

emphasized in supplementation programs for replacement heifers (Kane et al., 2004). However, reports on the influence of UIP and DIP on growth and reproduction in heifers are inconsistent.

Recent studies by Martin et al. (2007) and Harris et al. (2008) have examined the utilization of ethanol co-products in post-weaning heifer diets. In the former experiment, spring-born heifers were fed DDGS at 0.59% BW DM or a dried corn gluten feed (CGF)-based supplement at 0.78% BW DM for 194 d. Supplements were formulated to be isocaloric and supply similar levels of CP but differed in CP degradability. Daily intake of UIP averaged 267 and 90 g/heifer for DDGS and CGF supplements, respectively. Body weight gain and BCS were not impacted by excess supplemental UIP. Age and BW at puberty were similar between treatments. Response to estrous synchronization and overall pregnancy rates were not affected. However, heifers fed DDGS had increased A.I. conception and pregnancy rates. The authors were unable to resolve if excess DIP in the CGF diet depressed A.I. conception and pregnancy rates, instead of excess UIP enhancing A.I. conception and pregnancy rates. However, it was postulated highly degradable protein sources may depress uterine pH thereby impacting embryo implantation and blastocyst formation.

Harris et al. (2008) conducted two experiments comparing whole soybeans (SB), wet corn gluten feed (WCGF), or DDGS as sources of energy and protein in heifer development diets. In the first experiment, heifers were fed a DM equivalent of 1.25 kg/d SB, or 2.5 kg/d WCGF for 91 d. After the initial 91 d, WCGF was substituted with SB such that all heifers were fed 1.25 kg/d DM of SB for the final 114 d. Diets were formulated to provide similar levels of CP and TDN. Body weight and ADG were

similar between treatments after the first 91 d. Heifers fed WCGF during the initial

period were heavier than SB-fed counterparts at the start of breeding. The percentage of

females pubertal at any time point was not affected by dietary treatment. Artificial

insemination conception, and pregnancy rates as well as final pregnancy rates did not

differ. In the second trial, heifers were fed equal DM amounts (1.25 kg/d/heifer) of SB or

DDGS for 216 d. In contrast to results by Martin et al. (2007), ADG was greater for

DDGS-fed heifers. However, treatment did not influence reproduction. It was not the

intent of either experiment to quantify the impact of protein degradability on reproduction

as more discussion was given towards the effect of dietary fat. Regardless, these data

suggest protein degradability did not impact puberty or fertility.

Kane et al. (2004) evaluated the impact of increasing dietary UIP levels on

endocrine factors effecting reproduction. Estrus was synchronized prior to the onset of

supplementation. Heifers were individually fed 115, 216, or 321 g/d UIP for 30 to 32 d,

at which point heifers were harvested (d 12 to 14 of the estrous cycle). On d 28 of

supplementation, basal serum follicle stimulating hormone (FSH) concentrations were

greater for low- and mid- vs. high-UIP heifers. Likewise, serum FSH area under the

curve was increased for low- vs. high-UIP heifers. At slaughter, anterior pituitary

luteinizing hormone (LH) and FSH content was similar among treatments. Interestingly,

FSH βmRNA was elevated in mid-UIP heifers compared to those fed the low-UIP

supplement. The authors concluded differences in reproduction with UIP

supplementation in beef cattle may be attributed to alterations in anterior pituitary

hormone synthesis thereby impacting gonadotropin secretion and ovarian function.

Lalman et al. (1993) compared the effects of UIP and propionic acid on puberty and pregnancy in replacement heifers. Experimental diets were comprised of low-quality grass hay and straw with one of four supplements designed to preserve similar BW gain and ad libitum intake thereby minimizing confounding effects due to different protein and energy intakes. Heifers were fed a control supplement formulated to meet protein requirements; a supplement supplying an additional 250 g/heifer/d of UIP; a supplement providing 200 g/heifer/d of propionic acid; or a supplement containing 200 mg/heifer/d of monensin. By design, no differences were observed between treatments for breeding weight or ADG during the feeding period or overall ADG. However, females supplemented with additional UIP were 17 and 10 d older at puberty compared to those fed monensin and propionic acid or the control supplement, respectively. Although fewer heifers receiving supplemental UIP (64%) were serviced during the first 21 d of the breeding season relative to those fed the control diet (76%), final pregnancy rates were not impacted by development treatment.

Analyses of blood metabolites revealed elevated levels of blood urea nitrogen (BUN) for UIP-fed heifers suggesting additional protein absorbed post-ruminally was in excess for growth requirements. Concurrently, UIP-supplemented females had lower cholesterol levels. Due to the fact that cholesterol is rate limiting for steroidal synthesis, it was postulated the depression in cholesterol may hinder LH release. The authors reported heifers receiving supplemental UIP were most efficient in energy utilization because less TDN was required to gain 0.50 kg/heifer/d than those fed other supplements. Regardless, these data imply additional UIP does not reduce age at puberty. Further, age and BW at puberty may be controlled by diet composition independent of BW gain.

To test the effects of protein degradability on reproduction within calving date, multiparous Hereford x Angus cows were fed supplements containing either 25 or 50% UIP prior to breeding (Dhuyvetter et al., 1993). Supplements were formulated to be isonitrogenous (54% CP DM) and practically isocaloric. No difference in BW change from calving to breeding was observed between treatments for cows calving from March 20 to April 20. Interestingly, cows receiving a 25% UIP supplement returned to estrus 9 d sooner than those fed the 50% UIP diet. Conversely, feeding a 50% UIP supplement reduced BW loss postpartum for females calving earlier in the season (March 4 to March 20). However, neither the percentage of females cyclic at the start of the breeding season nor the proportion of cows serviced during the first estrous cycle was different between groups for early-calving cows. Final pregnancy rates were not impacted by supplemental UIP in spite of differences in date of parturition.

Collectively, these results suggest dietary protein degradability impacts reproduction in beef females. Specifically, responses in replacement heifers to differing levels of UIP supplementation have been inconsistent. Further characterization of the effects of protein degradability independent of energy or protein intake on heifer reproduction is necessary. However, additional factors associated with nutrition and management appear to interact strongly with dietary protein degradability.

<center>*Lipids*</center>

It has been widely accepted that energy status of the beef female is integral in manipulating reproduction (Hess et al., 2005). The understanding of this relationship has increased the attention of maintaining adequate dietary energy during critical time periods in reproduction. Lipids are the most energy-dense nutrient because they contain

approximately 2.25 times the energy of carbohydrates (Coppock and Wilks, 1991).

Therefore, dietary fat inclusion improves energy density (Hess et al., 2005) and can elicit

beneficial effects on reproduction independent of the contribution of energy (Funston,

2004). Further, inclusion of lipids prevents acidosis as is typically seen when dietary

concentrate levels are increased. For these reasons, fat supplementation has been

regularly practiced in the dairy industry as a method to improve the energy status of

lactating cows (Coppock and Wilks, 1991).

Supplemental lipids can be derived from numerous sources. Vegetable and

animal fat, yellow grease, soybeans, cottonseeds, sunflower seeds, canola seeds, and

fishmeal are a few of various fat-containing commodities (Funston, 2004). Corn oil,

CCDS, and fat in distillers grains all originate from the fat in corn grain (Bremer et al.,

2011). When stored at room temperature, corn oil is a liquid and therefore classified as

an unsaturated fat. These fats contain fatty acids that are able to gain additional hydrogen

ions, altering the shape of the fatty acid itself. Saturated fatty acids are solid at room

temperature and unable to attach additional hydrogen ions. Although a liquid, the fat in

CCDS is more saturated than that in corn oil. Uniquely, lipid in distillers grains is

surrounded by corn germ particles thereby inhibiting direct contact of fat with rumen

microorganisms once ingested.

The degree of saturation largely dictates the interaction between lipids and rumen

microbes because the ruminant has the ability to convert dietary unsaturated fatty acids to

those of the saturated form (Jenkins, 1993; Williams and Stanko, 2000; Bremer et al.,

2011). This process is recognized as biohydrogenation and is conducted by rumen

microbes to prevent the inhibition of fermentation due to unsaturated fatty acids.

Unsaturated fatty acids are more toxic to rumen bacteria than those that are saturated. Biohydrogenation further serves as an alternative method of disposing reducing equivalents by providing a sink for free hydrogen ions within the rumen (Russell, 2002; Bremer et al., 2011). Ruminal microbes hydrolyze triglycerides and phospholipids to resulting polyunsaturated fatty acids and glycerol. Glycerol is then fermented to propionic acid (Williams and Stanko, 2000). Unsaturated fatty acids can be almost completely saturated prior to passing the rumen. Once biohydrogenation is completed, little metabolism of lipids occurs within the rumen providing essentially no substrate for fermentation.

Hess et al. (2005) documented the current interest by researchers in the use of dietary fat as a reproductive nutraceutical. The effects of supplemental lipids on hormone secretion were summarized in a review by Funston (2004). It was noted the impact of supplemental lipids on metabolic hormones in beef cattle have been controversial. Supplementation of polyunsaturated plant oils increased serum growth hormone (GH) and insulin levels in both dairy and beef cows. However, these findings were not repeated when primiparous heifers were supplemented with safflower seeds. Circulating concentrations of cholesterol have been elevated by dietary fat intake. Cholesterol is a precursor for the synthesis of progesterone by ovarian luteal cells. Therefore, fat supplementation may heighten progesterone production or reduce progesterone clearance from blood leading to enhanced corpus luteum (CL) maintenance and improved conception rates. Dietary energy, as supplied through fat supplementation, increases LH secretion in females in an energy-deficient state. The mechanism by which this occurs is not understood. It has been hypothesized fat supplementation can increase glucose

production through the generation of propionate thereby enhancing LH release. It has been documented that supplemental fat increased preovulatory follicle size which may contribute to the formation of a larger corpus luteum and elevated progesterone production. Linoleic acid may be desaturated to form arachidonic acid which serves as a precursor for the synthesis of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$). $PGF_{2\alpha}$ is important for initiating uterine involution and estrous cycles following parturition. However, excess production may contribute to decreased fertility through luteolysis. Linoleic acid can also inhibit $PGF_{2\alpha}$ synthesis by competitive inhibition with certain enzymes. Further, supplementation of high-linoleate safflower seeds to beef cows postpartum tended to depress first-service conception rates. Clearly, a myriad of responses in metabolic hormone synthesis and reproduction from fat supplementation have been reported.

Studies evaluating the effects of lipid supplementation to primiparous and multiparous cows, both pre- and post-partum, are abundant (Bellows et al., 2001; Alexander et al., 2002). Data by Martin et al. (2005) suggest that supplementation of fat (0.40 kg/cow/d DM) from whole corn germ during either late gestation or early lactation has minimal impact on reproduction in beef cows. Because the hormone leptin is thought to be involved in the mechanism by which fat sporadically impacts reproduction, it was hypothesized a threshold leptin requirement may dictate reproduction in the cow. Published data on the utilization of lipids in diets for developing replacement heifers is lacking. However, the following reports have been published and warrant discussion.

