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Inclusion of Ethanol Co-Products in Beef Cow Diets: Impact on Cow Performance and Developmental Programming of the Progeny

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INCLUSION OF ETHANOL CO-PRODUCTS IN BEEF COW DIETS: IMPACT ON COWPERFORMANCE AND DEVELOPMENTAL PROGRAMMING OF THE PROGENY

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To my family

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LIST OF ABBREVIATIONS

ADG – average daily gain

AI – artificial insemination

AUC – area under the curve

BCS – body condition score

BF – backfat

BUN – blood urea nitrogen

BW – body weight

CDS – condensed distiller's solubles

CIDR – controlled intravaginal drug releasing device

CLA – conjugated linoleic acid

CP – crude protein

DDG – dried distiller's grains

DDGS – dried distiller's grains with solubles

DM – dry matter

DMI – dry matter intake

DPP – days postpartum

FA – fatty acid

HCW – hot carcass weight

IGF-1 – insulin like growth factor-1

KPH – kidney, pelvic, heart fat

LCFA – long chain fatty acid

LM – longissimus muscle

MCFA – medium chain fatty acid

MUFA – monounsaturated fatty acid

MUN – milk urea nitrogen

NE_g – net energy for gain

NE_m – net energy for maintenance

PUFA – polyunsaturated fatty acid

PUN – plasma urea nitrogen

RUP – rumen undegradable protein

SBM – soybean meal

SFA – saturated fatty acid

DUP – rumen undegradable protein

TAI – timed artificial insemination

WDS – wet distiller's grains with solubles

WSW – weigh-suckle-weigh

ABSTRACT

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The main goal for a cow-calf producer is profitability, which requires optimum reproductive performance, while keeping feed costs low and ensuring that nutritional needs are met. Cow herds are grazed on pasture or crop residues, but these may not always meet nutritional requirements. Ethanol co-products such as dried distiller's grains with solubles (DDGS) and condensed distiller's solubles (CDS) may be supplemented to increase the energy and protein concentration of the diet. Recently it has been discovered that maternal diet can have long lasting effects on progeny growth and development. Thus, the effects of feeding the ethanol co-products DDGS and CDS to gestating or lactating beef cow performance and calf growth was investigated in several experiments. The hypothesis for this thesis was that feeding ethanol co-products to cows during gestation and/or lactation would improve cow performance and reproductive efficiency while improving the pre- and post-weaning growth of their calves relative to control diets that did not contain ethanol co-products.

In the first experiment, cows with male progeny were fed isocaloric diets of DDGS or soybean meal (SBM) from calving until mid-lactation to determine the effect of

DDGS on cow performance, milk composition and calf growth. Feeding DDGS increased conception ($P < 0.02$) but not pregnancy rates ($P = 0.64$), did not alter cow BW ($P \geq 0.43$), BCS ($P \geq 0.13$) or milk production ($P \geq 0.75$) but altered milk composition compared to diets that did not contain DDGS. Distiller's grains with solubles had no effect on short chain fatty acids (FA) in milk ($P \geq 0.13$), but did decrease medium chain FA ($P < 0.01$) and increase long chain FA ($P < 0.01$). Saturated FA content of milk was decreased ($P < 0.01$) in DDGS cows, subsequently increasing monounsaturated FA ($P < 0.01$) and polyunsaturated FA ($P < 0.01$), including conjugated linoleic acid (CLA; $P < 0.01$). Feeding DDGS to dams during lactation resulted in greater calf ADG ($P < 0.01$) and heavier weights by the end of the trial ($P < 0.01$). Post-trial ADG was similar ($P = 0.90$) and calves whose dams were fed DDGS remained heavier at weaning ($P < 0.01$).

In the second experiment, male calves from the first experiment were placed in a feedlot to examine the effect of maternal diet during lactation on long-term progeny growth. Maternal treatment during lactation had no effect on days on feed ($P = 0.42$), ADG ($P = 0.80$), DMI ($P = 0.76$) or feed efficiency ($P = 0.90$) during the finishing phase. Glucose ($P \geq 0.17$) and insulin ($P \geq 0.16$) clearance were not affected by maternal nutrition during lactation, nor was glucose area under the curve ($P = 0.27$), insulin area under the curve ($P = 0.37$) or the glucose to insulin ratio ($P = 0.40$). Hot carcass weight ($P = 0.54$), dressing percent ($P = 0.50$), fat thickness ($P = 0.71$), longissimus area ($P = 0.17$), percent kidney pelvic heart fat ($P = 0.31$) and yield grade ($P = 0.19$) were not impacted. Marbling, however, was decreased ($P = 0.04$) in progeny whose dams were fed DDGS compared to progeny whose dams were fed a control diet.

In the third experiment, two studies were conducted to determine the effects of CDS inclusion with corn stover during gestation or lactation on beef cow and calf performance. Increased levels of CDS improved feed intake, although intake was hindered by high levels of corn stover. Cows lost weight ($P = 0.05$) when fed CDS during gestation but not lactation ($P > 0.22$), which may have been due to the greater levels of corn stover in the gestation diet. While cows lost weight, pregnancy rates were not negatively affected ($P = 1.00$). Milk urea nitrogen ($P = 0.08$) tended to increase when CDS was fed during lactation, but no other changes in milk composition were apparent when CDS was fed during gestation or lactation ($P \geq 0.19$). Feeding CDS during gestation had no effect on calf birth ($P \geq 0.29$) or weaning weights ($P \geq 0.42$), but calves whose dams were fed CDS during lactation grew more slowly ($P = 0.05$).

In conclusion, these experiments demonstrate that feeding DDGS during lactation can improve cow efficiency and reproductive performance and may be an effective method for improving pre-weaning calf growth, but has little effect on long-term feedlot performance of male progeny. If CDS is fed to gestating or lactating beef cows, it should be included at increased levels or with higher quality forages to prevent decreased in intake and performance.

CHAPTER 1. LITERATURE REVIEW

1.1 Cow-calf production

Beef cow herds are often grazed on pasture, range, or crop residues; however, in northern climates, there are times throughout the year when forage alone cannot meet the energy requirements of the animal. Nutritional requirements for the beef cow are greatest during late gestation due to the demands of fetal and placental growth as well as during early lactation due to the demands of milk production and uterine involution. For spring calving herds, late gestation and early lactation coincide with winter and early spring, a time when pasture resources are low and harvested feed must be fed. The cost of harvested feed is the single greatest expense in a cow-calf operation. In 2011 and 2012, harvested and purchased feed accounted for approximately 24% of total operation costs and for 75% of total feed costs (USDA ERS, 2013). Hay is the most common harvested feed used for wintering beef cows, but oftentimes hay must be supplemented with an energy source to maintain cow body weight. Historically, that energy source has been corn. Prior to 2005, corn price averaged $2.27 per bushel (USDA, 2013), however, use of corn for ethanol production has increased average corn price after 2006 to approximately $4.38 per bushel (USDA, 2013), making corn a less

attractive energy source. Ethanol co-products such as dried distiller's grains with solubles (DDGS) and condensed distiller's solubles (CDS) are economical alternatives to corn, and researchers (Kovarik et al., 2009; Shike et al., 2009; Braungardt et al., 2010) have determined that ethanol co-products are effective in beef cow diets. Co-products of the corn ethanol industry have become increasingly popular supplements for low quality forage due to their elevated energy and protein concentrations and decreased price compared to corn.

1.2 Distiller's grains

The U.S. primarily uses the dry grinding process to produce ethanol (Westcott, 2007). Corn is the principal grain used in the U.S. for ethanol production, but any grain that contains starch in its endosperm may be used (CBO, 2009). During the dry grinding process, corn is first ground and yeast, primarily *Saccharomyces cerevisiase,* is added to ferment starch to ethanol. This produces a mash that must then be distilled, leaving slurry that is known as stillage. Thin stillage is produced by removing the coarser particles from the stillage. The coarser particles can be marketed as wet distiller's grains (WDG) or can be dried to produce dried distiller's grains (DDG). Thin stillage can be further dehydrated to produce condensed distiller's solubles (CDS). Condensed distiller's solubles can be sold separately, or they can be added back to WDG or DDG to produce wet or dried distiller's grains with solubles (WDGS or DDGS, respectively; Stock et al., 1999). Wet and dry distiller's grains with solubles can be fed to many different types of livestock; however, WDGS is more expensive to transport and has a shorter shelf life

than DDGS, thus WDGS is fed in areas near ethanol plants and DDGS is transported to areas without ethanol plants.

Typically, two-thirds of corn is composed of starch, thus removal of the starch for ethanol production results in a three-fold increase in protein, fat and minerals in DDGS compared to corn (Klopfenstein et al., 2008). Distiller's grains are both a source of protein and energy for cattle. Historically, distiller's grains were used as a protein source, but the recent increase in ethanol production and availability of distiller's grains as well as the relative scarcity and increased price of energy feeds has led to a shift in feeding distiller's grains as an energy source to replace other grains like corn (Klopfenstein et al., 2008). According to the NRC (2000), DDGS contains approximately 10.3% fat and 29.5% protein on a DM basis, although these numbers are variable among ethanol plants and even among individual batches within a plant. Variation may occur when whole stillage is centrifuged (Belyea et al., 2010), or when CDS is added prior to drying (Kingsly et al., 2010). Dairy One Lab in Ithaca, NY reported an average fat content of 12.4% for 5,339 DDGS samples with a range between 9.3% and 15.6%, and a CV of 25.6% (Dairy One Forage Lab, 2012). This variation in fat content is mainly due to amount of CDS added back to the wet distiller's grains prior to drying, as 21.5% of the DM in CDS is fat (Schingoethe et al., 2010). The fat in DDGS is mostly composed of unsaturated fatty acids (FA), with linoleic (C18:2) and oleic (C18:1) acids comprising 50% and 25%, respectively, of total FA (Díaz-Royón et al., 2012). Condensed distiller's solubles contains 15-26 % crude protein and 13-23% fat on a DM basis (Dairy One Forage Lab, 2012). A higher inclusion of CDS in DDGS also results in lower concentrations of protein,

acid detergent fiber (ADF) and neutral detergent fiber for DDGS (NDF; Kingsly et al., 2010). Crude protein concentrations from 6,759 DDGS samples ranged between 27.0-35.6% crude protein, with an average of 31.3% and a CV of 13.7% (Dairy One Forage Lab, 2012). Heating during the fermentation and drying process causes sugars to complex with protein in distiller's grains, making a significant portion of the protein unavailable for digestion by ruminal bacteria. Thus, DDGS are a good source of ruminally undegradable protein (RUP), protein that escapes bacterial degradation but is available for digestion post-ruminally. The protein in DDGS is approximately 54% RUP (Schroeder 2003). However, overheating DDGS can cause the Maillard reaction, making the protein indigestible. In contrast to DDGS, CDS contains more rumen degradable protein (Coupe et al., 2008).

1.2.1 Weight and body condition score

Feeding DDGS to cows instead of hay or corn can improve BW, but can also decrease body condition scores in beef cows. Dried distiller's grains with solubles may have higher levels of energy compared to corn; however, energy content of DDGS can vary depending on dietary concentration and composition of other ingredients in the diet. When DDGS was fed at 155% of protein requirements, Radunz et al. (2010) estimated the feed value of DDGS for beef cows at 110% of corn NE_m based on data from Stock et al. (2001). In comparison, Gunn (2013) estimated the feed value of DDGS for beef cows at 98.7% of corn NE_m when dietary protein was fed at 182% of protein requirements. Greater concentrations of DDGS in diets increases nitrogen content of the

diet, and excess nitrogen decreases feed intake (Waldo, 1967) and weight gain (Zinn and Owens, 1993) in cattle. The excess nitrogen must be excreted at a metabolic cost, as it requires one ATP to excrete excess nitrogen in urine (Reynolds, 1992).The decreased energy value with increasing concentration of DDGS in beef cow diets is consistent with data from Gunn et al. (2009), who noted suppressed growth in finishing steers fed DDGS as an energy source in feedlot diets. The feed value of CDS is less clear, but has been estimated at 100-115% of DDGS NE_m (Lardy, 2007).

Radunz et al. (2010) reported that cows fed DDGS during late gestation gained more BW and were more efficient in gaining weight than those fed hay or corn. Although Radunz et al. (2010) saw no visual differences in body condition scores, ultrasound revealed that cows fed DDGS gained more back fat compared to those fed hay and suggested that energy was partitioned to subcutaneous fat deposition. In contrast, Gunn (2013) observed a decrease in body condition score with no change in BW when heifers were fed DDGS during late gestation compared to a corn silage based control diet. Again, protein was fed at more of an excess by Gunn (2013), possibly increasing energy costs associated with nitrogen disposal and decreasing fat deposition. It was also hypothesized by Gunn (2013) that this BCS change was due to a shift from subcutaneous to visceral fat deposition. This change in location of fat metabolism is supported by data from Depenbusch et al. (2009), who observed that internal fat increased concurrently with a decrease in 12th rib fat depth when feedlot heifers were fed 60% DDGS on a dry matter basis. Shike et al. (2009) reported that when fed to lactating beef cows, DDGS reduced weight loss and loss of body condition score

compared to cows fed corn gluten feed, which may have been due to decreased milk production and an alteration in energy partitioning from milk production to body weight gain. Wilson (2012) reported a tendency for heavier weights and better body condition scores when cows were limit-fed DDGS, corn bran, and cornstalks compared to those limit-fed hay. Wilson (2012) suggested that the differences in body weight and body condition score were due to decreased maintenance requirements caused by limit-feeding, as limit-feeding reduces visceral mass and energy requirements for maintenance (Sainz and Bentley, 1997), allowing for greater nutrients to be partitioned to body reserves. If DDGS is able to repartition body fat reserves it may also play an important role in decreasing postpartum anestrous, as energy reserves are important for reproductive function.

1.2.2 Reproduction

Energy requirements for basal metabolism, activity, growth, energy reserves and lactation must be met before estrous can be reestablished (Short et al., 1988) and high energy diets fed from calving until breeding decrease the postpartum interval and increase pregnancy rates compared to cows fed adequate energy diets (Wiltbank et al., 1964; Dunn et al., 1969). Distiller's grains are high in energy and could therefore enhance reproductive performance, but studies using distiller's grains have had inconclusive results as to its effects on reproduction. Smith et al. (2001) saw an increased number of cows cycling prior to estrous synchronization when fed DDGS; however, there were no differences in conception to artificial insemination or in overall

pregnancy rates. Similarly, feeding heifers DDGS as an energy source during late gestation and early lactation at a similar NE_g to the control group had no effects on conception rates (Gunn, 2013). While there were no differences in conception rates, heifers fed DDGS had increased follicle wavelengths and diameters and resumed estrus sooner than those fed corn silage (Gunn, 2013). In contrast, Engel et al. (2008) observed no effect of DDGS on the number of heifers that reached estrus by the beginning of the breeding season; however, they noted a tendency for greater overall pregnancy rates when heifers were supplemented with approximately 40% DDGS throughout late gestation. Other research suggests that supplementing heifers DDGS at 0.60% of BW increases conception to artificial insemination but has no effect on overall pregnancy rates (Martin et al., 2007). Radunz et al. (2010) noted no differences in pregnancy rates between cows limit-fed DDGS, limit-fed corn, and those fed hay throughout late gestation, when energy and protein intake varied between groups. When diets were formulated to be isocaloric and isonitrogenous, DDGS also had no effect on pregnancy rates compared to hay (Wilson et al., 2012). Similarly, feeding increasing levels of DDGS (0.77 kg/d, 1.54 kg/d or 2.31 kg/d) had no effect on luteal activity, conception rates or pregnancy rates compared to controls (Winterholler et al., 2012).

1.2.3 Milk composition

It is possible to manipulate milk composition in the cow, especially milk fat, through diet. Milk fat can originate through de novo synthesis or it can be derived from

the diet. For fatty acids (FA) C4:0 to C14:0 and a small amount of C16:0 or C16:2, de novo synthesis from acetate and β-hydroxybutyrate predominates. For FA greater than or equal to C16:0, absorption directly from the diet predominates (Mansbridge and Blake 1997). Milk fat depression occurs when dietary unsaturated FA alter microbial biohydrogenation, causing an increase in trans FA intermediates (Bauman and Griinari, 2003), including conjugated linoleic acid (CLA). Fatty acid intermediates formed through the altered microbial biohydrogenation pathway decrease de novo milk fat synthesis (Bauman and Griinari, 2003). Impairment of de novo synthesis causes a pronounced decrease in short (C4:0 – C8:0) and medium (C10:0 – C14:0) chain fatty acids and a smaller decrease in the percentage of milk long (≥ C16:0) chain fatty acids (Bauman and Griinari, 2003). Several isomers of CLA, including trans-10, cis-12 CLA and trans-9, trans-11 CLA can cause milk fat depression and alter the FA composition of the milk, resulting in an increased proportion of FA greater than or equal to C16:0 (Perfield et al., 2007).

In a study using Holstein cows, feeding isolipidic diets consisting of corn germ, DDGS, or corn oil, Abelqader et al. (2009) observed that feeding DDGS led to decreased milk fat percentage and increased milk urea nitrogen (MUN) but had no effect on milk yield. However, dietary DDGS increased milk content of cis-9, trans-11 CLA, total polyunsaturated fatty acids (PUFA), total monounsaturated fatty acids (MUFA), long chain fatty acids (LCFA) and subsequently decreased saturated fatty acids (SFA) and medium chain fatty acids (MCFA; Abelqader et al., 2009).

Kurokawa et al. (2012) reported that supplementing DDGS at 10% and 20% DM in Holstein diets increased milk yield, decreased percentage of milk protein and had no effect on milk fat. The 20% DDGS diet had the highest levels of milk unsaturated fatty acids (USFA) and milk CLA was increased 1.6 fold in the 10% DDGS treatment and 3.0 fold in the 20% DDGS treatment. Anderson et al. (2006) similarly demonstrated that Holstein cows fed DDGS at 10% and 20% of the diet on a dry matter basis increased milk yield. Milk protein was similar and milk fat depression did not occur, and while cis-9, trans-11 CLA and PUFAs were increased in both DDGS diets, feeding 20% DDGS had the greatest increase in milk CLA (Anderson et al., 2006). Conjugated linoleic acid content of milk from Holsteins also increased with increased inclusion of DDGS in a study by Leonardi et al. (2005). Sasikala-Appukuttan et al. (2008) observed an increase in milk yield when DDGS and/or CDS was supplemented in the diets of lactating dairy cows, but milk fat and protein were not affected. Additionally, MUFA, PUFA, and CLA were increased in milk when CDS and/or DDGS was fed, with a 3.2 fold increase in CLA compared to the control when DDGS and CDS were combined (Sasikala-Appukuttan et al., 2008). Feeding CDS to dairy cows increased milk production, protein and lactose production (Da Cruz et al., 2005). Collectively, these results show that feeding DDGS and other co-products like CDS can increase milk yield, PUFAs, CLA and can cause milk fat depression.

1.2.4 Carcass quality and consumer perception

Dried distiller's grains with solubles is considered an excellent feed for finishing beef cattle because of increased performance and average daily gain (Trenkle, 2004; Buckner et al., 2007). However, DDGS can decrease intramuscular fat deposition, change carcass composition, and alter muscle tenderness, fatty acid composition, color and flavor, particularly when fed in large quantities. Consumer perception of meat quality is based on many intrinsic and extrinsic factors, including but not limited to: tenderness, meat color, visible fat, drip loss, juiciness, flavor, safety, price, sustainability and ethics (Troy and Kerry, 2010). According to the National Consumer Retail Beef Study, the most important determinant of meat quality is tenderness (Sayell et al., 1987), and consumers are willing to pay premium prices for beef that is guaranteed to be tender (Boleman et al., 1997; Miller at al., 2001). Meat color is also important as a consumer uses it to determine product quality and freshness (Troy and Kerry, 2010), and color can be influenced by the presence of marbling (Varnam and Sutherland 1995). Marbling is the intramuscular fat that lies between muscle fibers. It affects flavor, juiciness and tenderness of meat and greater marbling is linked with greater palatability. Fat content between 3-7.3% is accepted by consumers, although greater than 7.3% fat content is considered too much by consumers who are health-conscious (Miller 2002). The flavor of beef can be affected not only by the extent of marbling, but also by the fatty acid composition of the lipids (Troy and Kerry, 2010).

While distiller's grains seems to have no effect on marbling when fed below 30% dry matter (Gorden et al., 2002; Leupp et al., 2009), marbling scores were decreased

when DDGS was fed at levels greater than 29% (Corah and McCully 2006; Mateo et al., 2004; Gunn et al., 2009). Glucose is the preferred substrate for intramuscular fat deposition (Smith and Crouse 1984), and glucose is primarily derived from ruminal fermentation of starch to propionate. The decrease in marbling seen in feedlot cattle fed distiller's grains is thought to occur because of the lower starch content of distiller's grains diets (Schoonmaker et al., 2010).

Roeber et al. (2005) found no differences in beef tenderness or sensory traits when steers were fed 50% DDG. These results agree with Koger et al. (2010), who observed no difference in beef tenderness when cattle were fed 20% or 40% DDG compared to 20% or 40% wet distiller's grains or a control diet of dry-rolled corn and soybean meal. In contrast, a linear increase in tenderness was observed with increasing inclusion of DDGS from 0 to 75% DM and steaks were more flavorful when heifers were fed 45 or 60% DDGS (Deupenbusch et al., 2009). Fatty acid composition is an important determinant of fat quality, lipid oxidation and flavor (Wood et al., 2002). Steaks from steers fed DDGS were juicier and had more flavor (Leupp et al., 2009) and contained greater amounts of polyunsaturated fatty acids (Segers et al., 2011). Polyunsaturated fatty acids were greater in steers fed 40% DGS compared to 20% DGS, however, steaks from the 40% DGS went rancid at a faster rate (Koger et al., 2010). Higher levels of polyunsaturated fatty acids may have increased lipid oxidation resulting in greater discoloration of DDGS steaks after nine days of retail display compared to steaks from steers fed soybean meal (Segers et al., 2011). Oxidation of lipids produces free radicals that cause rancidity and oxidation of oxymyoglobin and deoxymyoglobin to

metmyoglobin, causing a discoloration of the steak (Lynch et al., 2000; Yang et al., 2002). Beef color influences a consumer's decision to purchase, and consumers prefer beef that is bright red in color opposed to those that are purple or brown (Carpenter et al., 2001).

Distiller's grains can affect carcass quality when fed late in the animal's life, but it is uncertain if feeding distiller's grains to dams would affect fetal or neonatal development and ultimately the carcass quality of their calves. Such an impact of DDGS on early development is possible, as recent research has demonstrated that nutrition of mothers during gestation and lactation has long-lasting effects on progeny, an effect that has been termed "developmental programming." While first observed in humans, this phenomenon has also been observed in livestock and can affect growth and development and ultimately production characteristics (Wu et al., 2006).

1.3 Growth and development

1.3.1 Fetal development

Maternal recognition of pregnancy occurs 15 to 17 days after fertilization (Waters, 2013). The conceptus attaches to the maternal endometrium approximately 19 days after fertilization via the fetal cotelydons and maternal caruncles. The placentomes, which are the structures that connect fetal cotyledons and maternal caruncles, are the primary sites where respiratory gases, nutrients and wastes are exchanged between the fetus and the dam (Vonnahme, 2012; Redmer et al., 2004). Placentomes are not well developed until day 32 (Wathes and Wooding, 1980), after

which they play a major role in regulating fetal growth. Glucose is the primary source of energy for the fetus and energy and nitrogen requirements of the fetus are met almost entirely by placental uptake of glucose and amino acids from maternal blood (Bell, 1995). Concentration of glucose in the maternal circulation determines placental glucose because transport occurs by passive transport (Bell, 1995; Lucy et al., 2012).

Nutrient transport also depends on placental size, morphology, transporter abundance and blood flow (Fowden et al., 2006). The increase in transplacental exchange that occurs during the last half of gestation is dependent upon the vascular beds that are developed during the first half of pregnancy (Meschia, 1983; Reynolds and Redmer, 1995). Poor maternal nutrition can affect placental size and ability to exchange nutrients, which can disrupt the growth of the fetus and potentially the viability and long-term health of the neonate. Maternal glucose concentration, influenced by insulin, determines fetal glucose exposure as well as fetal insulin-like growth factor-1 (IGF-1) concentrations (Holt, 2002). Insulin-like growth factors are peptides structurally related to insulin and are critical for the development of skeletal tissues, the central nervous system and reproductive organs (Duan et al., 2010). A disruption in maternal insulin function will disrupt glucose metabolism, consequently affecting fetal glucose exposure. A reduction in fetal glucose increases catabolism of amino acids at the expense of protein synthesis and tissue deposition (Redmer et al., 2004; Bell, 1995). Although the fetus has little adipose tissue, its extent is dependent upon glucose exposure (Symonds, 2012). Thus, energy status of the dam and her ability to regulate glucose impacts fetal muscle, fat and organ development and can have long-term consequences for the fetus.

Placental growth occurs concurrently with organogenesis (Vonnahme, 2012). A heartbeat is detected by 20 to 22 days of gestation and by day 25 limb buds begin to develop along with the liver, pancreas, lungs, thyroid, brain, and kidneys (Waters, 2013). If the fetus is male, testicular development initiates at day 45, or if female, ovarian development initiates between 50 to 60 days (Waters, 2013). Hence, an alteration in maternal nutrition at early stages of fetal development can hinder organ development and function of these organs in the adult, particularly the β-cells of the pancreas and insulin secretion.

Muscle and adipose cells both originate from mesenchymal stem cells and while most of these stem cells become myocytes, some of them become adipocytes (Dodson et al., 2010). It is believed that cells not signaled to commit to the myogenic pathway default to the adipogenic pathway (Rudnicki et al., 1993; Brameld et al., 2010). Prenatal muscle development, known as myogenesis, occurs during the embryonic and fetal stage in two phases: primary myogenesis and secondary myogenesis (Brameld et al., 2010). Primary myogenesis occurs until approximately 60 days of fetal life. The primary muscle fibers formed in this stage provide a scaffold for the secondary muscle fibers that begin to develop during secondary myogenesis, at approximately 90 days of fetal life. It is during secondary myogenesis that the majority of muscle fibers develop (Picard et al., 2002). The fibers that are formed during primary myogenesis usually become slow oxidative (Type I) muscle fibers. Secondary fibers tend to become fast fibers (Type IIA and Type IIB; Brameld et al., 2010). As Type I fibers are oxidative and Type II fibers are glycolytic, muscle fiber type may play a role in insulin sensitivity and intramuscular fat

deposition (Radunz, 2009), thereby modifying meat quality and tenderness. While fiber number is established at birth, fiber type is capable of changing postnatally (Brameld et al., 2010). Postnatal skeletal development is dependent upon the increase in muscle fiber size (Brameld et al., 2010) due to the differentiation of muscle satellite cells that lie between the sarcolemma and basal lamina (Du et al., 2010a). Satellite cells increase muscle fiber size by proliferating, differentiating, and fusing with existing muscle fibers. Satellite cells are most active in the late prenatal and early postnatal stages of growth and their numbers decline with increasing age (Brameld et al., 2010; Dodson et al., 2010).

Adipogenesis, the formation of adipose tissue, starts during early fetal development, but adipocyte numbers increase mostly during late fetal development and early postnatal life due to the abundance of multipotent progenitor cells that decrease as the animal ages (Du et al., 2010a, 2010c). Adipogenesis occurs through the differentiation of stem cells into preadipocytes and adipocytes, a process known as hyperplasia. Hypertrophy is the ability of mature adipocytes to increase in size and lipid storage capacity. Adipogenesis and fibrogenesis occur during mid-gestation and overlap with secondary myofiber development (Dodson et al., 2010). Adipocyte size can change depending on lipogenesis and lipolysis, or adipocytes can increase in number through differentiation of stem cells (Dodson et al., 2010). However, progenitor cell number and hyperplasia decreases as the animal ages, and so nutrition during the fetal, postnatal and early postweaning stage will determine the number of adipocytes an animal will have (Du et al., 2010c; Du et al., 2013). Adipocytes can develop into visceral,

subcutaneous, intermuscular, or intramuscular fat depots. Intramuscular fat formation is thought to occur between the late fetal and early neonatal stage to approximately 250 days of age and adipocytes formed during this stage provide precursor cells that could mature into lipid-storing adipocytes that would improve marbling in the mature animal (Dodson et al., 2010; Du et al., 2010a; Du et al., 2013). Therefore, enhancing adipogenesis from the late fetal stage to approximately 250 days of age is an opportunity to enhance intramuscular adipocyte number and marbling (Du et al., 2013).