Funston et al. (2002) fed whole sunflower seeds (0.91 kg/heifer/d DM) to replacement heifers at four locations for 60, 30, or 0 d before A.I. Diets were formulated to be isocaloric and isonitrogenous. Estrus was synchronized by feeding melengesterol

acetate (0.50 mg/heifer/d) for 14 d followed by a single injection of $PGF_{2\alpha}$ 19 d later. Females fed sunflower seeds for 0 d had greater ADG than those fed sunflower seeds for 60 d. It was postulated the added dietary fat inhibited forage digestion, thereby reducing DMI and performance. Neither estrous response to synchronization nor pregnancy rate was impacted by fat supplementation. More than 90% of females across groups were cycling prior to the onset of treatments. Thus, it was proposed that nutritionally stressed heifers or those pre-pubertal may respond favorably to fat supplementation.

Lammoglia et al. (2000) evaluated the effects of supplemental dietary lipid and sire breed on puberty, pregnancy, body composition, and serum hormone levels in replacement heifers. Prepubertal females sired by Hereford, Limousin, or Piedmontese bulls were fed either low (1.9% DM) or high (4.4% DM) fat diets for 162 d. The authors reported feeding 4.4% DM dietary fat increased the percentage of heifers pubertal by the initiation of the breeding season. However, significant interactions between dietary lipid level and sire breed imply responses to additional lipid are breed dependent. Dietary fat did not impact final pregnancy rate. Interestingly, heifers fed the high-fat diet had increased serum progesterone concentrations. Moreover, serum cholesterol was elevated due to feeding a greater level of dietary fat. It was postulated females with a low body fat composition may have a dietary fat requirement different from heifers with a greater body fat composition. Results also suggest feeding supplemental fat for 60 d prior to breeding may be sufficient to elicit beneficial responses in reproduction.

Use of Corn Condensed Distillers Solubles in Diets for Growing Cattle

Determination of Feeding Values

Corn condensed distillers solubles can be used as a source of protein or energy in high-forage diets for growing cattle. The nitrogen content of CCDS can be easily measured. Because of this, CP values for CCDS have been published and are available for producers and nutritionists. The energy value of CCDS in high-forage diets is not well established. Research conducted with Holstein cows demonstrates CCDS can replace DDGS up to at least 20% of the diet DM without impacting milk production or DMI (Sasikala-Appukuttan et al., 2008). Although results from this study imply the feeding value of CCDS is equal to DDGS in dairy diets, it does not indicate the energy value of CCDS in diets for growing beef cattle.

Previous work (DeHaan et al., 1982; Ham et al., 1994) determined ethanol co-products contain more energy than corn grain. Wet distillers grains plus solubles have been reported to contain 130% of the energy of dry-rolled corn when included at 25% of the diet DM in high-forage rations (Nuttelman et al., 2009). Nuttelman et al. (2010) later reported energy values of WDGS to be 146, 149, and 142% the energy value of dry-rolled corn when fed at 15, 25, and 35% of the diet DM, respectively. Ahern et al. (2011) determined DDGS and WDGS contain 114 and 120%, respectively, the energy value of dry-rolled corn in high-forage growing diets. This agrees with data by Ham et al. (1994) suggesting drying ethanol co-products depresses energy content. Regardless, these experiments provide clear evidence that feeding ethanol co-products in high-forage diets results in superior performance relative to dry-rolled corn. The mechanism by which this phenomenon occurs is not completely understood. The UIP, energy density of fat, highly

digestible corn fiber, and absence of fermentable starch likely contribute to the enhanced energy value (Ham et al., 1994).

Unlike distillers grains, CCDS contains greater levels of DIP and essentially no digestible fiber. These differences may impact the feeding value of CCDS in forage-based diets. Data evaluating the energy value of CCDS relative to dry-rolled corn in high-forage rations are limited. Wilken et al. (2009) fed CCDS and WDGS mixed and ensiled with cornstalks at 15, 20, 25, and 30% of the diet DM. Intake was numerically the greatest for steers fed CCDS at 30% of the diet DM. Gain and F:G were significantly improved by including WDGS in the diet as compared to CCDS regardless of inclusion level. Using wheat straw as a forage source, CCDS was mixed and fed at 25, 35, and 45% of the diet DM to growing steers (Peterson et al., 2009). In similar fashion, WDGS was mixed with straw at equal levels plus an additional level of 55% co-product DM. Additional treatments evaluated four blends of CCDS and WDGS mixed with straw. Gain was similar for steers fed 25 and 35% CCDS but was greater for those fed the 45% level. Feed conversion tended to quadratically decrease as CCDS level increased. Intake and ADG increased linearly as WDGS increased. Because gain increased across levels, F:G also linearly improved with greater levels of WDGS. When comparing blends of CCDS and WDGS, gains were not different from those achieved by feeding either of the co-products separately. Therefore, the authors concluded no associative effects of feeding the combinations exist. Animal performance in the former experiment suggests WDGS contains more energy relative to CCDS. In the latter study, ADG within inclusion level was similar between co-products. The exception was the 25% level, in which ADG was greater for CCDS than WDGS. Co-product type was compared in both

trials. However, neither included a direct comparison to dry-rolled corn within the same experiment. This is needed before conclusions regarding energy values can be made.

Interactions with Forages

In forage-based diets, energy deficiencies are often met by supplementing cereal grains which contain starch. The rapid ruminal degradation of starch contributes to a lower rumen pH thereby depressing fiber digestion (Loy et al., 2008). This negative associative effect occurs between feedstuffs differing in carbohydrate type and explains the reduction in DMI and animal performance often seen. In contrast, a positive associative effect is observed when distillers grains are supplemented in forage-based diets. Because the starch is removed, there is no competition among rumen microbial populations for growth. Further, NDF in distillers grains stimulates fiber digestion and DMI. The positive associative effect between distillers grains and forages is one explanation for the increased performance observed. However, lipids can also negatively interact with forages by depressing fiber digestion when included at levels greater than 5% of the diet DM. Loy et al. (2008) calculated the TDN content of DDGS to be 130 and 118% of dry-rolled corn when fed at 0.21 and 0.81% of BW DM, respectively. When DDGS were fed at the high level, dietary fat was greater than 5.0%.

Corn condensed distillers solubles contain less digestible fiber and more fat in relation to distillers grains. These nutritional characteristics may lead to negative interactions when fed with forages. Gilbery et al. (2006) documented a linear increase in ruminal OM and NDF digestibility as CCDS inclusion level increased from 0 to 15% of the diet DM. Work by Corrigan et al. (2009) indicates that as the level of CCDS in DDGS increases, the optimum inclusion level for gain declines in forage diets.

Increasing levels of corn oil supplemented to grazing steers linearly reduced forage DMI (Pavan et al., 2007). In contrast, neither forage DMI nor true ruminal OM digestion was impacted by CCDS supplementation (Coupe et al., 2008). It is not clear from these studies whether CCDS negatively interacts with forages. Dietary inclusion level and fat content may dictate the occurrence of negative associative effects.

Evaluation of Methods for Storing Corn Condensed Distillers Solubles

Storage Techniques

The demand and price for ethanol co-products is seasonal and closely follows feedlot cattle inventories (Waterbury and Mark, 2008). Historically, lower feedlot demand for co-products during mid- to late-summer allows prices to decline. This creates opportunities for cow-calf and/or smaller feedlot operators to purchase co-products at economical rates. However, the need to incorporate co-products into nutrition programs for cows or growing calves usually does not occur until later in the fall or winter. Therefore, storage methods providing for the utilization of co-products at future time periods are beneficial to certain producers.

Liquid feeds are often housed in bulk storage tanks prior to feeding. Corn condensed distillers solubles can be stored using typical liquid feed handling systems. Lardy (2007) reported bulk storage tanks should be either buried underground or housed indoors to prevent CCDS from freezing during winter. Corn condensed distillers solubles will separate over time if stored in tanks. Thus, CCDS should be agitated prior to feeding. Liquid feed handling systems can present a significant equipment investment. Additionally, some cow-calf producers may have little previous experience with

management of liquid feeds. Therefore, strategies to store CCDS with minimal

equipment investment are advantageous.

Experiments conducted by Adams et al. (2008) demonstrated WDGS can be

successfully mixed with low-quality forages and stored for extended time periods in

commercial silo bags or bunker silos. These trials demonstrated the addition of dry

forages to wet ethanol co-products allows the material to be packed and stored

anaerobically. This method of storage allows for the utilization of low-quality forages

that may be deficient in protein or energy if fed separately. Corn condensed distillers

solubles is similar in moisture content to WDGS allowing for comparable storage with

forages.

Wilken et al. (2009) stored a mixture of CCDS and ground cornstalks at a 53:47

co-product to forage ratio (DM). The mixture was stored in a commercial agricultural

bag for 20 d and fed to growing steer calves. Although less for steers fed CCDS and

cornstalks relative to those fed WDGS and cornstalks, ADG was still adequate (0.47

kg/d) for CCDS-fed steers. A similar trial (Peterson et al., 2009) evaluated the impact of

feeding CCDS stored with wheat straw at three levels (25, 35, and 45% CCDS, DM) to

growing steers. Upon storage (50 d) in the commercial bag, two ratios of CCDS to wheat

straw included 25:75 and 45:55 (DM). The 35% level was produced by mixing the 25%

and 45% levels. Steers fed 25% and 35% CCDS had similar ADG, but ADG was greater

for those fed 45% CCDS. Dry matter intake was not different between the 35% and 45%

treatments. Thus, F:G was lower for calves fed 45% CCDS. Warner et al. (2011) limit-

fed (7.7 kg/cow/d) mature nonlactating, nonpregnant beef cows a 41:59 (DM) ratio of

CCDS to ground cornstalks. In this study, the CCDS and cornstalks mixture was packed

into a concrete bunker and covered with plastic for 30 d. Average daily gain tended to be greater for cows limit-fed CCDS and cornstalks than cows fed a forage-based control diet ad libitum.

These reports imply cattle performance is acceptable when diets of CCDS mixed and stored with low-quality forages are fed. Incorporation of CCDS and forages is best accomplished using a mixer-wagon or feed truck and by allowing sufficient time for mixing. The commercial agricultural bags and concrete bunkers used in these studies are recommended for use as they minimize losses. However, earthen or temporary bunkers constructed of hay bales can also be utilized (Erickson et al., 2008). Regardless of the chosen method of storage, removal of oxygen from the material is critical to prevent spoilage. Covering material with plastic tarps is effective in limiting oxygen penetration. Data suggest CCDS itself can be used to cover bunkered mixtures and extend storage (Christensen et al., 2010). However, 25% to 50% of the CCDS used as a cover may be lost during the storage process. Theoretically, mixtures of CCDS and low-quality forages can be stored indefinitely in the absence of oxygen.

Spoilage Considerations

Although the techniques previously described will reduce the rate and extent of spoilage, shelf life is a primary challenge with CCDS. Like all wet co-products, mold will eventually grow on CCDS even during cooler times of the year (Lardy, 2007). A preliminary field trial evaluated the use of lick tanks to supplement CCDS to lactating beef cows during the summer grazing season (Doran et al., 2008). Corn condensed distillers solubles was delivered to tanks and samples were collected weekly. Although mold development was visible throughout the investigation, few colonies were detected

during analysis. Strains of mycotoxins including aflatoxins and vomitoxins were either non-detectable or detectable at low levels (< 5 ppm). Similar results were reported by Harding et al. (2012) who documented no detectable mycotoxins in either spoiled or nonspoiled WDGS. It was further reported by the same author that feeding spoiled WDGS at 40% of the diet DM for finishing cattle does not impact ADG or F:G. In growing cattle fed a forage-based diet, spoiled WDGS reduced DMI without affecting gain or feed efficiency. However, spoilage generally causes a loss of nutrients and DM with corresponding increases in ash content. Limited data are published on the effects of feeding spoiled CCDS. Initial results suggest little risk to animal health or performance is posed by feeding spoiled CCDS with visible mold growth.