1.3.2 Neonatal growth

Because muscle fiber number is established at birth, postnatal skeletal development is dependent upon an increase in muscle fiber size (Brameld et al., 2000). The neonate has an abundance of totipotent stem cells in skeletal muscle, also known as satellite cells, which lie between the sarcolemma and basal lamina of skeletal muscle (Brameld et al., 2010; Du et al., 2010). Satellite cells increase muscle fiber size by proliferating, differentiating and fusing with existing muscle fibers (Brameld et al., 2010). Satellite cells deplete with age and the window between birth and weaning is an opportunity to manipulate growth and development (Du et al., 2010). Calves are born with little fat and they accrete much fat while nursing (Drackley, 2005). Although calves have white adipose tissue when they are born, brown adipose tissue predominates as it is used for non-shivering thermogenesis while they adapt to the extra-uterine environment (Symonds et al., 2012). Preadipocytes can proliferate during adult life, but they primarily proliferate during early life (Du et al., 2010a), as postnatal growth occurs

primarily through hypertrophy. Adipocyte hypertrophy is regulated by the processes of lipogenesis and lipolysis, which determines storage or removal of energy in existing adipocytes. During the postnatal period, there is a rapid increase in fat mass, but this is due to an increase in white adipose tissue and a loss of brown adipose tissue (Clark et al., 1997; Symonds et al., 2012).

Prior to parturition, an increase in fetal glucocorticoids, catecholamines, and thyroid hormones increase gluconeogenic activity and hepatic glycogen storage of the fetus (Fowden et al., 1997, 2003, 2009; Forhead et al., 2009; Fowden and Forhead, 2011). The hepatic glycogen provides an immediate source of energy for the neonate after parturition as the neonate switches from placental supply of glucose to a supply of lactose (glucose plus galactose) from colostrum, milk and endogenous glucose production (Girard et al., 1992; Hammon et al., 2013). Colostrum increases glucose absorption and the increase in postprandial plasma glucose concentrations leads to increased insulin secretion (Hammon et al., 2013). Insulin is important in both lipid and protein metabolism. Insulin increases the rate at which glucose is transported across muscle and adipose tissue cell membranes (Dimitriadis et al., 2011), which ultimately impacts growth of the animal. In adipose tissue, insulin increases the uptake of triglycerides from the blood, stimulates fatty acid and triacylglycerol synthesis, and decreases the rate of fatty acid oxidation (Dimitriadis et al., 2011). In muscle, insulin increases the rate of amino acid transport and increases the rate of protein synthesis (Dimitriadis et al., 2011). Greater glucose concentration and insulin secretion is also a likely prerequisite for the maturation of the somatotropic axis (Hammon et al., 2013)

and greater endogenous insulin like growth factor (IGF) production (Brahmeld et al., 1999; Butler et al., 2003). In mice, inactivation of the IGF-1 receptor in adipose tissue increased adipose tissue mass without an increase in glucose uptake (Klöting et al., 2008) and deletion of the IGF-1 receptor in pancreatic β-cells causes a defect in glucose-stimulated insulin secretion as well as glucose intolerance (Kulkarni et al., 2002). The nutrients in colostrum and milk could potentially alter the somatotropic axis and IGF-1 production, which could alter glucose tolerance and adipose tissue mass in later life.

In order for the nutrients in milk, particularly lactose, to be effectively utilized by the calf, these nutrients need to bypass bacterial digestion that would occur in the rumen. The esophageal groove is made of muscular folds that when stimulated by suckling, close, allowing milk to bypass the rumen by directing it to the abomasum. Thus, during the first few weeks of neonatal life, calves are pre-ruminants that function as monogastrics, and are able to integrate milk fatty acids into tissue lipids without alteration. As calves consume dry feed, rumen fermentation is established and rumen development is completed by approximately 8 weeks of age. However, nursing causes a reflex that closes the esophageal groove and thus the majority of milk bypasses rumen fermentation for the duration of time that calves nurse. Milk contains between 15 to 30% fat on a dry solids basis and calves deposit much of the long chain fatty acids (LCFA) directly into adipose tissue without any alterations (Drackley, 2005). Nursing calves are exposed to high levels of insulin due to the digestion of lactose. Insulin regulates lipid metabolism by reducing fatty acid oxidation by liver and muscle tissue and causing an

anti-lipolytic effect on adipose tissue, thus allowing FA to be incorporated into triacylglycerides in adipose for storage (Hocquette and Bauchart, 1999). When calves are weaned, the diet transitions from one high in fat to one that may only contain 2-6% fat on a dry matter basis. Furthermore, volatile fatty acids (VFAs) from microbial fermentation replace glucose as an energy source during the pre-ruminant to ruminant transition (Drackley, 2005). The ruminal microorganisms saturate fatty acids through biohydrogenation, and deposited fatty acids are less likely to reflect dietary fatty acid composition.

Because pre-ruminants function as monogastrics and nutrition affects glucose and insulin levels, altering milk composition may provide an opportunity to manipulate the glucose-insulin axis. Since glucose and insulin regulate fat and protein deposition, programming the glucose-insulin axis may change glucose metabolism and adipose tissue deposition in the adult animal.

1.4 Developmental programming

Mothers who were malnourished during the Dutch Famine of 1944 had children with normal birth weights but increased incidence of obesity, dyslipidemia, insulin resistance and coronary heart disease in later life (Barker et al., 2012). This led to the concept of fetal programming, the idea that an insult, whether nutritional, environmental, or stress related, to the mother during pregnancy, can have metabolic and physiological consequences on the adult offspring (Barker et al., 2012). This

phenomenon has been expanded to include early neonatal life and has been designated many names, including: neonatal programming (Spencer et al., 2011), lactational programming (Hinde and Capitanio, 2010), metabolic imprinting (Waterland and Garza, 1999), metabolic programming (Lucas, 2000) and developmental programming (Reynolds et al., 2010) which covers all of these developmental phases and concepts (Gunn, 2013). Developmental programming occurs during stages of growth characterized by plasticity of metabolic regulatory systems, namely in utero or in the neonate. While first observed in humans, this effect has also been observed in livestock and can impact production characteristics (Wu et al., 2006).

1.4.1 Epigenetics

Developmental programming is thought to be caused by epigenetic regulation. Epigenetics are changes in gene expression that are mitotically and meiotically heritable but do not arise from changes in DNA sequence (Gicquel et al., 2008; Maccani and Marsit, 2009). Epigenetic regulation occurs through DNA methylation, histone modification and changes in chromatin structure (Cooney et al., 2006). The external environment of the growing embryo can change the epigenetic regulation of its genome (Gicquel et al., 2008). Soon after fertilization, the genome of the sire is actively demethylated and then the genome of the dam is passively demethylated after the two-cell embryo stage, which may allow for reprogramming for somatic development (Haaf, 2006). Demethylation of the maternal genome is associated with the maternal to zygotic transition, as during early embryogenesis the embryo is dependent upon maternal

mRNAs and proteins produced by the oocyte, but the embryo becomes dependent upon the expression of its own genome as the maternal mRNAs and proteins degrade (Memili and First, 2000). Substantial de novo methylation occurs in the bovine embryo at the 8 to 16 cell stage (Haaf, 2006). DNA methylation can be influenced by nutrition as it is dependent upon dietary factors such as methionine, choline, folate and Vitamin B_{12} for use as cofactors and methyl donors (Maclennan et al., 2004). Methyl transferases add methyl groups to cytosine residues in areas abundant with cytosine-guanine, known as CpG islands (Maccani and Marsit, 2009). When CpG islands are methylated, transcription is repressed and the gene containing the CpG islands is silenced (Maccani and Marsit, 2009). Genetic silencing can also occur with changes in chromatin structure, as acetylation and deacetylation of histones changes the binding of the chromosome and the ability of transcription factors to bind to DNA, playing an important part in regulating gene expression (Memili and First, 2000).

Epigenetic changes may not be exclusive to the fetal stage, as postnatal nutrition and environment can alter epigenetic regulation (Gicquel et al., 2008; Dolinoy et al., 2007). A study using human monozygotic twins demonstrated that epigenetic markings can accumulate with age (Fraga et al., 2005). However, epigenetic changes have greater consequences during early embryogenesis and development due to the few number of cells that will amplify and provide a template for the majority of cells in the adult, compared to epigenetic alterations in the adult that are constrained to those cells and specific tissues (Feil and Fraga, 2012). Epigenetic markings can be stable in somatic cells, but they are also reversible with proper signaling (Dolinoy et al., 2007; Jirtle and Skinner,

2007; Szyf, 2009; Bonasio et al., 2010). This is important to note as epigenetic modifications may play a role in developmental programming (Dolinoy et al., 2007) and should be considered for future management or reversal of any negative effects of developmental programming (Meyer et al., 2012).

1.4.2 Fetal programming in livestock

In ruminant production systems, there are many opportunities for dams to be exposed to suboptimal nutritional conditions, including: high environmental temperatures and mature forages in late summer, poor forage quality during the winter, competition between nutrient partitioning for growth of developing heifers and growth of their developing fetus and neonate, competition between milk production and fetal growth in dams with greater milk yield, as well as competition between overnourished, rapidly growing dams and growth of their fetus (Wu et al., 2006). When nutrients are scarce, the fetus partitions nutrients based on a hierarchy of priorities that focus on immediate survival. The brain is at the apex of the hierarchy and organs that are not critical to short term survival, such as the kidneys and lungs, are placed at the bottom and receive fewer nutrients because they are not useful in the womb (Barker 2012).

The repercussions of maternal malnutrition on progeny development are also dependent upon the timing of the alteration: peri-conceptual, early, mid or late gestation and lactation have differing effects on growth because development occurs in stages. These stages include: ovulation, placental growth, organogenesis, myogenesis, and adipogenesis (Robinson et al., 1999; Du et al., 2010). Each point of development

provides a window of opportunity for developmental programming of later life (Figure 1).

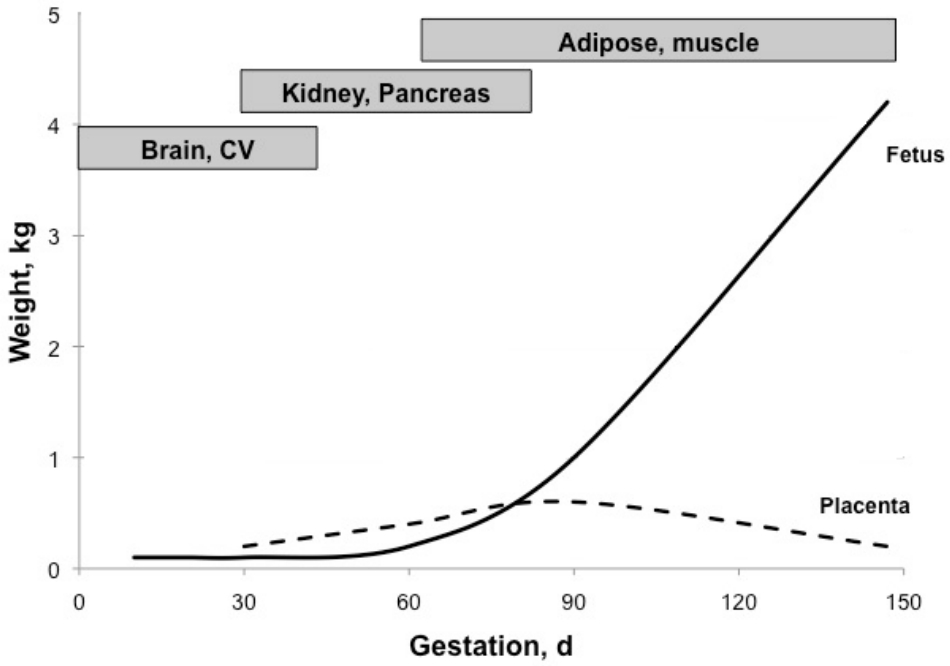

Figure 1.1. Placental and sheep conceptus development throughout gestation and critical windows at which maternal nutrition may affect placental or fetal growth. CV = cardiovascular system (adapted from Symonds et al., 2007 by Radunz, 2009)

1.4.3 The peri-conceptual period

The first stage at which developmental programming may occur is the peri-conceptual period prior to conception until implantation (Fleming et al., 2012; Velazquez and Fleming, 2013). Nutrition during the peri-conceptual period may have a substantial impact on postnatal phenotype because of the small number of cells present as opposed to when cellular mass is greater (Fleming et al., 2012).

Nutritional status influences follicular development, oocyte quality and ultimately embryo survival (Papadopoulos et al., 2001; Boland et al., 2001; Webb et al., 2004; Santos et al., 2008). Papadopoulos et al. (2001) and Borowczyk et al. (2006) noted poorer oocyte quality when ewes were fed 50% and 60% of maintenance requirements, respectively. After ovulation and fertilization of the oocyte, the zygote forms a blastocyst that is comprised of two cell lineages, one that will ultimately contribute to placental tissue and the other the fetal tissue (Watkins and Fleming, 2009). Maternal undernutrition not only decreased oocyte quality, but it also decreased cleavage and blastocyst formation rates in sheep (Papadopoulos et al., 2001; Borowczyk et al., 2006). During cleavage, embryonic gene activation, cell cycling, and lineage diversification must occur (Watkins and Fleming, 2009). Pisani et al. (2008) demonstrated that feeding sheep 50% of requirements for maintenance reduced the expression of genes necessary for oocyte metabolic activity and early embryonic development after implantation (Schmidt et al., 2009).