Economics of Corn Condensed Distillers Solubles Utilization

Most ethanol plants combine solid distillers grains with CCDS prior to sale. Traditionally, the two products are merged to a 90:10 ratio of solid grains to CCDS. When production inefficiencies within the plant occur, the amount of CCDS applied to the solid grain fraction may change, or CCDS itself is marketed separately. When offered as a single commodity, CCDS is typically priced at a discount relative to other ethanol co-products (Lardy, 2007). Generally, the low cost in relation to the high nutrient content makes CCDS an attractive ingredient for cattle diets. Depending on the price and moisture level, the cost per kg of nutrient purchased on a DM basis may be cheaper for CCDS than other co-products. For example, 35% DM WDGS containing 32% CP and offered for sale at $83.00/metric ton (as-is) equates to $0.74/kg of CP DM [($83.00/metric ton / ((1,000 kg x 0.35 DM) x 0.32 CP)) = $0.74]. However, 35% DM CCDS containing 24% CP and priced at $44.00/metric ton (as-is) calculates to $0.52/kg

of CP DM [($44.00/metric ton / ((1,000 kg x 0.35 DM) x 0.24 CP)) = $0.52].

Differences may exist between co-products when pricing is conducted on other nutrients.

Certainly, expenses associated with freight, storage, shrink, and feeding must be

accounted for when pricing ingredients. Regardless, the relationship between price and

chemical composition enables CCDS to be economically competitive. Further research is

necessary on the economic implications of incorporating CCDS into nutrition programs

for beef cattle.

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Chapter I. Applying corn condensed distillers solubles to hay windrows prior to baling. I. Procedure, and effects on bale temperature and nutrient composition.

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ABSTRACT: Two experiments were conducted to evaluate an alternative method of storing liquid ethanol co-products while concurrently improving forage quality. Corn condensed distillers solubles (CCDS) was applied to native grass hay windrows in a completely randomized design, and large-round bales were subsequently produced from treated windrows. In each trial, CCDS was added within 24 h of baling, bales were sampled for nutrient analysis, and internal temperature was measured. Inclusion levels of CCDS (% of bale weight, DM) equaled: 0 or 20% (Exp. 1); and 0, 16, or 32% (Exp. 2). In Exp. 1, CCDS level had no effect ($P = 0.58$) on internal temperature or DM. Bales treated with 20% CCDS had increased ($P \leq 0.001$) CP, fat, and S compared to bales with 0% CCDS. Accordingly, 20% CCDS bales had lower ($P \leq 0.001$) NDF than did 0% bales (60.0 vs. 69.2%, respectively). In Exp. 2, internal bale temperature linearly ($P \leq 0.01$) increased with greater CCDS levels when measured at 3 wk post-baling. Regardless, temperature declined ($P \leq 0.05$) across all levels from 0 to 3 wk after baling. No effect ($P = 0.34$) of sampling type (core vs. pile) was observed for DM in Exp. 2 despite increasing CCDS levels. Crude protein was greater ($P = 0.05$) for core than pile collected samples at all CCDS levels. Fat content numerically increased with additional CCDS regardless of sampling type. Relative to 0% bales, NDF decreased ($P \leq 0.01$) by 14.6 and 24.7% for 16 and 32% bales, respectively for core-collected samples. Data suggest up to 32% CCDS can be applied to grass hay windrows prior to baling without impacting internal bale heating or moisture retention. Nutrient analyses indicate

successful within-bale storage of CCDS occurred. Applying CCDS to hay windrows prior to baling is a viable strategy for storage of liquid co-products and improvement of forage quality.

Key Words: distillers solubles, forage, nutrient quality, storage

Introduction

In the Midwest, wet ethanol co-products serve as excellent sources of protein and energy for use in beef cattle diets. Historically, the price of co-products from the ethanol industry is directly related to feedlot cattle inventories, and therefore declines during late-summer (Waterbury and Mark, 2008). Because of this relationship, an opportunity to purchase co-products at lower prices may be possible for operations that do not buy large quantities on a regular basis. The ability to source co-products when less expensive and store until feeding is critical for small backgrounding and/or cow-calf operations that may feed later in the year and for shorter periods of time. This management concept was first investigated by Adams et al. (2008) where it was determined that adding low-quality forages to wet co-products provides dryness and bulk to the mixture. Because of this, mixtures of wet co-products and forages are able to be compressed into concrete bunkers or commercial silo bags much like packing corn silage.

Corn condensed distillers solubles (CCDS) is a nutrient dense wet (DM = 23-45%) ethanol co-product, and often sold at a discount relative to distillers grains. Because CCDS is a liquid, storage in bulk tanks is an ideal management strategy. Lardy (2007) noted the significant financial and management investment that often incurs with

the use of liquid feed storage and handling equipment, especially when used only at certain times of the year by some producers. Bagging (Peterson et al., 2009; Wilken et al., 2009) or bunkering (Warner et al., 2011) mixtures of CCDS with low-quality forages has been conducted, but these storage techniques require equipment and facilities for mixing and/or packing the material. Additionally, mixer-wagons or feed trucks are necessary for delivering such mixtures to cattle, which may not be practical for producers in extensive production settings. Less expensive storage methods that limit the use of machinery may be more advantageous for cow-calf or backgrounding operations. Therefore, the evaluation of alternative storage methods of liquid ethanol co-products is warranted.

Hay production is a common management practice throughout the northern Great Plains. In Nebraska alone, over 687,000 ha of hay (excluding alfalfa) were harvested in 2011 (NE Agri-Facts, 2012). This resource varies from the production of smooth bromegrass and native tallgrass hay in eastern Nebraska, to subirrigated meadow and upland range hay in the Sandhills. Regardless of production site, the chemical composition of harvested hay is often less than desired because of advanced plant maturity at harvest (Volesky et al., 2002). Other factors such as harvesting conditions (Han et al., 2004) and storage (Streeter et al., 1966) effect hay quality, but typically to a lesser degree. Thus, in an attempt to capture increased yield, CP and IVDMD is sacrificed as harvest is delayed later in the growing season (Reece et al., 1994). This creates the need for additional supplementation when forages are fed that do not meet animal requirements (NRC, 1996).

The necessity of forage resources for hay production to cow-calf and backgrounding/stocker operations is well established (Nayigihugu et al., 2007; Phillips et al., 2011). When hay supplies are diminished, due to drought or other factors, the importance of maintaining forage quality increases. Early research (Thomas, 1978) evaluated the use of compounds such as propionic acid or ammonia to improve forage quality or prevent deterioration during storage. Additionally, commercial molasses-based products have been developed to top-dress hay bales during storage in an effort to improve forage quality. Data evaluating alternative storage methods of liquid co-products have not been reported. Therefore, a management strategy to store CCDS while concurrently improving forage quality may be feasible. In theory, the quality of harvested forage could be improved such that additional supplementation of protein or energy may not be necessary. Our objectives of these experiments were: 1) to evaluate the ability to store CCDS in large-round bales by applying to hay windrows prior to baling; 2) to determine the influence of CCDS on internal bale temperature post-baling; and 3) to characterize the effects of applied CCDS on hay nutrient composition.

Materials and Methods

Both experiments described herein were conducted at the University of Nebraska-Lincoln Dalbey-Halleck Research Unit located near Virginia in southeast Nebraska.

Experiment 1

Equipment and Treatments

In 2010, one 16.19-ha field of native, warm-season, tallgrass prairie was swathed in late July. Predominant forage species included big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*). Hay was

allowed to dry in windrows without raking for three d. Following the drying period,

CCDS were applied directly to windrows prior to baling. Corn condensed distillers

solubles were sourced and delivered from a commercial ethanol plant (E-Energy Adams,

Adams, NE), and off-loaded into a 3,785.4-L liquid fertilizer trailer. Nutrient

composition data of CCDS applied in Exp. 1 is provided in Table 1. The trailer was

equipped with a 5 horsepower (hp) gasoline-powered engine which supplied power to

pump CCDS from the trailer to the windrows.

In order to effectively apply CCDS to windrows, modifications to the trailer were

necessary and included: 1) an electric shut-off valve (Banjo Corp., Crawfordsville, IN);

2) a flow-meter (Raven Industries, Sioux Falls, SD); and 3) and a spray boom. The 1.9-

cm diameter shut-off valve was used to start/stop the flow of CCDS through the system.

The flow-meter of larger (3.8-cm) diameter was added to monitor both the rate and total

volume of CCDS applied. The spray boom was constructed of polyethylene pipe

(Schaben Industries, Columbus, NE) measuring 2.13-m in length and 1.9-cm in diameter.

To this boom, 0.64-cm diameter drop holes were bored and spaced 3.18-cm apart. The

boom was positioned at a 90° angle to the frame of the trailer and extended beyond the

trailer's breadth. This allowed for a 0.91-m spraying width to effectively cover the

windrow without applying CCDS directly on the ground.

A tractor was used to pull the trailer and was driven between hay windrows when

applying CCDS. The shut-off valve and flow-meter were wired to a 12-V battery and

controlled by a single-pole, single-throw toggle switch. The toggle switch and battery

were positioned in the cab of the tractor providing direct control of the flow of CCDS by

the operator. The flow-meter was equipped with a digital read-out box allowing the

operator to continually monitor the rate and total volume of CCDS applied from the cab of the tractor. Application of CCDS to windrows began in late-morning and was completed by late-afternoon of the same day. Windrows were baled using a large-round baler once determined sufficiently dry by visual appraisal. All hay regardless of treatment was baled within 24 h of CCDS application. Upon baling, each bale was assigned an individual number, marked with permanent spray-paint, and moved to the edge of the field. All bales were placed in rows, buffed end-to-end, and stored directly on the ground without covering.

Corn condensed distillers solubles were applied to windrows in one of two levels: 1) 0 (0%); or 2) 20% (20%) CCDS of bale weight (DM basis), producing 0 (n = 45) or 20% (n = 36) bales, respectively. Corn condensed distillers solubles were applied to windrows in alternating fashion allowing for equal representation of treatments across the field. Application level was calculated using distance traveled to produce a large-round bale, bale weight, driving speed, and flow-rate of CCDS through the system. Prior to CCDS application, four windrows were randomly selected from varying areas of the field, and four subsequent bales from these windrows were made. Bale weight and linear windrow length necessary to produce the bale was recorded. These measurements were used to calibrate the initial CCDS application rate using the following formula and example:

Known Variables:

1) Linear windrow length = 335 m.

2) Bale weight (DM basis) = 531 kg.

3) Driving speed of tractor = 4 kph.

4) Flow-rate of CCDS being applied = 53 L/min.

5) DM (%) of CCDS = 35.0.

Then:

 - Linear windrow length = 0.335 km (335 m / 1,000 m per km).

 - Time necessary to travel windrow length = 4.8 min or 0.08 h (0.335 km / 4.0 kph).

 - Liters CCDS applied per windrow = 254.4 (53 L/min x 4.8 min).

 - Kilograms (As-is) CCDS applied per windrow = 274.8 (254.4 L x 1.08 kg per liter).

 - Kilograms (DM basis) CCDS applied per windrow = 96.2 (274.8 x 0.35).

Therefore:

 - % CCDS inclusion of bale weight (DM basis) = 15.3% (96.2 kg / (96.2 + 531.0 kg)).

Windrow lengths to produce each 20% bale were measured using a 30.48-cm aluminum distance measuring wheel (Stanley Black & Decker, New Britain, CT). Thus, the % CCDS inclusion (DM basis) was calculated for each individual bale. Corn condensed distillers solubles inclusion rates were originally calculated based off assumed DM values for CCDS and control hay. Actual inclusion rates were determined after adjusting for the observed CCDS and hay DM values.

Temperature Recordings, Core Sampling, and Nutrient Analyses

Internal bale temperatures were recorded at 2 and 3 wk post-baling on a subset of eight randomly selected bales within each treatment. Temperature was measured using a 76-cm long digital hay probe (AgraTronix, Streetsboro, OH) placed at five locations on the curved-side of each bale. At each measurement, the probe was inserted horizontally at a point within the approximate mid-section of the bale. To allow for calibration

between bales, one minute was allowed to elapse between probe insertion and temperature recording. For each bale, all five temperature measurements within collection date were averaged with the mean value used for analysis.

Core-samples were collected at 0, 2, 3, and 24 wk post-baling from a subset of eight randomly selected bales within each treatment. Samples were collected using a 91.44-cm long, 1.27-cm diameter drill-powered hay probe. Samples were taken with the probe inserted horizontally at a point within the approximate mid-section of each bale. Two samples were collected from each bale, one from either curved-side at opposite points, and were composited and frozen until laboratory analysis. Dry matter was determined by drying samples in a 60˚ C forced air oven for 48 h. Dried samples were then ground to pass through a 1-mm screen in a Wiley mill. Nitrogen content was measured by combustion method using a LECO N analyzer. Crude protein was derived by multiplying N% by 6.25. Sulfur content was analyzed using an internal combustion furnace. Fat was evaluated using the gravimetric biphasic lipid extraction procedure as modified by the University of Nebraska-Lincoln (Bremer et al., 2010). Neutral detergent fiber was subsequently analyzed post-fat extraction using the methods as described by Van Soest et al. (1991).

Corn condensed distillers solubles samples were collected directly from the delivery truck at the time of windrow application and frozen prior to analysis. Dry matter was determined as described above. Samples were then freeze-dried prior to analysis for CP, fat, sulfur, OM, phosphorus, and pH.

Statistical Analyses

All data were analyzed as a completely randomized design using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC). Internal bale temperature data were analyzed with a 2 x 2 factorial arrangement of treatments. Model fixed effects included CCDS level, date, and the level x date interaction. Nutrient composition data were analyzed with date as a random effect. The model for all analyses included the fixed effect of CCDS level. Because treatments were applied on a bale basis, the experimental unit for all analyses was bale.

Experiment 2

Equipment and Treatments

In 2011, a second trial of comparable design was conducted using the same field to evaluate applying increasing levels of CCDS to hay windrows prior to baling. Date of hay harvest, length of drying time prior to CCDS application, equipment, and calculations used to determine application rate were as described in Exp. 1. Corn condensed distillers solubles were delivered from a commercial ethanol plant (Abengoa Bioenergy, York, NE) and applied to windrows in one of three treatments: 1) 0 (0%); 2) 16 (16%); and 3) 32% (32%) CCDS of bale weight (DM basis), producing 0 (n = 30), 16 (n = 31), and 32% (n = 27) bales, respectively. Nutrient composition data of CCDS applied in Exp. 2 is provided in Table 1.

Similar to Exp. 1, application of CCDS to windrows began in late-morning and was completed by late-afternoon of the same day. Windrows were baled using a large-round baler once determined sufficiently dry by visual appraisal. All hay regardless of treatment was baled within 24 h of CCDS application. Upon baling, each bale was assigned an individual number within treatment, marked with permanent spray-paint, and

moved to the edge of the field. All bales were placed in rows, buffed end-to-end, and stored directly on the ground without covering.

Temperature Recordings, Core Sampling, and Nutrient Analyses

Internal bale temperature was measured on a subset of six randomly selected bales from within treatments at 0, 2, and 3 wk post-baling. Temperature was measured using the same digital hay probe and placement technique as described in Exp. 1. For each bale, three temperature measurements were recorded and averaged within collection date, with the mean value used for analysis.

Initial core-samples were collected at 0 and 3 wk post-baling from a subset of three randomly selected bales within treatment. Samples were collected in the same manner as described in Exp. 1, composited by date and level, and frozen until laboratory analysis. Samples were dried in a 60° C forced air oven for 48 h and then ground to pass through a 1-mm screen in a Wiley mill. Crude protein, fat, and NDF content were determined using the methods described in Exp. 1. Sulfur content was not measured in Exp. 2.

In December, bales from each treatment (n = 25) were transported to the University of Nebraska-Lincoln Agricultural Research and Development Center feedlot located near Mead, NE. Bales were ground through a tub-grinder to pass through a 7.62-cm screen prior to feeding in a concurrent experiment. The resulting mixture of ground grass hay and CCDS was stored in three separate piles (based on inclusion level) in a partially enclosed commodity bay with concrete flooring. From each pile, samples were collected weekly throughout an 84-d period, and immediately frozen prior to laboratory analysis. Within inclusion level, weekly samples were then composited by first and

second half of the feeding period. Dry matter determination, sample grinding, and CP,

fat, and NDF analyses were conducted using the methods previously described.

Corn condensed distillers solubles samples were collected directly from the

delivery truck at the time of windrow application and frozen prior to analysis. Dry matter

was determined as described above. Samples were then freeze-dried prior to analysis for

CP, fat, sulfur, OM, phosphorus, and pH.

Statistical Analyses

All data were analyzed as a completely randomized design using PROC MIXED

of SAS (SAS Inst. Inc., Cary, NC). Internal bale temperature data were analyzed with a 3

x 3 factorial arrangement of treatments with bale as the experimental unit. Model fixed

effects included CCDS level, date, and the level x date interaction. Orthogonal contrasts

were constructed to test linear and quadratic effects of increasing CCDS level within

sampling date because an interaction was observed. For nutrient composition data, the

effect of sampling date was initially evaluated for both core and pile samples, and

determined non-significant. Therefore, means were pooled across date and sampling type

(core vs. pile) was compared within CCDS level. The experimental unit tested was level

within date.

Results

Experiment 1

The projected CCDS inclusion level was approximately 20% of bale weight (DM

basis). After adjusting for actual DM values for both CCDS and 0% hay, the observed

inclusion level reflected our initial calculations accurately (Table 2). Variation in hay

density across the field produced differences in linear windrow length necessary to make

a large-round bale. Because of this, a range of 10.1% units was observed for bales applied with 20% (DM basis) CCDS (Table 2).

Internal temperature data are summarized in Table 3. A significant ($P \leq 0.01$) CCDS level x sampling date interaction was observed. Temperature was impacted ($P \leq 0.01$) by date post-baling but only for 20% bales. Interestingly, temperature declined ($P \leq 0.05$) from 2 to 3 wk post-baling for 20% bales but remained similar for 0% bales. Corn condensed distillers solubles level had no effect ($P = 0.85$) on bale temperature. Nutrient composition data are presented in Table 4. In agreement with the temperature data, DM was not different ($P = 0.58$) between treatments. Significant ($P \leq 0.0001$) increases in CP, fat, and sulfur were realized for 20%, relative to 0% bales. In addition, a corresponding reduction ($P \leq 0.0001$) in NDF content was observed by adding 20% CCDS (DM basis).

Experiment 2

In similar fashion to Exp. 1, the observed CCDS inclusion levels correctly reflected our preliminary calculations (Table 2). Individual bale to bale variation was directly proportional to the level of CCDS applied (SD = 4.6 vs. 2.5% units for 32 and 16% bales, respectively). The maximum inclusion amount for an individual bale in the 16% treatment group was less than the minimum for an individual 32% bale (Table 2). Therefore, CCDS inclusion rates for individual bales did not overlap across treatments.

Bale temperature data are summarized in Table 5. As in Exp. 1, a significant ($P \leq 0.01$) CCDS level x sampling date interaction existed. Additionally, fixed effects of both CCDS level and date impacted bale temperature. A significant ($P \leq 0.01$) quadratic response of temperature to increasing CCDS levels was observed at 0 wk post-baling. At

that time, temperature was greatest for 16% bales, but 0 and 32% bales were similar.

Treatment means were not different ($P \geq 0.05$) at 2 wk post-baling. Temperature linearly

($P \leq 0.01$) increased with greater CCDS levels when measured by 3 wk post-baling.

Despite internal temperature being greatest for 32% bales at 3 wk, temperature declined

for all treatments across time.

Hay chemical composition data are presented in Table 6. Sampling type did not

($P = 0.34$) impact DM indicating sufficient drying of both CCDS and hay had occurred

pre-baling regardless of level applied. Core samples had significantly ($P = 0.05$) greater

CP content compared to pile samples at all levels of CCDS. In agreement, fat content

was numerically ($P = 0.15$) greater for core than pile samples at 16 and 32% CCDS

levels. Crude protein and fat were numerically lowest for 0% bales, greatest for 32%

bales, with 16% bales intermediate for both sampling types. There was a tendency ($P =$

0.10) for NDF to be lower for samples collected with the core-technique than pile

samples. Compared to bales that had no CCDS added, fiber was decreased by 14.6 and

24.7% for 16 and 32% bales, respectively, for core samples only. However, for pile-

collected samples, this decrease was only 7 and 13.7% for 16 and 32% bales,

respectively. Therefore, within-bale storage of CCDS appeared greater when core

samples were collected and analyzed.

Discussion

The DM of CCDS applied in both experiments was greater than anticipated.

Other workers (Gilbery et al., 2006) have reported DM values from 22.5-30.7% for

CCDS. This was an advantage in the current study, as it allowed for less drying time

needed prior to baling. Additionally, CCDS fat values in the current study were higher

than previously noted (Tjardes and Wright, 2002; Gilbery et al., 2006). As more water is removed, the proportion of remaining nutrients increases, and this perhaps was of benefit in our trials. The fat may have bound CCDS to the forage particles, allowing it to remain on the surface of the windrow and effectively dry. In each trial, our original inclusion rates were calculated using assumed DM values of 35 and 90% for CCDS and hay, respectively. However, after accounting for actual CCDS and hay DM values, our observed inclusion levels were accurate with initial projections.

Windrow density varied considerably across the field during both years of the study. Singer (2002) noted precipitation, nutrient availability, and temperature as factors interacting to influence growth rates and tiller density of cool and warm-season grasses. These variables contribute to stand differences within individual fields. This variation, although expected, was greater than anticipated and created differences in linear lengths necessary to produce a round bale. As a result, CCDS inclusion rates differed on an individual bale basis, but treatment means were consistent with original calculations. In Exp. 2, this variation was directly proportional to inclusion level (SD = 2.5 vs. 4.6% units for 16 and 32% bales, respectively). This assumes mean bale weight (DM basis) remains approximately constant, with the length necessary influencing CCDS inclusion rates.