Peri-conceptual undernutrition can have long-term negative consequences for the fetus. Gallaher et al. (1998) observed that undernourishment of ewes from 60 days prior to mating until 30 days after conception reprogrammed regulation of the fetal IGF-1 axis, resulting in a decrease in IGF-1 concentrations when exposed to nutrient restriction during late gestation. Similarly, 70% nutrient restriction from 60 days prior to 7 days after mating altered the development of the hypothalamo-pituitary adrenal axis in twin lamb fetuses that caused an increased release of cortisol when challenged with corticotropin-releasing hormone during late gestation (Edwards and McMillen, 2002). In

sheep, undernutrition from 61 days prior to 30 days after mating had no effect on fetal or birth weights, but it altered fetal growth trajectory, increased fetal insulin response to a glucose bolus in late gestation (Oliver et al., 2001) and impaired glucose tolerance in adult offspring (Todd et al., 2009). Maternal undernutrition of ewes from 0 to 30 or 31 days of pregnancy increased cardiovascular dysfunction at one year of age (Gardner et al., 2004) and altered cardiovascular morphology in the adult (Cleal et al., 2007). Maternal dietary deficiency in Vitamin B_{12}, folate and methionine during the periconceptional period in sheep resulted in hypertension and increased adiposity, which may have been due to epigenetic changes (Sinclair et al., 2007).

1.4.4 Gestation

Fetal nutrient supply can be affected when there are maternal alterations in energy, protein, vitamins, or minerals during gestation, whether due to maternal under or overnutrition. This change in maternal nutrition can consequently initiate fetal programming. Nutrient requirements of the fetus are low during the first trimester, but critical events such as the establishing uteroplacental circulation, organogenesis, myogenesis and adipogenesis occur and they direct later stages of development (Robinson et al., 1999; Du et al., 2010). During the second trimester the fetus grows to approximately 25% of the size it will be at birth (Symonds et al., 2010). The majority of fetal development has occurred by the third trimester and it is during the third trimester that 75% of fetal growth occurs in the form of increased cellular mass (Robinson et al.,

1977). Thus, the timing of alterations in maternal nutrition can have varying effects on the fetus.

Maternal overnutrition during gestation yields similar results in the adult offspring as maternal undernutrition during gestation. This may be due to nutrient restriction to the fetus in late gestation because of decreased placental vascularity and nutrient transport in obese ewes (Ma et al., 2011). Fetuses of nutrient restricted and obese ewes may similarly partition energy and nutrients to organs less critical for short term survival, leading to the development of obesity, cardiovascular disease and glucose tolerance in adult life (Ford and Long, 2012).

It is also important to note that species differences may affect the extent of programming, as differences in timing of placental and fetal growth between species may make cattle less susceptible to changes in nutrition than sheep (Greenwood and Cafe, 2007). This could possibly explain differences among studies and why programming is more pronounced in sheep.

1.4.4.1 Early gestation

Nutrient restriction during the first trimester decreases placental development, restricts uteroplacental nutrient transfer and limits fetal growth. Feeding ewes at 68.1% and 86.7% of their maintenance energy and crude protein requirements, respectively, from 30 to 125 days of gestation reduced placental angiogenesis, and cotyledon and fetal weight at 125 days; however, there were no differences in fetal weight after realimentation (Zhu

et al., 2007). Birth weight appears to be unaffected by early maternal malnutrition. However, metabolism is affected as progeny had increased adipose deposition (Bispham et al., 2003) and were longer and thinner than control lambs (Whorwood et al., 2001), which could increase their risk of glucose intolerance and insulin resistance in later life (Godfrey and Barker, 2000). Insulin resistance is associated with increased triglyceride storage within muscle (Lewis et al., 2002). Intramuscular adipose cells are more insulin sensitive than subcutaneous adipose cells (Rhoades et al., 2009) because glucose is the preferred substrate for intramuscular adipose tissue (Smith and Crouse 1984). Radunz et al. (2012) proposed that subcutaneous fat is deposited at an increased rate when animals become insulin resistant. Feeding ewes 50% of the Agricultural and Food Research Council (AFRC) requirements for maintenance energy from 1 to 30 days of gestation had no effect on glucose clearance rate of progeny at one year of age (Gardner et al., 2005), but feeding ewes 50% of NRC energy requirements from 28 to 78 days of gestation resulted in increased levels of glucose and insulin in progeny 63 days after lambing (Ford et al., 2007). At 250 days of age, lambs from mothers that were nutrient restricted during early to mid-gestation increased glucose but decreased insulin response compared with the controls, and at slaughter their carcasses were heavier and had more visceral adipose tissue (Ford et al., 2007). When ewes were fed 60% of energy requirements for maintenance from 1 to 39 days of gestation, males had increased adipose tissue and females had elevated levels of circulating leptin. It was concluded that offspring of dams that were nutrient restricted during early pregnancy had elevated leptin concentrations, greater subcutaneous fat and less muscle (Muñoz et al., 2009).

Because myofiber number is established at birth and postnatal muscle growth occurs by hypertrophy, prenatal muscle fiber hyperplasia has the potential to effect postnatal muscle growth and development (Zhu et al., 2004). Undernutrition during early gestation has been shown to decrease muscle fiber size and muscle fiber number in sheep (Zhu et al., 2004; Quigley et al., 2005) and the secondary to primary fiber ratio (Wilson et al., 1988; Zhu et al., 2004; Quigley et al., 2005). Also, feeding 50% of daily requirement for energy to sheep before muscle cell differentiation led to a decrease in number and diameter of fast fibers (Type II) in the longissimus dorsi and vastus laterus muscles compared to nutrient restriction during and after differentiation (Fahey et al., 2005). Similarly in the pig, undernutrition in utero resulted in low birth weight and decreased muscle fiber number (Dwyer et al., 1994).

In contrast, a study by Long et al. (2010b) demonstrated that feeding 55% of NRC requirements for energy and 50% of NRC requirements for protein to beef heifers from 32 days until 115 days of gestation had no effect on birth weight, weaning or 15 month old weights, nor did it have an effect on insulin or glucose tolerance in progeny at 15 months of age compared to offspring whose dams were fed 100% of NRC energy requirements. Carcass characteristics were not changed by maternal undernutrition, but steers from nutrient restricted dams had greater muscle fiber area (Long et al., 2010c).

Excessive maternal energy, especially in adolescent dams, can also impede placental development and development of progeny. Wallace et al. (2006) reported that overnourishing adolescent singleton-bearing ewes increased maternal growth and adipose deposition, resulted in placental growth restriction by 30-40%, premature

delivery of lambs, and a 20-30% decrease in birth weight of lambs. Furthermore, Da Silva et al. (2001) observed that overnourished ewes produced less colostrum and their lambs had lower growth rates from birth to weaning and Tong et al. (2008, 2009) reported increased adipogenesis in fetal skeletal muscle when ewes were fed 150% NRC requirements during the first trimester.

Feeding 150% of NRC requirements for energy to multiparous ewes from 60 days prior to conception until 135 days of gestation led to accelerated growth of the fetus in early gestation that declined by late gestation (Ma et al., 2010). A decrease in pancreatic β-cell numbers and insulin concentration (Zhang et al., 2011), greater adiposity at term (Long et al., 2012), as well as greater adiposity as an adult (Long et al., 2010a) was noted in progeny when 150% of NRC requirements were fed to ewes. The decline in growth rate during late gestation of the fetuses of obese ewes may have been due to a reduction in cotyledon growth, which may be a mechanism to reduce fetal growth to reduce risk of dystocia caused by heavy birth weight (Ma et al., 2010). During the second half of gestation when fetal growth rate slows due to maternal overnutrition, β-cell apoptosis increases and β-cell numbers decrease, which could lead to glucose intolerance in later life (Zhang et al., 2011). Increased adiposity of fetuses from obese ewes, which is also associated with glucose intolerance, has been suggested to be accounted for by an increase in nutrient transporters associated with fat deposition (Long et al., 2012). Maternal obesity during gestation can also increase feed intake and adiposity and elevate levels of circulating leptin in adult offspring (Long et al., 2010a).

Organogenesis may also be stunted by overnutrition, as fetuses of adolescent sheep fed twice the energy requirements fed to control ewes had smaller livers, spleens, kidneys and hearts (Redmer et al., 2012). These effects were exacerbated when the obese adolescent sheep were switched from the high energy diet during the first two trimesters to half the energy for the last trimester of gestation (Redmer et al., 2012).

1.4.4.2 Late gestation

Nutrient restriction during late gestation generally decreases fetal growth, decreases birth weights and increases morbidity rates throughout life. Energy restriction at 70% of NRC recommendations for energy during the last 100 days of gestation decreased calf birth and weaning weight and delayed the attainment of puberty in heifer progeny compared to those who were fed 100% requirements (Corah et al., 1975). Furthermore, Corah et al. (1975) reported increased morbidity and mortality rates of calves whose dams were fed 70% of NRC recommendations. Gardner et al. (2005) observed that a 50% restriction in energy from 110 days of gestation to parturition produced a reduction in glucose tolerance and caused insulin resistance in lambs. Lambs from ewes restricted during late gestation had a decrease in GLUT 4 receptors, the major glucose transporter in cell membranes. This decrease was seen in adipose, but not muscle tissue, suggesting that glucose intolerance was related to an inability of adipose tissue to absorb glucose rather than the ability of muscle to consume glucose (Gardner et al., 2005). Thus, ensuring that the fetus has adequate nutrients during the

last trimester will optimize birth weight and neonatal growth, as birth weight is positively correlated with pre-weaning growth and weaning weight (Greenwood et al., 2010). However, it is important to avoid overnutrition, as it may also negatively affect fetal nutrient supply and progeny birth weights. This was demonstrated by Swanson et al., (2008) who observed that feeding 140% of nutritional requirements to growing ewes from day 50 of pregnancy to parturition resulted in decreased cotyledonary and birth weight (Swanson et al., 2008). Although under or over-nutrition during the last trimester usually decreases lamb birth weights, its effect on postnatal growth can be ameliorated or exacerbated by postnatal nutrition through weaning until one year of age (Greenwood et al., 2010).

1.4.5 Nutrient composition

The amount of energy fed during gestation is important for progeny development, but studies are beginning to reveal that nutrient composition is also important. Supplementing protein during late gestation to cows fed winter range or crop residue tended to increase progeny 205 day weight at weaning and increased quality grades at slaughter (Larson et al., 2009). Grazing improved pastures that were higher in protein from mid to late gestation did not increase day 205 weight, but progeny had heavier live weights at slaughter (Underwood et al., 2010). Steers had increased number of adipocytes as well as increased tenderness when dams grazed improved pasture (Underwood et al., 2010).

When heifers were fed a low level of protein and energy during the first trimester, male calves were approximately 4% heavier at birth than those fed a high level of nutrition (Micke et al., 2010). However, when males were fed a fed a high level of protein and fat during the second trimester, they were approximately 8% heavier than those fed low levels of protein and fat (Micke et al., 2010). Postnatal plasma IGF-1 was higher in male offspring when maternal plane of nutrition was changed after the first trimester from low to high or vice versa during the second trimester compared to those whose dams remained on the same diet (Micke et al., 2010). At 680 days of age, IGF-1, IGF-2 and IGF-2R mRNA expression was upregulated in the semitendinosus muscle of steers whose dams were fed low protein diets during the first trimester (Micke et al., 2011a). The increase in IGF-2 mRNA may have increased primary myofiber development in the first trimester that allowed for greater development of secondary myofibers in later gestation (Micke et al., 2011a). Insulin-like growth factor-1, IGF-1R, IGF-2, IGF-2R and leptin mRNA also influenced fat deposition in a depot specific manner (Micke et al., 2011b). The differences seen were attributed to increased protein because while the diets were not equal in protein or energy content, the difference in protein (3.3-3.6 fold) between treatments was greater than that of energy (1.2-1.3 fold; Micke et al., 2010, 2011a, 2011b).

1.4.6 Dried distiller's grains with solubles

Source of protein and energy appear to affect progeny growth as well and have been demonstrated in studies that utilize DDGS, a feed high in both fat and protein.

Feeding diets of corn or DDGS that were isocaloric with a hay based diet during late gestation resulted in heavier birth weights of corn and DDGS calves compared with the calves from cows fed hay (Radunz et al., 2010). During finishing, there were no differences in overall insulin sensitivity and steers whose dams were fed DDGS or hay had greater marbling scores than those fed corn, indicating that maternal diet during late gestation altered adipose deposition (Radunz et al., 2012). Heavier progeny birth weights were also seen when ewes were fed isoenergetic diets of corn or DDGS compared to haylage from mid-gestation until parturition (Radunz et al., 2011a). The increased birth weight of lambs whose mothers were fed corn was attributed to an increase in glucose supply while the increase in birth weight of lambs whose mothers were fed DDGS was attributed to an increase in amino acid supply, although amino acids were not quantified. While birth weights differed, maternal diet had no effect on pre-weaning performance of lambs (Radunz et al., 2011a). However, lambs whose mothers were fed DDGS from mid-gestation to parturition were heavier at slaughter than those from ewes fed hay (Radunz et al., 2011b), which may have been due to the difference in birth weights, as growth rate from birth to slaughter was not affected. Lambs whose dams were fed DDGS from mid-gestation until parturition had greater internal fat and an increased initial insulin response during a glucose tolerance test, suggesting that the lambs were insulin resistant (Radunz et al., 2011b). Glucose concentrations were lower compared to offspring from ewes fed corn and hay (Radunz et al., 2011b). The increase in internal fat deposition and consequent insulin insensitivity in progeny from dams fed DDGS was attributed to the altered insulin response of the dams during gestation

(Radunz et al., 2011b). Wilson et al. (2012) reported no differences in post-weaning performance of progeny when cows were fed isocaloric and isonitrogenous diets of limit-fed ground grass hay or limit-fed corn co-products and ground corn stalks 90 days before calving. However, calving difficulty was increased due to increased birth weights of the co-product calves (Wilson et al., 2012). Gunn et al. (2012) also observed greater birth weights and dystocia rates when heifers were fed DDGS as an energy source during late gestation and early lactation compared to those fed corn silage. The female progeny of these heifers were heavier at attainment of puberty and also had a 112% increase in timed AI conception rates (70.6% vs. 33.3%) compared to progeny whose dams were fed corn silage (Gunn, 2013).