Issues, either managerial or mechanical, associated with applying CCDS to hay windrows were not encountered. Equipment used was intended to be simple in design and effective in function. Undoubtedly, other techniques of applying CCDS to hay windrows could be developed with equal effectiveness. Our design was modeled such that a producer could simply rent/borrow a liquid fertilizer trailer from a commercial business, and then purchase other necessary items (i.e. valve, flow-meter...ect.). This

could result in significant savings to the producer, given some materials may be acquired at a one-time cost and used for several years. It is highly recommended that a flow-meter be used, as knowing CCDS flow-rate is key in determining inclusion rate. It would not be necessary for producers to measure the length required to produce each bale. Rather, measurements could be made on a limited number of initial bales, the mean length determined, and used for calculating CCDS inclusion rates for an entire field. Further, determination of CCDS and hay DM values is advised, as this would improve the accuracy of the desired application level, and avoid under- or over-application.

Windrows with 16 or 20% CCDS (DM basis) baled with ease. However, in Exp. 2, windrows with 32% CCDS (DM basis) were more difficult to bale. Specifically, CCDS material collected on the rolling-pins, and the lipid caused the wrapping-belts to slide from position when releasing a bale from the chamber of the machine. Although a minor problem, this suggests additional drying time beyond that allowed in the current study is necessary for increased inclusion rates. However, DM was similar across inclusion levels implying sufficient drying of both CCDS and hay occurred. Windrows with 32% CCDS (DM basis) were somewhat "tacky" upon touch, even after 8 h had passed since application. In both experiments, bales wrapped, handled, and kept adequately for several months post-baling.

Hay DM was not different between treatments in Exp. 1, nor was it influenced by sampling type at any CCDS level in Exp. 2. In accordance, level of CCDS had no impact on internal bale temperature in the initial trial, and only small changes in temperature were observed in Exp. 2. Coblentz et al. (2000) reported hays baled with greater moisture concentrations generate internal heat at intense levels and for extended time

periods. A result of elevated microbial activity and oxidation of nonstructural carbohydrates, internal heating can limit ruminal degradability of forage N (Nelson et al., 1989; Coblentz et al, 2001). Rectangular bales of bermudagrass hay baled at five moisture concentrations (178, 208, 248, 287, and 325 g kg^{-1}) developed different temperature response curves; however, maximum internal temperature was greatest for hay baled at 325 g kg^{-1}moisture (Coblentz et al., 2000). Hay baled at the lowest moisture concentration had a maximum temperature of 43°C, similar to the greatest value observed in the current study (40.7°C = 16% CCDS, 0 wk post-baling). Further, response curves from Coblentz et al. (2000) demonstrate spontaneous heating begins immediately after baling, subsides briefly for two d, and begins again for approximately two to three wk. In Exp. 2 of the current study, temperature gradually declined across all treatments by 3 wk post-baling, suggesting microbial fermentation had diminished.

The acidity (pH < 5.0) of CCDS may have aided in bale preservation aside from its relatively low moisture content. Previous studies (McGuffey et al., 1973; Knapp et al., 1976) have evaluated the use of mycostatic compounds such as propionic acid to decrease pH and preserve moist hay and silage during storage. Growth of undesirable bacteria during storage can be prevented by low pH (Thomas, 1978). Nelson et al. (1989) evaluated the efficacy of lactic acid-producing bacteria on forage quality of large-round bales of alfalfa baled at different moisture levels. The authors reported internal heat-induced nutrient changes for alfalfa baled at 64.3% DM. However, benefit from inoculation was only observed when alfalfa was baled at 73.4% DM. In addition, the authors reported there was little evidence that altered anaerobic fermentation was responsible for the observed benefits, given inoculation did not substantially decrease pH.

Our results indicate the absence of internal heating in CCDS treated bales was largely due to adequate drying prior to baling. Although mold growth was not quantified, little visible mold was present when bales were fed 6 mo post-application. It is possible the addition of CCDS may have aided in mold prevention, and the decreased pH may be of greater benefit in minimizing microbial activity when hay is baled at a lower DM than observed in the current study.

Forage quantity and quality are dynamic and seasonal as described by Adams et al. (1996) and Lardy et al. (2004). Plant nutrient density is primarily associated with stage of maturity and is well document in studies by Worrell et al. (1986) and Greenquist et al. (2009). Warm-season forage in the current study was harvested in late-July, and core-samples collected from 0% CCDS bales contained approximately 7.0% CP (DM basis). In agreement, Kirch et al. (2007) reported values from 5.0-7.5% (DM basis) for warm-season tallgrass in the reproductive stage of development. In Exp. 2, samples collected from 0% bales after tub-grinding had less CP than core samples. Core samples were collected within 3 wk of baling, whereas pile samples were collected after bales had been stored for at least 5 mo. Nelson et al. (1989) reported the nutritional value of forages declines from cutting to feeding due to wilting and loss of leaves. Conversely, other studies (Huhnke, 1993; Werk et al., 1998; Turner et al., 2007) have shown increases in forage CP due to the effects of weathering on stored hay. Early work by Streeter et al. (1966) with baled upland Sandhills hay showed little change in N by 6 mo post-baling. Although significant, the difference between core and pile samples is relatively small (0.7% units), and most likely represents the loss of N due to volatilization of ammonia.

Crude protein and fat were significantly increased by adding 20% CCDS in Exp. 1. In Exp. 2, these nutrients were lowest for 0% bales, intermediate for 16% bales, and greatest for 32% bales. Core samples had statistically greater CP content than pile samples for both 16 and 32% bales. A similar tendency was observed for fat content. This discrepancy of nutrient values between core and pile-collected samples is consistent, yet not clearly understood. At the onset of the trial, it was expected that samples collected post-grinding may more accurately reflect the nutrient composition of treated hay. This is largely due to an increased sample size and more uniform collection from all bales within treatments, rather than a subset of bales within treatments as was used for core samples. The technique followed for collecting core samples in the current study has been utilized in other trials (Nelson et al., 1989; Turner et al., 2007) and is the approved method as certified by the NFTA (2012). Samples taken from piles were hand-collected which may have biased our results in several ways including: inconsistencies with the manner in which they were obtained, disproportional collection of plant parts, or a failure of uniformly collecting samples from throughout the hay pile.

Because the CCDS adequately dried before baling, it appeared to have bound to forage leaves and stems within the bale. It is possible CCDS was pulverized to dust or fines during the grinding process, and therefore not collected from the pile samples. Beardsley (1964) reported grinding alfalfa has minimal impact on actual nutrient composition, although intake and digestibility can be enhanced through a reduction in particle size. However, separation of leaves from stems does occur during forage processing which can influence overall sample or diet quality (Waldo, 1977). Although CP and fat data would suggest CCDS was lost during storage within the bale, bales

treated with 32% CCDS were more challenging to process through the tub-grinder. This provides evidence that within-bale storage of CCDS occurred, and the observed nutrient characteristics are likely due to sampling differences which inadvertently created differences in the proportion of CCDS within the sample.

Nitrogen and fat can be low and highly variable in forages (Villalobos et al., 1997; Revello-Chion et al., 2011). Small differences with regards to the amount of CCDS within core or pile samples can create significant variation in nutrient values. Perhaps NDF analyses provide the most information regarding the extent that CCDS inclusion levels were obtained. Because CCDS contains essentially no fiber, hay NDF would be diluted with substitution of CCDS. Compared to bales that had no CCDS added, fiber was decreased by 14.6 and 24.7% for 16 and 32% bales, respectively, for core samples only. However, for pile-collected samples, this decrease was only 7 and 13.7% for 16 and 32% bales, respectively. These data provide further evidence of the apparent difference in CCDS content between core and pile-collected samples. Therefore, using NDF as a predictor, within-bale storage of CCDS appeared successful at levels near those originally calculated at the time of application. Future research evaluating alternative methods of storing liquid ethanol co-products using forages is warranted.

Implications

Adding CCDS to native grass hay windrows before baling was conducted at levels up to 32% of bale weight (DM basis). In either experiment, application of the wet material did not impair the ability of hay to expel heat post-baling suggesting adequate drying of both CCDS and hay occurred. An increase in CP and fat content, and

decreased NDF for hay treated with CCDS indicates successful within-bale storage existed. Applying CCDS to forage windrows prior to baling is a viable strategy for storing liquid co-products while simultaneously improving forage quality.

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Table 1. Nutrient analysis of CCDS applied to grass hay windrows prior to baling.

Item[1]	Experiment 1 (2010)	Experiment 2 (2011)
DM	37.5	39.3
CP	23.4	31.4
Fat	25.9	21.7
OM	89.9	90.2
S	1.1	1.2
P	1.9	1.9
pH	4.6	4.2

[1]% of DM.

Table 2. Inclusion rates of CCDS treated bales by year[1].

Year	n	Level[2]	Mean[3]	SD	Minimum	Maximum
2010	36	20	20.4	2.5	13.8	23.9
2011	31	16	16.1	2.5	10.7	21.4
	27	32	32.3	4.6	22.0	41.7

[1]% inclusion (DM basis) of bale weight.
[2]Projected inclusion level, %.
[3]Observed inclusion level, %.

Table 3. Effect of level of CCDS and sampling date on hay bale internal temperature in experiment 1.

	0		20			*P*-value		
Item	2 wk	3wk	2 wk	3wk	SEM	Level[2]	Date[3]	L x D[4]
Temperature, °C[1]	34.5[a,b]	34.6[a]	35.6[a]	33.3[b]	0.41	0.85	<0.01	<0.01

[1]Measured using a digital hay probe.

[2]Fixed effect of CCDS level.

[3]Fixed effect of sampling date.

[4]CCDS level x sampling date interaction.

[a,b]Within a row, least squares means without common superscripts differ at $P \leq 0.05$.

Table 4. Effect of level of CCDS on hay bale nutrient composition in experiment 1.

Item[1]	Treatment		SEM	P-value
	0	20		
DM	90.4	90.1	1.09	0.58
CP	7.2	9.8	0.20	<0.0001
NDF	69.2	60.0	0.36	<0.0001
Fat	1.7	4.7	0.14	<0.0001
S	0.1	0.3	0.01	<0.0001

[1]% DM basis.

Table 5. Effect of level of CCDS and sampling date on hay bale internal temperature in experiment 2.

Item	0 wk			2 wk			3 wk			SEM	P-value		
	0	16	32	0	16	32	0	16	32		Level[2]	Date[3]	L x D[4]
Temp., °C[1,5]	36.9[b,c]	40.7[a]	38.4[b]	34.8[d,e]	35.3[c,d]	34.6[d,e]	27.9[g]	31.1[f]	33.2[e]	0.72	<0.01	<0.01	<0.01

[1]Measured using a digital hay probe.
[2]Fixed effect of CCDS level.
[3]Fixed effect of sampling date.
[4]CCDS level x sampling date interaction.
[5]Quadratic effect of level within 0 wk bales, and linear effect within 3 wk bales ($P \leq 0.01$).
[a-g]Within a row, least squares means without common superscripts differ at $P \leq 0.05$.

Table 6. Effect of sampling type on hay nutrient composition by CCDS inclusion level in experiment 2.

Item[1]	Core[2]	Pile[3]	SEM	P-value
0%				
DM	92.3	89.5	1.59	0.34
CP	6.9	6.2	0.04	<0.01
NDF	74.6	76.2	0.55	0.17
Fat	1.8	2.3	0.37	0.48
16%				
DM	93.1	90.4	1.68	0.37
CP	11.5	7.3	0.35	0.01
NDF	63.7	71.2	1.83	0.10
Fat	4.2	2.9	0.48	0.19
32%				
DM	91.4	90.0	1.73	0.63
CP	12.8	9.2	0.63	0.05
NDF	56.2	65.8	2.26	0.10
Fat	5.4	3.7	0.52	0.15

[1]% of DM.

[2]Mean of samples collected on 0 and 21 d post-baling.

[3]Mean of samples collected during first and second half of feeding period.

Chapter II. Applying corn condensed distillers solubles to hay windrows prior to baling: II. Effects on replacement heifer growth and reproduction and growing steer calf performance.

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ABSTRACT: Two experiments evaluated feeding grass hay bales previously treated with corn condensed distillers solubles (CCDS) and supplementing to meet metabolizable protein requirements in diets for growing cattle. In Exp. 1, four pens (16-17 heifers per pen) of crossbred replacement heifers (age = 332 d) were allotted randomly to one of two dietary treatments 1) ad libitum intake of native large-round hay bales treated with CCDS at 20% of bale weight (DM) (CCDS) or 2) ad libitum intake of native large-round hay bales and fed dried distillers grains plus solubles (DDGS) at 20% of the diet (DM) (DDGS). Gain and final BW were greater ($P = 0.01$) for DDGS than CCDS heifers. Likewise, DDGS females had numerically ($P = 0.18$) greater BCS compared to CCDS heifers (5.5 vs. 5.1, respectively). Although pregnancy rates were statistically ($P = 0.23$) similar, puberty at breeding was influenced by treatment (94 vs. 70% for DDGS and CCDS, respectively). In Exp. 2, 60 crossbred steers (initial BW = 288 ± 11.6 kg) were allotted to one of six treatments in a 3 x 2 factorial design with factors including level of CCDS (0, 15, or 30% of diet, DM) and supplementing to meet metabolizable protein requirements or not (MP or No MP). Gain and final BW linearly ($P \leq 0.01$) improved as CCDS inclusion increased, but were only greater for MP-diets at 0% CCDS. Additionally, DMI increased linearly ($P \leq 0.01$) with greater dietary CCDS, but was similar ($P = 0.60$) between MP and No MP-diets. Gain efficiency improved in linear fashion ($P \leq 0.01$) as dietary CCDS increased, but was only enhanced by MP-diets up to

15% CCDS. Supplementing growing cattle to meet metabolizable protein requirements had little impact on gain or efficiency beyond 15% dietary CCDS, but cattle responded to increasing CCDS levels, thereby validating that within-bale storage occurs and CCDS-treated bales are adequate for use in growing diets.

Key Words: beef cattle, distillers solubles, growing, metabolizable protein

Introduction

The utilization of ethanol co-products in diets for growing cattle has increased in recent years in response to an emerging corn dry-milling industry (Klopfenstein et al., 2008). When priced on $/kg (DM) basis, these co-products are typically the most economical source of energy and protein for use in ruminant diets. Corn condensed distillers solubles (CCDS) is one co-product that has been less extensively evaluated for use in growing cattle diets, as compared to other forms (wet, modified, or dry) of distillers grains. However, the rumen degradability of CP, fat, and P lend to the attractiveness of CCDS as an ingredient in forage-based diets (Stalker et al., 2010). Because it has a DM content similar to wet distillers grains plus solubles (WDGS), CCDS adds moisture and palatability to the diet, reduces dust, and encourages the consumption of low-quality forages. In recent years, ethanol plants have merchandized CCDS at a discount to solid distillers grains, thereby allowing it to be formulated into diets more readily.

Initial work (Coupe et al., 2008) determined CCDS mixed with low-quality forages and fed to growing steers at levels up to 27% of the diet (DM basis) increased

true ruminal CP digestion with minimal impact on NDF digestion. Peterson et al. (2009)

fed CCDS mixed with wheat straw at 25, 35, and 45% of the diet (DM basis) to growing

steers, and reported an ADG of 0.48, 0.45, 0.56 kg, respectively. In another study,

Wilken et al. (2009) fed CCDS or WDGS mixed and ensiled with cornstalks at 15, 20,

25, and 30% of the diet DM. Intake was numerically greatest for steers fed CCDS at

30% of the diet DM. Gain and F:G were significantly ($P < 0.01$) improved by including

WDGS in the diet as compared to CCDS regardless of inclusion level. These trials

suggest CCDS has a similar feeding value as WDGS in growing diets, but other reports,

including those directly comparing it to distillers grains, are limited.

A critical distinction between CCDS and distillers grains is the rumen

degradability of CP. Early work by DeHaan et al. (1982) demonstrated CCDS is high in

soluble protein which is rapidly degraded in the rumen. The opposite is true of distillers

grains which contains approximately 65% undegraded intake protein (UIP; Klopfenstein

et al., 2008). Growing cattle have greater requirements for metabolizable protein (MP),

and typically respond to supplemental UIP. It is accepted that UIP contributes to the high

energy value of distillers grains when used in forage-based diets for growing cattle,

which has been demonstrated in several studies (Loy et al., 2008; Nuttelman et al., 2010;

Ahern et al., 2011). Growing cattle consuming forage-based diets and CCDS may be

deficient in MP, and would respond to additional dietary UIP.

Recent data (Martin et al., 2007) suggests excess dietary UIP from distillers grains

may improve conception rates in heifers independent of BW gain. Conversely, protein

source had no impact on synchronization or pregnancy rates, but heifers developed on

distillers grains had increased ADG (Harris et al., 2008). In addition, the energy

contributed from fat in ethanol co-products may have beneficial effects on reproduction aside from gain. Corn condensed distillers solubles (17.4 %, DM) contains greater levels of fat than distillers grains (10.0%, DM) (Tjardes and Wright, 2002; Gilbery et al., 2006). Thus, incorporation of CCDS into diets for growing replacement heifers may have positive effects on reproduction, provided fiber digestion is not impacted. The effects of fat on reproduction in beef females have been thoroughly evaluated (Lammoglia et al., 2000; Funston, 2004; Martin et al., 2005). Although lipids contribute to the synthesis and regulation of hormones necessary for reproductive function, responses to dietary fat have been inconsistent. A review of the literature indicates CCDS has not been evaluated for use in heifer development diets.

Related experiments have evaluated applying CCDS to hay windrows before baling as an alternative form of within-bale storage. Performance of cattle fed CCDS-treated bales can indicate the extent that storage was successful. Further, limited data exist evaluating the use of CCDS in diets for growing cattle and replacement heifers. Therefore, our objectives of these experiments were: 1) to evaluate the feeding value of hay bales previously treated with CCDS in diets for replacement heifers and growing calves, and thus determine the extent of within-bale storage; and 2) to measure the effect of supplemental by-pass protein on the performance of growing cattle fed CCDS in forage-based diets.

Materials and Methods

All procedures and facilities described in the following experiments were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee.

Experiment 1

    Animals and Treatments

    Weaned, crossbred (Simmental x Angus), spring-born heifers (n = 66, initial age = 332 d) were utilized in a development trial conducted at the University of Nebraska-Lincoln Dalbey-Halleck Research Unit located near Virginia in southeast Nebraska. Heifers were weaned in October of the previous year and fed a common diet to target an approximate ADG of 0.55 kg prior to the experiment beginning in mid-winter. In February, heifers were stratified by BW and randomly assigned within strata to one of four pens (2 pens per treatment, 16-17 heifers per pen). Pens were assigned randomly to one of two dietary treatments: 1) ad libitum intake of native large-round hay bales treated with CCDS at 20% of bale weight (DM basis) (CCDS) or 2) ad libitum intake of native large-round hay bales not treated with CCDS and fed DDGS at 20% of the diet (DM basis) (DDGS). The CCDS-treated bales used in the current study were produced in a concurrent experiment at the same research location. A complete description of this trial is in Exp. 1 of the former chapter of this thesis.

    Treatment diets (Table 1) were formulated using the NRC (1996) model to contain a 20% dietary inclusion (DM basis) of ethanol co-products, while remaining similar in CP and TDN, to allow heifers to achieve approximately 60% of mature BW at the onset of the breeding season. This inclusion level was chosen based on previous research (Martin et al., 2007) demonstrating DDGS fed at 0.59% of BW (DM basis) is sufficient to produce an ADG of 0.68 kg for developing heifers prior to breeding. Using an NRC projected DMI value of 2.4% of BW (DM basis), the observed co-product

inclusion level in the current study calculated to 0.50% of BW, slightly less than reported by Martin et al. (2007).

Large-round hay bales were offered to both treatment groups in metal bale-ring feeders, and hay DMI was not quantified. Limestone was added to DDGS prior to feeding to achieve a minimum Ca:P ratio of 1.5:1. In addition, both treatments were offered ad libitum access to a mineral and vitamin supplement (18.7% Ca, 18.0% salt, 6% Mg, 5,500 ppm Zn, 2,500 ppm Cu, 26.4 ppm Se, 881,840 IU/kg vitamin A, and 881.84 IU/kg vitamin E). DDGS heifers were group-fed at approximately 0830 daily in metal feed bunks with at least 0.46 m of bunk space per heifer.

Three d consecutive initial and final BW measurements were recorded to determine heifer performance. The same three d initial weights were used to stratify and assign heifers to pens. Weights (without restriction from feed and water) were collected after heifers had been fed a common diet of grass hay and DDGS for 1 wk. Body condition score (Wagner et al., 1988; 1 = emaciated; 9 = obese) was assessed visually at the beginning and end of the experiment by the same experienced technician during the days weights were collected. Heifers remained in pens and received treatment diets for 62 d. Average daily gain during the drylot period was calculated by subtracting initial BW from final BW divided by 62. Following the drylot period, heifers were managed as a single group, and grazed predominately smooth bromegrass (*Bromus inermis*) pastures for 145 d from late-April through September.

In late May, heifers were exposed to fertile Angus bulls at a bull:heifer ratio of 1:22 for a 45 d breeding season. Estrus was synchronized via a single injection (25 mg) of $PGF_{2\alpha}$ (Lutalyse, Pfizer Animal Health Inc., New York, NY) administered 96 h

following bull exposure (Whittier et al., 1991). Injections were given intra-muscularly in the neck, using an 18-guage, 3.81-cm needle. Pregnancy was diagnosed 60 d post-bull removal via transrectal ultrasonography. Body condition score was assessed at the time of pregnancy evaluation, and single day BW measurements (without restriction from feed and water) were collected at that time. Average daily gain during the summer grazing/breeding period was calculated by subtracting the final BW during the drylot period from pregnancy BW divided by 145.

Blood Collection and Hormone Assays

Three blood samples were collected from all heifers starting approximately 1 mo prior to the beginning of the breeding season to measure serum progesterone (P_4) concentrations to determine the attainment of puberty. Samples (5 mL) were collected on 14 d intervals using 2.54-cm needles (Becton Dickinson Vacutainer Systems, Becton Dickinson and Company, Franklin Lakes, NJ) and vacutainer blood-collection tubes (Preanalytical Solutions, Becton Dickinson and Company) via coccygeal venipuncture. Samples were cooled on ice immediately, centrifuged (4°C, 15 min., 1,305 x g), and serum was harvested and frozen at -20°C until analysis. Serum P_4 concentrations were determined by direct solid-phase RIA (Coat-A-Count, Diagnostic Products Corp., Los Angeles, CA). Serum P_4 concentrations ≥ 1 ng/mL were interpreted to indicate ovarian luteal activity and therefore used as an indicator of attainment of puberty before the onset of the breeding season.