1.4.7 Neonatal programming

Neonatal nutrition can mitigate or aggravate the effects of fetal programming (Greenwood et al., 2010). This was demonstrated by Freetly et al. (2000), who reported a decrease in calf birth weight but no difference in 205 day calf weight when dams were nutrient restricted from the second trimester until parturition. Neonatal nutrition may not only alleviate the effects of fetal programming, but can also have its own programming effect. Altering tissue growth through dietary supplementation of neonatal calves may be difficult as they are still nursing (Du et al., 2010); however, milk composition has been shown to alter calf growth.

Colostrum is the first milk that a neonate consumes and it provides the newborn with nutrients, vitamins, immunoglobulins, hormones, growth factors, cytokines and biologically active peptides (Campana and Baumrucker, 1995; Blum and Hammon, 2000; Blum, 2006; Gauthier et al., 2006; Blum and Baumrucker, 2008; Hammon et al., 2013). Colostrum promotes villus size and/or mucosal cell proliferation in the enterocyte (Bühler et al., 1988; Blätter et al., 2001; Roffler et al., 2003; Sauter et al., 2004), intestinal glucose absorption (Hammon and Blum, 1997a; Rauprich et al., 2000; Sauter et al., 2004; Steinhoff-Wagner et al., 2011) and can have lasting effects on plasma glucose concentrations (Hadorn et al., 1997; Hammon and Blum, 1998b*;* Rauprich et al., 2000).

Growth and development of the neonate is influenced by milk yield and composition, although most of the research in this area has been performed on neonatal dairy calves fed milk replacer and few have looked at the effects of milk composition on beef calf performance. In beef cows, there is a positive correlation between dam postpartum energy status and calf average daily gain (Perry et al., 1991; Lalman et al., 2000), milk yield and calf average daily gain (Beal et al., 1990), and milk fat and calf average daily gain (Beal et al., 1990; Brown and Brown, 2002**;** Lake et al., 2005). In numerous studies using milk replacer, it has been shown that milk replacer composition, especially increased protein and/or energy increases calf growth, protein accumulation (Bartlett et al., 2006; Diaz et al., 2001), fat deposition (Bascom et al., 2007; Brown et al., 2005) and average daily gain (Gerrits et al., 1996; Tikofsky et al., 2001;

Blome et al., 2003; Hill et al., 2006). In dairy calves, feeding isocaloric milk replacer varying from 16 to 26% crude protein at 1.5% BW resulted in a linear increase in body weight and protein deposition, and more efficient growth (Blome et al., 2003). However, Bartlett et al. (2006) concluded that increased protein concentration of milk replacer was only beneficial if energy supply was adequate.

The source of energy and fatty acid composition of the milk can also play a role in calf growth. Fatty acid length and saturation determine how the fatty acid will benefit the calf. Short chain fatty acids are absorbed by the portal vein and are used by the liver before reaching peripheral circulation (Drackley, 2005; 2008). Butyrate promotes maturation of the gastrointestinal tract through increased rumen papillae development and secretion of digestive enzymes and also increases weight gain (Guilloteau et al., 2009). Butyrate may also have antibacterial effects (Kabara, 1978). Medium chain fatty acids are preferentially oxidized for energy (Hammon et al., 2012). Long chain fatty acids can be oxidized for energy for the heart and skeletal muscle but are primarily deposited in adipose tissue (Drackley, 2005). Polyunsaturated fatty acids also have antimicrobial and antiviral effects (Hristov et al., 2004), and increase cell differentiation (Allen et al., 1985; Hurley et al., 2006), increase bone formation (Watkins et al., 2001), and reduce intestinal inflammation (Caplan et al., 2001).

Holstein bull calves had greater average daily gains when butyrate, canola oil, or a combination of canola and coconut oil were added to milk replacers (Hill et al., 2007a, Hill et al., 2007b; Guilloteau et al., 2009). Elevating levels of specific FA (C4:0, C8:0, C10:0, C12:0, C14:0, C18:3) in milk replacers resulted in more efficient growth and

higher rates of gain and fewer reports of scours (Hill et al., 2007a). Similar results were seen when a similar mixture of FA (C4:0, C8:0, C10:0, C12:0, C14:0, C18:2, C18:3) were added to dairy calf starter (Hill et al., 2007c). Supplementation of flax oil, a good source of linolenic acid (C18:3), in calf starter also improved average daily gain and feed efficiency of Holstein calves (Hill et al., 2009). However, supplementation of fish oil (C20:4, C20:5, C22:6) had no effect on calf growth (Ballouo and DePeters 2008; Hill et al., 2009). Collectively, these studies help highlight the importance of milk composition and fatty acid composition on calf growth.

Feeding DDGS to beef cows during late gestation and early lactation decreased percentage of milk fat and increased milk protein (Winterholler et al., 2012). The calves of these dams were significantly heavier at birth and remained heavier until weaning (Winterholler et al., 2012). In another study, feeding DDGS at 1.2% of BW during late gestation and early lactation to cows led to decreased milk fat, increased MUN, CLA, MUFA and PUFA percentage in the milk (Gunn, 2013). These alterations moderately changed muscle fatty acid composition in later life (Gunn et al., 2012) but there were no other changes in carcass characteristics. However, since the diets were fed during late gestation and early lactation, it is unclear as to whether these changes were due to gestation, lactation, or both. It is reasonable to conclude that these effects were due to a change in milk composition during lactation. As maternal diet is able to influence milk composition, it may therefore be an effective method to positively program calf growth and carcass quality.

1.5 Summary

As corn prices continue to rise, producers will look for alternative feedstuffs to reduce cost of production, and DDGS is one such option. Distiller's grains with solubles have been used extensively in feedlot diets but less is known about feeding DDGS in beef cow diets. Feeding DDGS during late gestation increased birth weights (Radunz et al., 2010; Gunn, 2013). However, the increase in gestation length and birth weight increased dystocia rates (Gunn, 2013), which can be costly to a beef cow-calf herd as it delays rebreeding and may result in the loss of the calf or the cow. The heavier weights of calves whose dams were fed DDGS continued through to weaning. It is known that maternal diet is able to influence long-term growth of the progeny, but because the dams were fed DDGS during both late gestation and early lactation it was unclear if the effect was a result of fetal programming, neonatal programming, or a combination of the two. Because nutrition can alter milk composition and the nutrients in milk influences calf growth, we hypothesized that feeding DDGS to cows during lactation would change milk composition and consequently improve the weaning weight and feedlot performance of the calves and improve cow reproductive performance while avoiding the greater dystocia rates seen by Gunn (2013). We also hypothesized that feeding CDS to cows during gestation or lactation would improve cow performance and calf pre-weaning growth.

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CHAPTER 2. FEEDING DRIED DISTILLER'S GRAINS WITH SOLUBLES DURING LACTATION: I. IMPACT ON COW PERFORMANCE, MILK COMPOSITION AND PRE-WEANING PROGENY PERFORMANCE

2.1 Abstract

Multiparous Angus x Simmental cows (n = 54, 5.22 ± 2.51 yr) with male progeny were fed one of two diets supplemented with dried distiller's grains with solubles (DDGS) or soybean meal (CON), from calving until mid-lactation to determine effects of DDGS on cow performance, milk composition and calf growth. Diets were isocaloric (0.95 Mcal/kg NE_g) and consisted of rye hay supplemented with DDGS at 1% of BW (19.4% CP; 8.76% fat), or corn silage and rye hay supplemented with SBM (11.7% CP; 2.06% fat). Cow-calf pairs were allotted by calf birth date, birth weight and breed and by cow age and breed. At the termination of the trial at 129 d post-partum (dpp), treatment groups were combined and managed as one group. Calf birth weights did not differ (P = 0.93). Cow BW ($P \geq 0.43$) and BCS ($P \geq 0.13$) were similar throughout the study. A weigh-suckle-weigh was performed on 64 and 110 ± 10 dpp to determine milk production. Milk was collected on 68 and 116 ± 10 dpp for analysis of milk components. Milk production on 64 and 110 dpp was unaffected ($P \geq 0.75$) by dietary treatments. Milk urea nitrogen was increased at both time points when cows were fed DDGS ($P < 0.001$). Protein was decreased ($P < 0.001$) and fat was increased ($P < 0.001$) in milk from DDGS fed cows on d

68 dpp. Distiller's grains with solubles did not influence the percentage of short chain fatty acids (FA) in milk ($P \geq 0.13$), but did decrease medium chain FA ($P < 0.01$) and increase long chain FA ($P < 0.01$) at both time points. Saturated FA content of milk was decreased ($P < 0.01$) on 68 and 116 dpp in DDGS cows, which resulted in an increase in monounsaturated FA ($P < 0.01$) and polyunsaturated FA ($P < 0.01$), including conjugated linoleic acid (CLA; $P < 0.01$). Average daily gain of the DDGS calves was increased ($P < 0.01$) throughout the study, resulting in heavier BW at the termination of dietary treatments on d 129 ($P < 0.01$). Average daily gain from d 129 to weaning at d 219 did not differ ($P = 0.90$) between treatments, but the heavier weights of DDGS calves was maintained through weaning ($P < 0.01$). Timed artificial insemination (TAI) rates were greater for cows fed DDGS ($P < 0.02$), but dietary treatment had no effect on overall pregnancy rates ($P = 0.64$). In summary, feeding DDGS to lactating beef cows did not change BW, BCS, or pregnancy rates, but did improve TAI rates and altered milk composition. As a result, cows fed DDGS during lactation bred back sooner and produced male progeny that had greater ADG through 129 d and were heavier at 129 d and at weaning. Feeding DDGS to cows could be used as a method to program the neonate for improved long-term growth.

2.2 Introduction

During certain periods of the yearly production cycle, grass and/or baled hay do not provide adequate amounts of energy and/or protein to meet the nutritional demands of beef females. These periods include the last trimester of pregnancy, when

nutrients are needed for fetal and placental growth, and following parturition, when increasing milk production necessitates greater nutritional inputs. Failure to meet these requirements can result in a significant reduction in cow condition and reproductive performance, as well as progeny growth.

Feed costs are the single largest expense of a cow-calf operation. Between 2011 and 2012, purchased and harvested feed consisted of 24% of total operation costs and 75% of total feed costs (USDA ERS, 2013). Most of this cost came from purchasing or harvesting hay. Studies have demonstrated that limit-feeding corn to gestating cows does not alter performance compared to feeding hay or stockpiled forages (Loerch et al., 1996; Schoonmaker et al., 2003) and that corn was a more economical source of energy. However, corn is no longer an economical alternative, as corn price has increased from an average of to $2.71 per bushel in 1996 to $4.26 in 2003 to $6.22 per bushel in 2011 (USDA, 2013) . Increased demand for corn for ethanol production is largely responsible for increasing corn prices. Dried distiller's grains with solubles (DDGS) is a co-product of ethanol production that is high in protein and energy, and may be a more economical source of energy than corn for the beef cow herd. Furthermore, feeding DDGS to pregnant and lactating cows could have long-term benefits for progeny through developmental programming (Gunn, 2013).

Developmental programming is the concept that conditions during pregnancy (fetal programming) or lactation (lactational or neonatal programming) can have long-term consequences for the progeny (Barker et al., 2012). While fetal programming was first observed in humans, this phenomenon has also been observed in cattle and can

impact production characteristics (Wu et al., 2006). Feeding DDGS during late gestation to beef cows has increased progeny birth weights compared to cows fed hay (Radunz et al., 2010; Wilson et al., 2012) and progeny remained heavier through weaning (Radunz et al., 2012). When DDGS was fed as an energy source to beef heifers during late gestation and early lactation, calves were heavier at both birth and weaning compared to calves whose dams were not fed DDGS (Gunn, 2013). It was speculated in that study that the increase in progeny weight gain was attributed to an alteration in milk composition. It is unclear what component in milk may have caused an increase in progeny ADG; however, DDGS increased the percentage of long chain fatty acids (LCFA) and polyunsaturated fatty acids (PUFAs) in the milk. In pre-ruminant calves, LCFA oxidation provides less than 20% of total energy and most LCFA are deposited in adipose tissue (Drackley, 2005). Conversely, PUFAs increase oxidation, decrease adipose deposition and increase insulin sensitivity (Clarke, 2000). As the study by Gunn (2013) was conducted through late gestation and early lactation, it is unclear if increased growth for progeny of DDGS fed cows was due to fetal programming or lactational programming, through changes in dam milk composition. Furthermore, increases in birth weight for progeny of DDGS fed cows in Gunn (2013) resulted in increased calving difficulty. Therefore, our objective was to evaluate the performance of the dams fed DDGS from calving to mid-lactation and to characterize the growth of their progeny. Our hypothesis was that feeding DDGS from calving until mid-lactation would improve the reproductive performance of the cows, alter the composition of the milk, and consequently improve the growth of male calves.

2.3 Materials and methods

2.3.1 Animals and diets

The study was conducted at the Purdue Animal Sciences Research and Education Center in West Lafayette, IN and all procedures were approved by the Purdue Animal Care and Use Committee. Angus x Simmental cows (n = 54, BCS = 5.17 ± 0.06, BW = 653 ± 9 kg, age = 5.22 ± 2.51 yr) with male progeny were used in a complete randomized design to determine effects of DDGS on cow performance, milk composition and calf growth when fed from calving to mid-lactation.

Cow-calf pairs were allotted at within 1 week of calving by calf birth date, birth weight, breed, and cow age. Cow-calf pairs were placed in one of two pastures according to their dietary treatment. Diets were isocaloric (0.95 Mcal/kg NE_g) and were formulated to meet or exceed NRC (1996) protein, energy, and mineral requirements for lactation (Table 1)**.** Diets consisted of 45.3% rye hay and 53% DDGS on a DM basis (DDGS; n = 27) or 25.5% rye hay, 65.1% corn silage and 8.5% soybean meal on a DM basis (CON; n = 27). Diets differed in CP (19.4% DDGS vs. 11.7% CON) and fat (8.8% DDGS vs. 2.1% CON) due to the composition of DDGS. Dry matter intake was targeted to be similar between treatments (15.0 kg DDGS vs. 15.2 kg CON). All diets were formulated using individual ingredient chemical composition analyses obtained by wet chemistry methods (AOAC, 1990) prior to the beginning of the trial (Sure-Tech Laboratories, Indianapolis, IN). Rye bales were weighed before delivery and were fed ad libitum in a hay ring. Dried distiller's grains with solubles and mineral for the DDGS diet, and corn silage, SBM, and mineral for the CON diet were mixed and offered to cows

once daily in concrete bunks at approximately 0800. Feed samples were collected and composited for analysis of DM, CP, ether extract, fatty acids, and minerals. Dry matter was calculated by drying feed ingredients in a forced air oven at 60 °C for 72 hours.

Dietary treatments were terminated at 129 ± 10 dpp and cow-calf pairs were placed on pasture and managed as one group until weaning at 219 ± 10 dpp. Initial and final BW was determined by taking the average pre-prandial weights taken on two consecutive days. Subsequent BW and BCS (1 = emaciated, 9 = obese; Wagner et al., 1988) were assessed monthly throughout the treatment period. Body condition scoring was conducted by the same investigator at all time points throughout the study. Calf weights were recorded the same day as cows and were used to calculate calf ADG.

2.3.2 Milk

Milk production was measured on 64 and 110 ± 10 dpp through a twelve hour weigh-suckle-weigh procedure (Buskirk et al., 1992). Calves were separated from their dams at 0000, allowed to nurse at 0600, and then separated until 1200. At 1200, calves were weighed before nursing and were re-weighed immediately after suckling ceased. The weigh-suckle-weigh procedure was repeated at 1800. The difference in calf weight before and immediately after nursing was calculated as the milk production for the six hour period. Milk production at 1200 and 1800 were added together then multiplied by two to estimate 24 hour milk production. During separation, cows were returned to their pasture where they had access to feed and water and calves were penned in groups of 4 or 5 and were denied dry feed and water throughout the procedure.

Before feeding on 68 and 116 ± 10 dpp, cows and calves were separated for 3 hours and milk was totally collected from one quarter of the udder of each cow by hand-milking. Milk was placed in a vial containing methylene blue and shipped to Dairy One Cooperative (Ithaca, NY) for analysis of protein, fat, lactose, total solids, and milk urea nitrogen (MUN). A second sample was transferred to a 50-mL polystyrene conical tube (BD Falcon, San Jose, California) and stored at - 20 ° C for analysis of fatty acid composition.

2.3.3 Fatty acid analysis

Total lipid was extracted from feed or milk with a solution of chloroform and methanol (2:1) according to the procedures of Folch et al. (1957) and derivatized to fatty acid methyl esters according to Li and Watkins (1998). Fatty acid methyl ethers were analyzed by gas chromatography (GC; model 3900, Varian) equipped with a 30 m column (Varian CP-WAX 52 CB, Varian Inc., Palo Alto, CA) and a flame ionization detector. Samples were run in duplicate, and fatty acid percentage was calculated by averaging the duplicate values for each fatty acid and dividing the individual fatty acid peak areas by the aggregate area. Short chain fatty acids (SCFA) were classified as C4:0 to C8:0, medium chain fatty acids (MCFA) as C10:0 to C15:0 and long chain fatty acids (LCFA) as those ≥ C16:0.

2.3.4 Estrous synchronization and breeding

Cows were synchronized using the 5 d CO-Synch + CIDR protocol and time-artificially inseminated (TAI) in May of 2011. Cows were placed with a bull 10 d after TAI for the remainder of the 60 d breeding season. Cows were ultrasounded (Variable MHz linear array transducer, MicroMaxx, Sonosite, Bothell, WA) 30 and 90 d after TAI to determine conception and overall pregnancy, respectively.

2.3.5 Blood urea nitrogen

Blood samples were taken from cows and calves one day prior to termination of treatment for analysis of blood urea nitrogen (BUN). Blood samples were collected in BD Vacutainer tubes containing 158 USP Sodium Heparin (Becton Drive, Franklin Lakes, NJ), inverted, then placed on ice until centrifugation at 3000 x g for 20 min at 4 ° C. Plasma was separated and stored at -20 ° C until analysis of BUN, using a commercial kit (Stanbio Urea Nitrogen Procedure No. 0580, Stanbio Laboratory, Boerne, TX). Samples were read at 530 nm in an Opsys MR microplate reader (Dynex Technologies Inc., Chantilly, VA). The intra-assay CV was 6.61% and the inter-assay CV for a control sample containing 30 mg/dL of urea nitrogen was 2.15%.

2.3.6 Statistical analysis

Timed-artificial insemination and pregnancy rates were calculated using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC). Cow BW, BCS, milk production, milk composition, milk fatty acid profile, and calf BW and ADG were analyzed using the MIXED procedure of SAS for repeated measures. The covariance structures

autoregressive order one, heterogeneous autoregressive order one, unstructured, and compound symmetric were compared and the covariance structure with the smallest Bayesian information criterion was chosen for analysis of results. The model included the fixed effects of treatment and day, as well as the appropriate treatment × day interaction. Simple effects within day were generated using the SLICE function of SAS. Blood urea nitrogen was analyzed using the MIXED procedure of SAS as a completely randomized design. Animal served as the experimental unit. For all variables analyzed, a *P*-value ≤ 0.05 was identified as significant and 0.05> *P* ≤ 0.10 was identified as a tendency approaching significance.

2.4 Results

2.4.1 Cow performance

Cow BW (*P* ≥ 0.43) and BCS (*P* ≥ 0.13) did not differ for the duration of the study (Table 2). Timed-artificial insemination rates were greater in cows fed DDGS compared to cows fed CON (*P* = 0.02; 81.5% vs. 48.1%), although there were no differences in overall pregnancy rates (*P* = 0.64).

2.4.2 Milk

Dried distiller's grains with solubles did not influence milk production on either 64 or 110 dpp (*P* ≥ 0.75) as determined by the weigh-suckle-weigh procedure (Table 3). The high level of CP (19.4%) in the DDGS diets increased BUN (*P* < 0.001) as well as MUN (*P* < 0.001) of cows. Milk protein was decreased on 68 dpp (*P* < 0.001), yet tended to be greater on 116 dpp (*P* = 0.07) for cows fed DDGS. Cows fed DDGS had a greater

percentage of milk fat on 68 dpp ($P < 0.001$), but not on 116 dpp ($P = 0.34$). Dietary treatment also had no effect on total solids ($P \geq 0.88$) or lactose ($P \geq 0.28$) on either day.

Feeding DDGS resulted in an increase in long chain fatty acids (≥C16:0; $P < 0.001$) in cows' milk and a decrease in medium chain fatty acids (C10:0 to C15:0; $P < 0.001$) on 68 and 116 dpp, but did not change the amount of short chain fatty acids (C4:0 to C8:0; $P \geq 0.13$) in milk on either 68 (Table 4) or 116 (Table 5) dpp. Polyunsaturated fatty acid (PUFA) and monounsaturated fatty acid (MUFA) content of milk were increased ($P \leq 0.01$) due to DDGS supplementation, and concentration of saturated fatty acids (SFA) were consequently decreased ($P < 0.001$) on both 68 and 116 dpp. The concentration of cis-9, trans-11 conjugated linoleic acid (CLA) was increased 2-fold on 68 dpp ($P < 0.001$) and 3.6-fold on d 116 dpp ($P < 0.001$). The n-3:n-6 ratio was decreased on 68 dpp ($P < 0.001$), but was not affected on 116 dpp.

2.4.3 Pre-weaning progeny performance

As designed, there were no differences in progeny birth weight ($P = 0.93$; Table 6). However, calves whose dams were fed DDGS had a greater ADG ($P < 0.01$), were heavier by d 110 ($P = 0.02$) and were 15.2 kg heavier at treatment termination on d 129 ($P < 0.01$). Average daily gain from d 129 to weaning at d 219 was similar ($P = 0.90$), however the weight difference between DDGS and CON progeny remained, thus DDGS calves were heavier at weaning on d 219 ($P < 0.01$; 278 vs. 264 kg).

2.5 Discussion

2.5.1 Cow performance

The objective of this study was to assess the performance of calves and cows when the dams were fed DDGS as a primary energy source, at an energy concentration similar to a corn silage/soybean meal based control diet from early to mid-lactation. Dietary intakes were similar, although diets differed in source of energy, amount of starch and fat, and amount of CP. Previous research has demonstrated that source of energy and amount of protein promotes (Radunz et al., 2010) or does not impact cow weight gain (Gunn, 2013). Although Radunz et al. (2010) saw no visual differences in body condition scores, ultrasound revealed that cows fed DDGS gained more back fat compared to those fed hay and suggested that energy was partitioned to subcutaneous fat deposition. In contrast, Gunn (2013) reported that feeding DDGS during late gestation did not increase BCS whereas control diets did. It was hypothesized by Gunn (2013) that the lack of increase in BCS by feeding DDGS was due to a shift in location of fat deposition, where internal fat was deposited rather than subcutaneous fat. Such a change in fat location may be caused by the metabolic cost of excess nitrogen being metabolized, as diets fed by Gunn (2013) contained protein at 182% of protein requirements. Reynolds (1992) reported that excreting excess nitrogen in urine requires one ATP. The distiller's diets fed by Radunz et al. (2010) were only fed at 155% of protein requirements. A change in location of fat metabolism is also supported by data from Depenbusch et al. (2009) who observed a linear decrease in 12^{th} rib fat along with a quadratic increase in internal fat when feedlot heifers were fed from 0 to 75% DDGS

on a DM basis. It appears from our data that DDGS does not decrease subcutaneous fat stores (as measured by BCS) as dramatically as when it is fed during lactation.

Previous research with feeding DDGS during gestation has been inconclusive as to an effect on reproduction. Studies with heifers have reported a decrease in postpartum anestrous when feeding 40-50% DDGS during late gestation (Engel et al., 2008) or when feeding 43% DDGS during late gestation and early lactation (Gunn, 2013). Pregnancy rates have improved for some studies when DDGS was fed during late gestation (Engel et al., 2008), but TAI and overall pregnancy rates have not been altered in other studies when DDGS was fed during late gestation (Radunz et al., 2010) or during early lactation (Shike et al., 2009). Gunn et al. (2012) observed an increase in TAI when DDGS was fed as an energy source, and noted that DDGS increased follicle wavelengths, increased follicle diameters, and decreased the anestrous period compared to control fed cows (Gunn, 2013). In the current study, supplementation of DDGS during lactation may have decreased the anestrous period, and helped the cows to resume cyclicity sooner than those fed SBM, thus allowing greater conception rates to TAI. In this study, both fat, PUFA, and protein levels were elevated in the DDGS diets and it has been proposed that fat supplementation (Santos et al., 2008); fatty acid composition, specifically PUFAs (Staples et al., 1998; Mattos et al., 2000); and CP levels, specifically RUP (Martin et al., 2007), or a combination of both fat and CP (Engel et al., 2008) improve reproductive performance. The specific nutrient and the mechanism by which

fat, PUFAs, protein, or their combination increase TAI conception rates remains to be elucidated.

2.5.2 Milk

In accordance with previous research feeding beef cows and heifers DDGS at isocaloric concentrations similar to control diets (Radunz et al., 2012; Gunn, 2013), DDGS in the present study had no effect on milk production on either 64 or 110 dpp. However, Shike et al. (2009) reported a decrease in milk production when multiparous and primiparous cows were limit-fed a 55% DDGS diet at an energy concentration isocaloric with a control diet containing 57% corn gluten feed. The decrease in milk production from DDGS supplementation observed by Shike et al. (2009) was attributed to a shift in energy partitioning from milk to BW, as the DDGS cows lost less weight than control cows. Winterholler et al. (2012) observed a tendency for increased milk production in multiparous and primiparous cows with increased inclusion of DDGS, which may have been due to the increased energy intake in DDGS fed cows. Studies in Holstein cows are also inconsistent, as some studies have shown no change (Abelqader et al., 2009) or an increase in milk yield (Anderson et al., 2006) when DDGS were included in diets at an energy concentration isocaloric with control diets.

The high level of CP (19.4%) in the DDGS diets in the current study resulted in an increase in BUN as well as MUN. Urea in the blood diffuses into the milk and thus the concentration of BUN is proportional to the concentration of MUN (Roseler et al., 1993)

and is a reflection of excess dietary protein. Milk protein was decreased in DDGS cows on d 68 ± 10 dpp, but tended to be higher in DDGS cows on 116 ± 10 dpp**.** Winterholler et al. (2012) observed an increase in milk protein percentage as the percentage of DDGS inclusion increased. Other studies (Anderson et al., 2006; Abdelqader et al., 2009; Shike et al., 2009; Gunn, 2013) have reported no differences in milk protein percentages when cows were fed DDGS compared to those fed control diets. Similar to the current study, Gunn (2013) and Abdelqader et al. (2009) observed no differences in milk protein percentages but an increase in MUN when cows were fed DDGS compared to cows fed control diets. Anderson et al. (2006) reported lower MUN and no differences in milk protein percentage when Holsteins were fed DDGS instead of a control diet. A slight decrease in milk protein percentage was seen when beef cows were fed DDGS during lactation, but MUN was not affected (Shike et al., 2009). Supplemental fat can decrease microbial protein production (Coppock and Wilks, 1991), thus Shike et al. (2009) suggested that a decrease in milk protein by feeding DDGS may have been due to an increase in dietary fat, as DDGS diets contained 5.8% ether extract and control diets contained 3.0% ether extract. However, although specific dietary amino acids weren't quantified, the DDGS diet may have been limiting in lysine and methionine as feeding DDGS at 55% DMI decreased milk protein and feeding DDGS at 77% DMI did not, and supplementation may have alleviated the protein depression (Coppock and Wilks, 1991).