Statistical Analyses

All performance data were analyzed as a completely randomized design using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC). Performance data collected during

the 62 d drylot period were analyzed using pen as the experimental unit. Pregnancy BW and BCS, summer ADG, and reproduction data were analyzed using individual animal as the experimental unit. Pregnancy and cyclicity data were binomially distributed using a logit transformation and analyzed using PROC GLIMMIX of SAS (SAS Inst. Inc., Cary, NC). The model for all analyses included the fixed diet treatment effect.

Experiment 2

Animals and Treatments

A total of 60 crossbred (½ english x ½ continental) steer calves (initial BW = 288 ± 11.6 kg) were utilized in a 84-d growing experiment conducted at the University of Nebraska-Lincoln Agricultural Research and Development Center feedlot located near Mead, NE. The trial was a completely randomized design with a 3 x 2 factorial arrangement of treatments resulting in six dietary treatments (10 steers per treatment). Treatment factors included: 1) level of CCDS (0, 15, and 30% of diet; DM basis) mixed with ground grass hay and 2) with or without supplemental UIP to meet MP requirements (No MP or MP). The mixture of ground grass hay and previously-applied CCDS served as the basal diet ingredient with a supplement top-dressed at the time of feeding. Composition of treatment diets and supplements are presented in Table 2. All diets were formulated using the NRC (1996) model using actual nutrient composition values of both CCDS and non-treated hay. Supplemental UIP was provided using a 1:1 ratio of Soypass® (LignoTech USA, Rothschild, WI) and corn gluten meal (Cargill Corn Milling, Blair, NE) to meet, but not exceed, predicted MP requirements for all MP-diets. To prevent a response to DIP, urea was added to diets containing 0% CCDS to meet DIP

requirements. All supplements were formulated to provide 200 mg/hd/d of monensin sodium (Rumensin 90, Elanco Animal Health, Indianapolis, IN).

The CCDS-treated round bales fed in the current study were produced in a concurrent experiment at the Dalbey-Halleck Research Unit. A complete description of this trial may be found in Exp. 2 of the former chapter of this thesis. In December, grass hay bales treated with 0, 16, or 32% (DM basis) CCDS the previous summer were transported from the Dalbey-Halleck Research Unit to the Agricultural Research and Development Center feedlot. Bales were ground through a tub-grinder to pass through a 7.62-cm screen. The resulting mixture of ground grass hay and CCDS was stored in three separate piles (based on inclusion level) in a partially enclosed commodity bay with concrete flooring prior to feeding. A complete description of sampling techniques and nutrient analyses of samples obtained from piles is in Exp. 2 of the initial chapter of this thesis.

Cattle were limit-fed (2% of BW; DM basis) a diet of 50% alfalfa hay and 50% wet corn gluten feed for 5 d prior to initiation and upon completion of the trial to minimize variation in gastrointestinal tract fill. Initial and final BW measurements were the mean of 3 d consecutive weights. Mean initial 2 d weights were used to stratify steers by BW and randomly assign animals within strata to treatments. Steers were housed in a partially enclosed barn with slatted floors and individually fed with Calan electronic gates (American Calan, Northwood, NH) for ad libitum consumption at approximately 0830 daily. Bunks were evaluated daily, feed refusals collected weekly, and DM determination was conducted using a 60°C forced air oven for 48 h. Dry matter intake was calculated on an individual basis by subtracting DM refused from DM offered.

Likewise, individual ADG was determined by subtracting initial BW from final BW divided by 84.

Statistical Analyses

All data were analyzed using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC) with individual animal as the experimental unit. Model fixed effects included corn condensed distillers solubles inclusion level, supplemental metabolizable protein, and the level x protein interaction. Orthogonal contrasts were constructed to test the linear and quadratic effects of inclusion level within No MP and MP diets when an interaction occurred, or for the main effect of level when an interaction was not observed.

Results

Experiment 1

Heifer performance and BCS data collected during the drylot period are presented in Table 3. By design, initial BW and BCS was similar ($P \geq 0.42$) for CCDS and DDGS heifers. Average daily gain during the drylot period was greater ($P = 0.01$) for DDGS than CCDS heifers (0.55 and 0.31 kg, respectively). As a result, DDGS heifers had increased ($P = 0.01$) final BW relative to CCDS females (325 vs. 309 kg, respectively). Although not statistically different ($P = 0.18$), BCS responded in similar fashion and was 0.40 units greater for DDGS than CCDS heifers. Based upon actual cow BW measurements collected at weaning the previous year, DDGS heifers were developed to approximately 62% of mature BW within 1 mo of the breeding season, compared to 58% for CCDS heifers.

Replacement heifer BW and BCS data measured at pregnancy diagnosis, and reproduction characteristics are reported in Table 4. In contrast to the drylot period,

summer ADG was greater ($P = 0.05$) for CCDS than DDGS heifers (0.38 vs. 0.33 kg, respectively). Although gain during the summer was low regardless of treatment, these data suggest CCDS heifers compensated for decreased drylot gains once pasture turn-out was initiated. However, DDGS heifers maintained a numerical ($P = 0.24$) BW advantage at pregnancy diagnosis. The difference in BCS between treatment groups at the end of the drylot period had diminished by late-summer ($P = 0.35$). Interestingly, the proportion of females pubertal before the onset of the breeding season was influenced ($P = 0.02$) by treatment (70 vs. 94% for CCDS and DDGS, respectively). Likewise, pregnancy rate was numerically ($P = 0.23$) greater for DDGS females.

Experiment 2

The dietary nutrient composition and daily protein balance of treatments is shown in Table 5. Protein balances were calculated using the 1996 NRC model based on average BW, DMI, and ADG during the feeding period. Supplements for all MP-diets were formulated to meet, but not greatly exceed, requirements for MP. Based on actual animal data, supplements formulated appeared to adequately meet requirements for 15 and 30% CCDS levels, but was deficient (-96 g/d) at 0% CCDS.

Simple effect means for steer performance data are presented in Table 6. As intended, initial BW was not different among treatments. There was no significant ($P = 0.13$) CCDS level by protein interaction, nor was there an effect of MP on DMI. Intuitively, DMI increased linearly ($P \leq 0.01$) with greater dietary levels of CCDS. There was a significant ($P \leq 0.01$) level by protein interaction for ADG. Within No MP-diets, daily gain increased linearly as CCDS inclusion level increased. However, the response to increased dietary CCDS was both linear and quadratic for MP-diets. Supplemental MP

improved ($P \leq 0.01$) ADG and final BW, but only for cattle fed diets with no added CCDS. Because ADG improved linearly as CCDS inclusion increased, final BW responded in similar fashion regardless of supplement type.

A significant ($P \leq 0.01$) CCDS level by protein interaction was observed for G:F; however, gain efficiency improved linearly as CCDS inclusion level increased despite type of supplement. Cattle fed MP-diets had improved G:F compared to those fed No MP-diets but only up to 15% CCDS (DM basis).

Discussion

Explanations for the difference in gain between treatments during the drylot period in Exp. 1 are not immediately clear. DDGS heifers were bunk-fed and consumed essentially all their supplement daily, whereas CCDS heifers had ad libitum access to treated hay. Even though metal bale feeders were used, CCDS heifers appeared to waste a considerable amount of forage which may have produced differences in co-product intake because the CCDS was already applied to the hay. Data from Miller et al. (2007) suggest hay wastage may be as great as 40% (DM basis) when cows are allowed ad libitum access using similarly designed feeders. Thus, differences in nutrient intake (kg/d basis) would have occurred if co-product intakes were not equal. Also, cattle were not limit-fed prior to collecting weights, and ruminal fill variation may have influenced BW measurements. However, weights were collected over 3 d which would minimize the impact of fill discrepancies. Therefore, treatment differences are likely due to other dietary factors.

In the current study, DDGS heifers had comparable ADG to those developed on essentially the same diet in the study by Martin et al. (2007). Harris et al. (2008)

included DDGS at 16.9% of the diet (DM basis) and observed an ADG of 0.71 kg.

Jaeger et al. (2012) fed WDGS at 12.4% of the diet (DM basis) and reported a daily gain

of 0.32 kg. This supports that DDGS fed at approximately 0.50-0.60% of BW (DM

basis) is sufficient for producing moderate gains prior to breeding. CCDS heifers had a

daily gain of nearly half the rate of DDGS heifers, suggesting the actual CCDS inclusion

level was only 56% of the targeted amount. However, using actual analyses of the CCDS

applied to hay at baling, dietary CP was similar between treatments (11.8 vs. 10.4%, DM,

for DDGS and CCDS, respectively). Further, calculated dietary energy was equal

between treatments (63% TDN, DM). However, this assumes CCDS is equal in energy

content to DDGS, as was predicted when formulating our diets.

Dietary fat was 6.5 and 3.8% (DM basis) for CCDS and DDGS heifers,

respectively. Loy et al., (2008) observed a depression in the energy value of DDGS due

to a dietary fat content of 5.2% (DM basis), but this was only at an inclusion higher than

in our study (0.81% of BW, DM). Gilbery et al. (2006) documented a linear increase in

ruminal OM and NDF digestibility as CCDS inclusion level increased from 0 to 15% of

the diet (DM). Conversely, increasing levels of corn oil supplemented to grazing steers

linearly reduced forage DMI (Pavan et al., 2007). However, neither forage DMI nor true

ruminal OM digestion was impacted by CCDS when fed at levels greater than in the

current study (Coupe et al., 2008). Whitney et al. (2000) reported 10.5% dietary fat (DM

basis) has minimal effect on diet digestibility. Because DMI was not measured in the

current study, it is unclear if additional dietary fat for CCDS heifers negatively impacted

forage digestion, thereby influencing intake and performance. It is unlikely that a

reduction in performance of this magnitude was mediated solely through the influence of dietary fat.

Based upon actual dam BW records collected at weaning the previous fall, DDGS and CCDS heifers were developed to approximately 62 and 58% of mature BW prior to breeding, respectively. Historically, it has been accepted that reaching a given percentage of mature BW prior to breeding is necessary for achieving puberty and pregnancy (Bagley, 1993). Data from Lynch et al. (1997) indicate the timing with which a given BW is obtained is of less importance than originally thought. Recently, development systems designed for low BW gains post-weaning, followed by a brief period of increased gains prior to breeding have had minimal impact on final pregnancy rates (Funston and Larson, 2011). Funston and Deutscher (2004) developed spring-born heifers on two planes of nutrition prior to breeding. Similar to the current study, fewer heifers developed on a low winter ADG were cycling at the start of the breeding season, but no difference in pregnancy rate was noted. In relation to those in the study by Funston and Deutscher (2004), heifers in our study were developed to an adequate pre-breeding BW.