In the present study, DDGS increased milk fat on 68 ± 10 dpp, but not on d 116 ± 10 dpp. The milk fat percentage on both days were lower than would be expected for an Angus cow based on data of Melton et al. (1967), who recorded 2.68% milk fat for Angus

cows between 2 to 10 years of age. Marston et al. (1992) reported 4.3%, 3.63% and 3.17% milk fat for Angus cows at 60, 106 and 194 dpp, respectively. In Holsteins, it was reported that dietary DDGS causes milk fat depression in some cases (Abelqader et al., 2009), while other studies have shown no effect of dietary DDGS on milk fat (Anderson et al., 2006; Kurokawa et al., 2012). However, inclusion level may have played a role in these studies, as no effects on milk fat percentage were seen when DDGS was included in dairy cow diets at 10 or 20% of the diet DM (Anderson et al., 2006; Kurokawa et al., 2012) as opposed Abelqader et al. (2009) who observed a decrease in milk fat when dairy cows were fed 30% of the diet DM as DDGS. Milk fat was decreased when beef heifers were fed 43% DDGS (Gunn, 2013) and because cows in the present study were fed 53% DDGS, one could expect to see a decrease in milk fat compared to the control diet.

Polyunsaturated fatty acids, MUFAs and CLA were increased in this study and are consistent with previous studies that have fed DDGS to Holsteins (Anderson et al., 2006; Abelqader et al., 2009; Kurokawa et al., 2012) and Angus x Simmental cows (Gunn, 2013). Feeding DDGS also decreased the n3:n6 ratio on d 68 ± 10 dpp which agrees with Gunn (2013), whose samples were collected 64 ± 4 d in milk. Milk fatty acid chain length in the current study was altered in accordance with Gunn (2013), resulting in an increase in LCFA, a decrease in MCFA and no effect on SCFA. Short and medium chain fatty acids are mainly derived from de novo synthesis in the mammary gland, whereas LCFA from are derived from the diet (Bauman and Griinari 2003). Dried distiller's grains with solubles contain elevated PUFA and LCFA, which are protected from ruminal

biohydrogenation (Vander Pol et al., 2009). Additionally, PUFA can hinder de novo synthesis of SCFA and MCFA, resulting in an increased proportion of dietary LCFA in the milk (Bauman and Griinari, 2003).

2.5.3 Pre-weaning progeny performance

Calves whose dams were fed DDGS had a greater ADG through 129 d ($P < 0.01$) and were heavier by treatment termination at d 129. Shike et al. (2009) reported lower calf ADG when dams were fed DDGS during lactation, but this may be accounted for by decreased milk production, and because of a positive correlation between milk yield and calf ADG (Beal et al., 1990; Lake et al., 2005). There were no differences in milk production in the current study, suggesting that the increase in growth may have been due to alterations in milk composition**.** Studies with milk replacer in dairy calves suggest that increasing protein may increase calf body weight and protein deposition (Blome et al., 2003), although protein may only be beneficial if energy supply is adequate (Bartlett et al., 2006). A portion of nitrogen requirements for nursing calves can be met by urea as early as 6 weeks of age (Brown et al., 1956), thus increased MUN in DDGS fed cows may have been responsible for increased growth rates of progeny. Increased fat content of milk also improves calf growth (Brown and Brown, 2002; Lake et al., 2005) and fatty acid composition may be responsible for enhanced calf growth as well. Fatty acids can be oxidized for energy or deposited in adipose tissue depending upon chain length (Hammon et al., 2012; Drackley, 2005). Medium chain fatty acids are primarily oxidized for energy (Hammon et al., 2012) and while LCFA may be oxidized, they are primarily

deposited into adipose tissue (Drackley, 2005). Unsaturated fatty acids may promote growth (Watkins et al., 2001; Hurley et al., 2006) and provide antimicrobial and antiviral effects (Hristov et al., 2004). Increased concentrations of MCFA, PUFAs, particularly C18:3, or butyrate (4:0) in milk replacer increased efficiency and rate of gain in dairy calves (Hill et al., 2007). In the current study, MCFAs were decreased by the DDGS treatment, but LCFAs and PUFAs were increased and may have improved calf growth. Because ADG was similar after the termination of treatment, DDGS calves were persistently heavier through weaning.

In conclusion, feeding DDGS to cows as an energy source from calving until mid-lactation did not affect BW or BCS of the cows. Distiller's grains with solubles improved TAI conception rates, which would allow producers to improve the genetic value of their herd, and result in a higher proportion of calves born early in the calving season, even though DDGS had no influence on overall pregnancy rates at the conclusion of the breeding season. Milk production was not altered, but milk composition and fatty acid profile were modified by DDGS, resulting in greater weaning weights of calves from dams fed DDGS. Adding DDGS to cow diets after calving yielded similar results to Gunn (2013), including improved TAI rates and increased calf gain, while preventing the high rates of dystocia seen when DDGS was fed during late gestation. In summary, feeding DDGS to lactating cows may be a useful method for improving TAI rates and calf growth through weaning.

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Table 2.2.1 Diet composition

	Treatment[1]	
	CON	DDGS
	---% DM basis---	
Corn silage	65.10	-----
Rye Hay	25.50	45.30
Dried distiller's grains with solubles (DDGS)	-----	53.00
Soybean meal	8.50	-----
Mineral supplement[2]	0.90	1.00
Limestone	-----	0.70
Nutrient composition[3]		
Crude protein, %	11.72	19.43
Fat, %	2.06	8.76
NE_m, Mcal/kg	1.55	1.56
NE_g, Mcal/kg	0.95	0.95
Calcium, %	0.48	0.53
Phosphorus, %	0.33	0.40
Potassium, %	1.46	2.10
Sulfur, %	0.12	0.38
DMI, kg/d	15.00	15.20

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

[2]Vitamin/mineral pre-mix contained (DM basis): 11.0% Ca, 5.0% P, 2.0% Mg, 2.0% K 40 ppm Co, 1000 ppm Cu, 3000 ppm Mn, 27 ppm Se, 3700 ppm Zn, 400 IU/g vitamin A, 40 IU/g vitamin D, 200 IU/kg vitamin E.

[3]Analyzed by Sure-Tech Laboratories, Richmond, IN

Table 2.2.2 Effect of diet from calving until 129 ± 10 d post-partum on cow weight, body condition score and pregnancy rates

	Dietary Treatment[1]			
	CON	DDGS	SEM	*P*-Value
Weight, kg				
Day 29	653.5	653.1	12.21	0.98
Day 129	660.5	653.5	12.21	0.69
Day 219	622.0	615.1	12.21	0.69
BCS				
Day 29	5.20	5.20	0.091	0.83
Day 129	5.30	5.00	0.091	0.13
Day 219	4.90	4.90	0.091	0.63
Timed artificial insemination, %	48.1	81.48	-----	0.02
Pregnancy, %	92.6	88.89	-----	0.64

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

Table 2.2.3 Effect of diet from calving until 129 ± 10 d post-partum on milk production and milk composition[1]

	Dietary Treatment[2]			
	CON	DDGS	SEM	*P*-Value
Milk production, kg/d				
64 ± 10 d	10.14	10.41	0.673	0.78
110 ± 10 d	8.32	8.00	0.673	0.75
ECM production, kg/d[4]				
68 ± 10 d	6.31	6.65	0.496	0.63
116 ± 10 d	6.28	5.68	0.488	0.40
Milk fat, %				
68 ± 10 d	0.49	0.83	0.056	<0.001
116 ± 10 d	1.50	1.26	0.175	0.34
Milk protein, %				
68 ± 10 d	3.4	3.0	0.05	<0.001
116 ± 10 d	3.3	3.5	0.09	0.069
Milk lactose, %				
68 ± 10 d	5.1	5.2	0.04	0.28
116 ± 10 d	4.9	4.9	0.04	0.96
Milk total solids, %				
68 ± 10 d	9.9	9.9	0.09	0.9
116 ± 10 d	10.7	10.8	0.17	0.88
Milk urea N, mg/dL				
68 ± 10 d	8.0	12.1	0.37	<0.001
116 ± 10 d	9.0	13.8	0.38	<0.001

[1]Samples collected 64 ± 10 and 110 ± 10 d post-partum and analyzed by Dairy One Cooperative Inc., Ithaca, NY

[2]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

[4]Energy corrected milk (ECM) = (0.3246 x kg milk/d) + (12.86 x kg milk fat/d) + (7.04 kg milk protein/d)

Table 2.2.4 Effect of diet from calving until 129 ± 10 d post-partum on 68 ± 10 d postpartum milk fatty acid composition (g/100 g)

	Treatment[1]			
Fatty Acid[2]	CON	DGGS	SEM	P-Value
C4:0	1.08	0.42	0.464	0.32
C6:0	0.36	0.29	0.055	0.34
C8:0	0.74	0.34	0.167	0.10
C10:0	1.95	1.43	0.109	<0.01
C12:0	3.56	2.22	0.137	<0.001
C14:0	11.25	7.91	0.290	<0.001
C14:1	0.35	0.63	0.058	<0.001
C14iso1	0.30	0.30	0.013	0.90
C14iso2	0.46	0.42	0.020	0.16
C15:0	1.30	0.92	0.042	<0.001
C15:1	0.30	0.27	0.024	0.49
C16:0	37.65	24.34	1.298	<0.001
C16:1	2.78	1.30	0.088	<0.001
C16:2	0.73	0.61	0.794	0.31
C16:3	0.73	0.36	0.104	0.01
C17:0	0.56	1.06	0.416	0.40
C17:1	0.38	1.36	0.802	0.39
C18:0	6.13	14.68	0.516	<0.001
C18:1n9	21.87	27.78	1.202	<0.01
C18:1n7	0.43	2.67	0.465	<0.001
C18 Isomer	0.25	0.28	0.066	0.73
C18:2n6	1.73	3.84	0.211	<0.001
C18:3n6	0.23	0.10	0.032	0.01
C20:0	0.04	0.17	0.051	0.08
C18:3n3	0.33	0.21	0.022	<0.01
C18:2 9,11	1.05	2.25	0.123	<0.001
C18:2 10,12	0.04	0.01	0.014	0.17
C20:1n9	0.05	0.14	0.024	0.01
C20:2	0.03	0.18	0.019	<0.001
C20:3	0.10	0.23	0.045	0.04
C20:4	0.43	0.67	0.179	0.35
C20:5n3	0.17	0.24	0.065	0.49

C20:5	0.33	0.20	0.037	0.02
C22:0	0.18	0.20	0.060	0.83
C22:1	0.16	0.12	0.091	0.80
C22:4n6	0.07	0.11	0.040	0.52
C22:5	1.11	1.32	0.239	0.54
C24:0	0.16	0.26	0.128	0.59
C22:6	0.36	0.46	0.087	0.45
SCFA[3]	2.48	1.32	0.518	0.13
MCFA[4]	20.12	14.81	0.519	<0.001
LCFA[5]	77.40	83.87	0.958	<0.001
SFA[6]	65.25	54.95	1.027	<0.001
MUFA[7]	27.31	34.28	0.754	<0.001
PUFA[8]	7.45	10.77	0.735	<0.01
PUFA/SFA	0.12	0.20	0.013	<0.001
MUFA/SFA	0.43	0.63	0.019	<0.001
UFA/SFA	0.54	0.83	0.030	<0.001
Omega-3 FA	1.39	0.89	0.147	0.02
Omega-6 FA	0.35	0.46	0.087	0.41
Omega-3/Omega-6	5.96	2.44	0.452	<0.001

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with
solubles used as an energy source
[2] g/100 g of fatty acids
[3] Short chain fatty acids (C4:0 to C8:0)
[4] Medium chain fatty acids (C10:0 to C15:0)
[5] Long chain fatty acids (C16:0 and above)
[6]Saturated fatty acids
[7]Monounsaturated fatty acids
[8]Polyunsaturated fatty acids

Table 2.2.5 Effect of diet from calving until 129 ± 10 d post-partum on 116 ± 10 d postpartum milk fatty acid composition (g/100 g)

	Treatment[1]			
Fatty Acid[2]	CON	DDGS	SEM	P-Value
C4:0	0.76	0.25	0.464	0.43
C6:0	0.46	0.18	0.055	<0.01
C8:0	0.27	0.27	0.167	0.88
C10:0	2.05	1.07	0.109	<0.001
C12:0	3.22	1.98	0.137	<0.001
C14:0	11.27	7.53	0.290	<0.001
C14:1	1.47	0.84	0.050	<0.001
C14iso1	0.45	0.34	0.016	<0.001
C14iso2	0.63	0.52	0.019	<0.01
C15:0	1.13	0.94	0.043	0.03
C15:1	0.35	0.24	0.024	<0.01
C16:0	37.65	23.18	1.298	<0.001
C16:1	2.94	1.45	0.088	<0.001
C16:2	0.75	0.61	0.015	<0.001
C16:3	0.65	0.51	0.016	<0.001
C17:0	0.61	0.54	0.016	<0.01
C17:1	0.51	0.29	0.016	<0.001
C18:0	5.96	13.22	0.516	<0.001
C18:1n9	22.39	29.68	0.845	<0.001
C18:1n7	1.27	4.33	0.299	<0.001
C18 Isomer	0.23	0.38	0.039	0.01
C18:2n6	1.94	4.18	0.143	<0.001
C18:3n6	0.23	0.18	0.034	0.35
C20:0	0.04	0.09	0.051	0.47
C18:3n3	0.52	0.25	0.022	<0.001
C18:2 9,11	0.94	3.42	0.083	<0.001
C18:2 10,12	0.01	0.04	0.014	0.15
C20:1n9	0.08	0.21	0.024	<0.01
C20:2	0.11	0.28	0.019	<0.001
C20:3	0.11	0.24	0.045	0.03
C20:4	0.38	0.37	0.050	0.89
C20:5n3	0.12	0.17	0.065	0.61

C20:5	0.33	0.29	0.037	0.36
C22:0	0.09	0.15	0.060	0.49
C22:1	0.04	0.07	0.150	0.12
C22:4n6	0.05	0.13	0.030	0.08
C22:5	1.02	1.08	0.239	0.86
C24:0	0.17	0.12	0.032	0.29
C22:6	0.28	0.51	0.018	<0.001
SCFA[3]	1.85	0.90	0.518	0.26
MCFA[4]	20.23	13.25	0.519	<0.001
LCFA[5]	77.92	85.85	0.606	<0.001
SFA[6]	63.48	50.72	0.808	<0.001
MUFA[7]	29.06	37.00	0.754	<0.001
PUFA[8]	7.46	12.28	0.342	<0.001
PUFA/SFA	0.12	0.24	0.013	<0.001
MUFA/SFA	0.47	0.73	0.020	<0.001
UFA/SFA	0.59	0.98	0.024	<0.001
Omega-3 FA	1.50	1.18	0.147	0.14
Omega-6 FA	0.63	0.51	0.022	<0.01
Omega-3/Omega-6	2.44	2.42	0.257	0.94