Despite having lower ADG, BCS remained constant throughout the feeding period for CCDS heifers. However, DDGS heifers gained BW and BCS indicating they were on an increasing nutritional plane as breeding approached. In mature cows, BCS prior to breeding has been proven to impact first-service conception rates and pregnancy rates (Houghton et al., 1990) primarily through effects on ovarian function and LH release (Rasby et al., 1991). Nutritional restriction of heifers by 1.4 BCS units resulted in alterations of plasma glucose and IGF-1 prior to cessation of estrous cycles (Bossis et al.,

1999). Restriction of energy has been shown to prevent the prepubertal increase in LH pulse frequency thereby hindering follicle growth and ovulation (Schillo et al., 1992; Melvin et al., 1999; Diskin et al., 2003). It is possible CCDS heifers were nutritionally restricted if the differences in co-product intake were real. Given the short duration of the trial, this restriction was probably not severe or long enough to be detected by changes in BCS, if it even occurred. An acceptable percentage of females were cyclic prior to the start of the breeding season suggesting BW and BCS were adequate.

Funston (2004) noted that although published data on the use of supplemental fat in replacement heifer diets is limited, more consistent reproductive responses seem to be evident in nutritionally challenged females. Supplemental fat may be of little benefit in well-developed females such as those in the current study. Long et al. (2007) reported supplementing females with rumen protected fat prior to breeding improved pregnancy rates. Fat from DDGS is coated with corn germ particles, and essentially protected from rumen fermentation prior to intestinal absorption. This may partially explain the difference in reproduction between DDGS and CCDS females in our study. Supplementing developing heifers with excess (+180 g/d) MP improved A.I. conception and pregnancy rates (Martin et al., 2007). Conversely, data by Lalman et al. (1993) and Kane et al. (2004) discount the concept that high levels of UIP benefit reproduction in beef females. Heifers developed on DDGS or soybeans before breeding had similar follicle characteristics and pregnancy rates (Martin et al., 2010). The number of females utilized in our study was limited. Therefore, the reproduction data are challenging to interpret and additional replication is needed to further evaluate the effects of feeding CCDS and CCDS-treated hay bales in heifer development diets.

Experiment 2 was subsequently designed based on the results of Exp. 1 to test the effects of increasing CCDS levels and supplementing to meet MP requirements on steer performance. Reasons for the difference in performance for cattle fed CCDS-treated bales between the two experiments are not immediately clear. Although both experiments were conducted during late-winter, it could be debated that favorable weather conditions during Exp. 2 may have contributed to enhanced cattle performance. Monensin has been repeatedly shown to improve gain as much as 17% in forage-based diets (Schelling, 1984). Thus, dietary inclusion of monensin in Exp. 2 certainly explains some, but not all of the response in cattle performance.

In response to increasing levels of CCDS, DMI linearly increased in the current study. At the 30% CCDS inclusion level, calculated dietary fat is approximately 7.8%, DM, which apparently was not enough to negatively impact forage digestion. This response is in contrast to data from Peterson et al. (2009) and Wilken et al. (2009). In those studies, DMI did not respond in a linear fashion but small numerical increases were seen as inclusion level advanced. However, CCDS inclusion levels were in increments of either 5 or 10% units, as compared to 15% units as in the current study. The greater difference in inclusion level between treatments in our study may have improved our ability to detect differences in intake. A decrease in forage intake is usually observed as DDGS supplementation increases (Corrigan et al., 2009; Wahrmund et al., 2011). Conversely, studies by Gilbery et al. (2006) and Coupe et al. (2008) suggest forage intake is not impacted by CCDS supplementation. In agreement, Corrigan et al. (2009) further reported no difference in forage intake as the proportion of CCDS in DDGS increases. Therefore, assuming equal forage intake across treatments, DMI data in the current study

suggest that CCDS inclusion levels in the hay fed were approximately 12 and 26.5% (DM basis). These values are comparable to our original inclusion rates (16 and 32%, DM), indicating that successful within-bale storage of CCDS occurred. Supplementing to meet MP requirements had negligible influence on DMI in our study. Patterson et al. (2003) supplemented primiparous heifers to meet MP requirements reporting no impact on forage DMI. In addition, UIP supplementation to growing steers cubically effected total DMI, but forage DMI was not reported (Zinn and Owens, 1993).

Average daily gain responded linearly to increasing CCDS for cattle fed No MP-diets. This response was both linear and quadratic for cattle fed MP-diets, simply due to the slopes of the two lines. These responses are similar to those observed for DDGS in other studies (Morris et al., 2005). In the study by Peterson et al. (2009), ADG was only different at 45% CCDS, but increasing inclusion levels did linearly improve both gain and F:G in trial by Wilken et al. (2009). Cattle only responded with increased gain and final BW to meeting MP requirements when fed diets with no added CCDS, and this is intuitive given the predictions from the NRC (1996) model. Supplementing 2% dietary UIP to lightweight (198 kg) steers resulted in the greatest increase in both rate and efficiency of gain, with less response noted at greater levels (Zinn and Owens, 1993). Apparently, a MP deficiency of approximately 70 g/d is not great enough to elicit performance differences.

Implications

Collectively, our data indicate grass hay bales treated with up to 32% CCDS (bale weight, DM basis) are effective for use in growing cattle diets. Further research is necessary to quantify the impact of CCDS in diets for growing replacement heifers, as

well as measuring the effect of feeding CCDS-treated hay bales in free choice feeders.

Cattle gain and efficiency improved in response to increasing CCDS levels when bales

were ground and fed daily as a mixed diet. Supplementing to meet MP requirements

does not appear to be necessary when cattle are fed CCDS at the levels used in our study.

Within-bale storage is an acceptable method for utilizing CCDS, and treated bales may be

used in growing diets to minimize the need for additional protein or energy

supplementation.

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Table 1. Composition of dietary treatments fed to growing replacement heifers in experiment 1.

Ingredient[1]	Treatment	
	CCDS[2,4]	DDGS[3,4]
Grass hay	80.00	80.00
Corn condensed distillers solubles	20.00	-
Dried distillers grains plus solubles	-	20.00
Total	100.00	100.00

[1]% of diet DM.
[2]CCDS = heifers fed ad libitum grass hay bales treated with corn condensed distillers solubles at 20% of bale weight (DM basis).
[3]DDGS = heifers fed ad libitum grass hay bales and DDGS at 20% of diet (DM basis).
[4]Salt, trace mineral, and vitamin supplement provided free choice.

Table 2. Diet and supplement composition of treatments fed to growing steer calves in experiment 2.

	Treatment					
	No MP			MP		
Ingredient[1]	0	15	30	0	15	30
Grass hay	93.83	78.82	63.80	93.83	78.82	63.80
CCDS	0.00	15.01	30.03	0.00	15.01	30.03
Supplement	6.17	6.17	6.17	6.17	6.17	6.17
Total	100.00	100.00	100.00	100.00	100.00	100.00
Supplement[1]						
Corn gluten meal	0.000	0.000	0.000	2.240	1.680	1.680
Soypass®	0.000	0.000	0.000	2.240	1.680	1.680
Soybean hulls	4.632	4.700	4.700	0.000	1.271	1.271
Limestone	0.413	0.963	0.963	0.502	1.032	1.032
Urea	0.320	0.000	0.000	0.480	0.000	0.000
Salt	0.300	0.300	0.300	0.300	0.300	0.300
Dicalcium phos.	0.298	0.000	0.000	0.201	0.000	0.000
Tallow	0.125	0.125	0.125	0.125	0.125	0.125
Trace min.	0.050	0.050	0.050	0.050	0.050	0.050
Vitamin	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-90®[2]	0.013	0.013	0.013	0.013	0.013	0.013
Total	6.17	6.17	6.17	6.17	6.17	6.17

[1]% of diet DM.

[2]Formulated to provide 200.00 mg/hd/d monensin sodium.

Table 3. Effect of diet on replacement heifer performance in drylot in experiment 1.

Item	CCDS[1]	DDGS[2]	SEM	P-value
	Treatment			
Pens (n)	2	2		
Initial BW, kg	290.7	290.6	0.26	0.81
Initial BCS	5.1	5.1	0.04	0.42
Final BW, kg	309.4	325.0	1.11	0.01
Final BCS	5.1	5.5	0.14	0.18
ADG, kg	0.31	0.55	0.02	0.01
Pre-breeding BW, %[3]	58.4	62.3		

[1]CCDS = heifers fed ad libitum grass hay bales treated with solubles at 20% DM.
[2]DDGS = heifers fed ad libitum grass hay bales and DDGS at 20% DM.
[3]Pre-breeding BW relative to dam BW at weaning.

Table 4. Effect of diet on replacement heifer reproduction and gain during summer grazing period in experiment 1.

| Item | Treatment | | SEM | *P*-value |
	CCDS[1]	DDGS[2]		
Heifers (n)	33	33		
Pregnancy BW, kg[3]	364	373	5.27	0.24
Pregnancy BCS[3]	5.5	5.6	0.07	0.35
Summer ADG, kg	0.38	0.33	0.02	0.05
Cycling, %	70	94	0.08	0.02
Pregnant, %	84	94	0.06	0.23

[1]CCDS = heifers fed ad libitum grass hay bales treated with solubles at 20% DM.
[2]DDGS = heifers fed ad libitum grass hay bales and DDGS at 20% DM.
[3]Weights and body condition scores taken at ultrasound pregnancy diagnosis.

Table 5. Nutrient composition (DM basis) and daily protein balance of dietary treatments in experiment 2.

Item	No MP			MP		
	0	15	30	0	15	30
CP, %[1]	6.2	9.2	13.2	9.0	10.9	14.9
TDN, %[1]	54.6	61.0	66.7	55.0	61.0	67.0
MP balance, g/d[2]	-151	-68	-37	-96	+3	+52
DIP balance g/d[2]	-15	+4	+195	+44	+25	+221

[1]Calculated using 1996 NRC model level 1.

[2]Predicted MP and DIP balances calculated using 1996 NRC model level 1 based on average BW and DMI.

Table 6. Effect of level of CCDS and metabolizable protein on growing steer calf performance in experiment 2.

Item	No MP			MP			SEM	P-value		
	0	15	30	0	15	30		Level[1]	Protein[2]	L x P[3]
Initial BW, kg	288	288	288	288	288	288	3.86	0.99	0.89	0.99
Final BW, kg[4]	318[c]	341[b]	380[a]	338[b]	348[b]	380[a]	4.76	<0.01	0.03	0.09
ADG, kg[5]	0.35[d]	0.64[b,c]	1.10[a]	0.59[c]	0.71[b]	1.10[a]	0.04	<0.01	<0.01	<0.01
DMI, kg/d[6]	5.6[c]	6.9[b]	8.1[a]	6.3[b,c]	6.6[b]	8.1[a]	0.25	<0.01	0.60	0.13
G:F[4]	0.063[d]	0.093[c]	0.136[a]	0.096[b,c]	0.108[b]	0.135[a]	0.005	<0.01	<0.01	<0.01

[1]Fixed effect of CCDS level.
[2]Fixed effect of metabolizable protein.
[3]CCDS level x metabolizable protein interaction.
[4]Linear effect of CCDS level within No MP and MP diets ($P \leq 0.01$).
[5]Linear effect of CCDS level within No MP diets, and linear and quadratic effect within MP diets ($P \leq 0.01$).
[6]Linear main effect of CCDS level ($P \leq 0.01$).
[a-d]Within a row, least squares means without common superscripts differ at $P \leq 0.05$.