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source
[2] g/100 g of fatty acids
[3] Short chain fatty acids (C4:0 to C8:0)
[4] Medium chain fatty acids (C10:0 to C15:0)
[5] Long chain fatty acids (C16:0 and above)
[6]Saturated fatty acids
[7]Monounsaturated fatty acids
[8]Polyunsaturated fatty acids

Table 2.2.6 Effect of diet from calving until 129 ± 10 d post-partum on calf weight and average daily gain

	Dietary Treatment[1]			
	CON	DDGS	SEM	*P*-Value
Weight, kg				
Birth	41.0	41.4	3.86	0.93
Day 29	77.1	81.5	3.86	0.43
Day 64	116.6	124.0	3.86	0.18
Day 129	190.2	205.4	3.86	<0.01
Day 219	263.5	278.0	3.86	<0.01
ADG, kg/d				
0-129	1.1	1.3	0.059	<0.01
129-219	0.8	0.8	0.059	0.85
0-219	1.0	1.1	0.059	<0.05

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

Table 2.7 Effect of diet from calving until 129 ± 10 d post-partum on cow and calf blood urea nitrogen on d 128[1]

	Treatment[2]			
	CON	DDGS	SEM	*P*-Value
Cow BUN	9.53	15.88	1.071	<0.001
Calf BUN	8.69	13.16	0.562	<0.001

[1]One day prior to termination of dietary treatment

[2]CON = Soybean meal supplemented as an energy source; DDGS = dried distiller's grains with solubles used as an energy source

CHAPTER 3. FEEDING DRIED DISTILLER'S GRAINS WITH SOLUBLES DURING LACTATION: II. IMPACT ON FEEDLOT PERFORMANCE, GLUCOSE TOLERANCE AND CARCASS CHARACTERISTICS OF STEER PROGENY

3.1 Abstract

Feeding dried distiller's grains with solubles (DDGS), a feed high in fat and protein, to lactating beef cows can alter milk production and composition, resulting in improved pre-weaning growth of progeny. This alteration in milk profile may consequently alter the growth and carcass composition of the offspring after weaning. Therefore, Angus x Simmental steers (n = 48) whose dams were fed one of two diets supplemented with either DDGS or soybean meal (SBM) from calving to mid-lactation were placed in a feedlot to determine the effects of maternal nutrition during lactation on progeny development and carcass composition. Cow-calf pairs were allotted to treatments at birth by cow and calf BW, breed and age. Maternal diets were isocaloric (0.95 Mcal/kg NE_g) and consisted of rye hay supplemented with DDGS at 1% of BW (19.4% CP; 8.76% fat) or rye hay and corn silage supplemented with SBM (11.7% CP; 2.06% fat). After conclusion of the treatments at 129 d postpartum (dpp), cow-calf pairs were co-mingled and managed as one group until weaning at 219 dpp. Steers were then transitioned to a common diet composed of 60% DDGS, 34% corn silage and 6%

vitamin/mineral supplement until 256 dpp, when steers were placed indoors in individual pens with slatted floors. A glucose tolerance test was performed 134 d after feedlot entry on 16 steers (CON n = 7; DDGS n = 9) to determine the effect of maternal diet on glucose and insulin clearance. Steers were slaughtered at a target BW of approximately 591 kg. Categorical and continuous data were analyzed using the GLIMMIX and MIXED procedures of SAS, respectively. Initial BW at feedlot entry was 287.7 kg for SBM and 296.1 kg for DDGS steers ($P = 0.18$). Days on feed ($P = 0.42$), ADG ($P = 0.93$), daily DMI ($P = 0.76$) and overall feed efficiency ($P = 0.90$) did not differ between treatments. Glucose ($P \geq 0.17$) and insulin ($P \geq 0.16$) clearance were not affected by maternal nutrition nor was glucose area under the curve ($P = 0.27$), insulin area under the curve ($P = 0.37$), or the glucose to insulin ratio ($P = 0.40$). Hot carcass weight ($P = 0.54$), dressing percent ($P = 0.50$), fat thickness ($P = 0.71$), LM area ($P = 0.17$), percent kidney pelvic heart fat ($P = 0.31$) and yield grade ($P = 0.19$) were not affected by maternal diet. Marbling score was decreased ($P = 0.04$) by maternal DDGS supplementation, but did not influence percentage of carcasses grading choice or greater ($P = 0.39$). In summary, feeding DDGS to lactating cows did not affect post-weaning growth of steer progeny; however, marbling was decreased in steers whose dams were fed DDGS.

3.2 Introduction

Developmental programming is the idea that maternal nutrition during gestation (fetal programming) and/or lactation (neonatal programming) can influence

development and health of progeny in later life, specifically with regard to cardiovascular and endocrine disorders (Barker et al., 2012). While first observed in humans, this effect has also been observed in livestock and can impact production characteristics (Wu et al., 2006). Previous research in sheep has shown that both maternal supplementation of distiller's grains from mid-gestation until parturition decreased insulin sensitivity and increased adipose deposition in lambs (Radunz et al., 2011). In cattle, feeding DDGS during late gestation increased marbling compared to steers whose dams were fed hay (Radunz et al., 2012). However, Radunz et al. (2012) observed no change in overall insulin sensitivity, indicating that maternal diet could have more of an effect on adipose tissue deposition than postnatal nutrition.

When dried distiller's grains with solubles (DDGS) was fed as an energy source to 2-yr old cows during late gestation and early lactation, calves were heavier at both birth and weaning compared to those fed silage (Gunn, 2013). Increased birth weight was attributed to increased gestation length and pre-weaning growth was attributed to an alteration in fatty acid composition of milk, as DDGS increased the percentage of long chain fatty acids (LCFA) and polyunsaturated fatty acids (PUFA) in the milk (Gunn, 2012a). These alterations in composition of milk intake influenced LM fatty acid profile of steer progeny at slaughter, increasing the proportion of stearic (C18:0) and eicosenoic (C20:1 n-9) acids and decreasing myristoleic (14:1) and palmitoleic (16:1) acids in progeny whose dams were fed DDGS (Gunn et al., 2012a). In contrast, other studies have reported that maternal diet has no effect on composition of growth (Wilson, 2012).

Our previous study demonstrated that feeding DDGS to cows from calving until mid-lactation improved the pre-weaning performance of their calves (Chapter 2). However, the effects of maternal supplementation of DDGS during lactation on long-term progeny performance in the feedlot is unknown. Our hypothesis was that feeding DDGS to dams from calving until mid-lactation would have a long-term impact on metabolism and improve the post-weaning performance and carcass composition of the offspring. Our objective was to characterize feedlot performance, glucose tolerance, and carcass characteristics of the progeny whose dams were fed DDGS from calving until mid-lactation.

3.3 Materials and methods

3.3.1 Animals and diets

The study was conducted at the Purdue Animal Sciences Research and Education Center in West Lafayette, IN and all procedures were approved by the Purdue Animal Care and Use Committee. Angus x Simmental cows (n = 54) were used in a complete randomized design to determine effects of maternal nutrition from calving until mid-lactation on progeny post-weaning growth and carcass composition. Cows were fed diets supplemented with either dried distiller's grains with solubles (DDGS; n = 27) or soybean meal (CON; n = 27) from calving to 129 d post-partum (dpp). Cow-calf pairs were allotted at birth by cow and calf BW, breed, and age to one of two treatments. Maternal diets were isocaloric (0.95 Mcal/kg NE_g) and consisted of rye hay supplemented with DDGS as 1% of BW (19.4% CP; 8.76% fat) or corn silage and rye hay

based diet supplemented with SBM (11.7% CP; 2.06% fat). After conclusion of the treatments, cow-calf pairs were comingled and treated as one group until weaning at 219 dpp. From weaning until 255 dpp, calves continued to be managed as one group and were adapted to feedlot diets until feedlot entry when 48 calves were placed in individual pens (2.7 x 1.5 m) in a curtain-sided, slatted-floor finishing barn.

At feedlot entry, steers were vaccinated against bovine rhinotracheitis, bovine viral diarrhea, parainfluenza-3, bovine respiratory syncitial virus (Bovi-Shield Gold FP5®; Zoetis, Florham Park, NJ), *Haemophilus somnus, Pasteurella,* and *Clostridia* (Vision-7 Somnus; Merck Animal Health, Summit, NJ), treated with an anthelmintic (Valbazen®,Zoetis) for internal and external parasites, and implanted with Revalor-XS® (4 mg estradiol and 20 mg trenbolone acetate; provided courtesy of Merck Animal Health).

A common diet composed of 60% DDGS, 34% corn silage and 6% vitamin/mineral supplement (Table 1) was fed for the duration of the study. The diet was formulated to meet or exceed the nutrient requirements for protein, energy, vitamins, and minerals of a finishing steer (NRC, 2000). Feed was offered for ad libitum consumption once daily at 0800 and steers had free access to water. Ad libitum intake was determined based on the South Dakota State University 4-point bunk scoring system (Pritchard, 1993) with cattle fed to obtain a score of 0.5 at morning bunk check. Individual feed intake was recorded daily. Feed refusals were weighed and discarded. Individual feed ingredients were collected bi-weekly and dried in a forced air oven at 60°C for 72 h for analysis of DM. Subsequently, bi-weekly feed samples were

subsampled, composited, and analyzed for chemical composition by wet chemistry methods (AOAC, 1990; Sure-Tech Laboratories, Indianapolis, IN).

3.3.2 Post-weaning growth, feedlot performance and carcass data

Initial and final BW of calves was determined by averaging individual pre-prandial weights obtained on two consecutive days. Individual pre-prandial BW was taken monthly to monitor feedlot performance. All steers were slaughtered at a commercial abattoir (Tyson, Joslin, IL) when a target BW of approximately 590 kg was achieved. Hot carcass weight was recorded immediately following evisceration. Following a 24-h chill, 12^{th} rib fat thickness, longissimus (LM) area, kidney pelvic heart fat (KPH), yield grades, marbling scores and quality grades were determined by trained university personnel.

3.3.3 Intravenous glucose tolerance test

An intravenous glucose tolerance test (IVGTT) was performed on 10 steers 134 d after feedlot entry and on another set of 10 steers 5 d later; however, only 16 steers were used for analysis (DDGS = 9, CON = 7) due to difficulties with catheter lines that resulted in untimely sample collection. Steers were chosen for the IVGTT based on BW, such that the average BW of the steers chosen was equal to the treatment average BW. Steers were removed from feed 12 hours prior to the IVGTT but had ad libitum access to water. The morning of the IVGTT, steers were weighed to determine the bolus dose (0.25 g of glucose/kg of BW) which was delivered in a 50% dextrose solution (Agripharm

Products, Westlake TX). Jugular catheters (Hospira, Inc., Lake Forest IL) were inserted, secured, and a 3.5% sterile solution of sodium citrate was injected into the catheter line to prevent clotting. Steers were immediately placed in stalls and allowed approximately 2 h to adapt. Blood samples were collected in tubes containing 15 mg Sodium Fluoride and 12 mg Potassium Oxalate (BD Vacutainer; Becton-Dickinson, Franklin Lakes, NJ) at 10 and 5 min prior to glucose infusion, and 2, 5, 10, 15, 20, 25, 30, 45, 60, 75, 90, and 120 min after glucose infusion. At each timepoint, a 5 mL sample was removed and discarded to clear the catheter line of sodium citrate before blood samples were taken. After collection, blood samples were inverted then placed on ice until they were centrifuged at 3,000 x g for 20 min at 4 ° C. Plasma was separated into two aliquots and stored at -20 ° C until analysis of insulin (Coat-A-Count Insulin, Siemens Medical Solutions Diagnostics, Malvern, PA) and glucose (Glucose Liquicolor Procedure No. 1070, Stanbio Laboratory, Boerne, TX). The glucose procedure was modified and used a standard curve of 0, 31.25, 62.5, 125, 250 and 500 mg/dL that was created using a 500 mg/dL glucose standard. Glucose samples were read in 96-well polystyrene plates at 495 nm in an Opsys MR microplate reader (Dynex Technologies Inc., Chantilly, VA) and insulin samples were measured in a gamma counter (Cobra II Auto-Gamma; Packard Instrument Co., Downers Grove, IL). The intra-assay CVs were 5.07% and 1.45%, and the inter-assay CVs were 3.5% and 27.3% for glucose and insulin, respectively, for pooled serum samples.

3.3.4 Statistical analysis

Steer BW, ADG and daily DMI were analyzed using the MIXED procedure of SAS for repeated measures (Version 8.0, SAS Inst. Inc., Cary, NC). The covariance structures autoregressive order one, heterogeneous autoregressive order one, unstructured and compound symmetric were compared and the covariance structure with the smallest Bayesian information criterion was chosen for analysis results. Glucose and insulin results were analyzed using the MIXED procedure of SAS as a completely randomized design. Days on feed (DOF), hot carcass weight (HCW), dressing percent (DP), back fat (BF), longissimus (LM) area , kidney pelvic heart (KPH), yield grade (YG) and marbling were also analyzed using the MIXED procedure of SAS as a completely randomized design. Percent choice and select were analyzed using the GLIMMIX procedure of SAS. Animal served as the experimental unit. For repeated measures, the model included the fixed effects of treatment and day, as well as the appropriate treatment × day interaction. Simple effects within day were generated using the SLICE function of SAS. For all variables analyzed, a *P*-value ≤ 0.05 was identified as significant, while 0.05 > *P* ≤ 0.10 was identified as a tendency approaching significance.

3.4 Results

Feed intake ($P \geq 0.44$) and gain:feed ($P = 0.90$) were similar throughout the feedlot phase and it took a similar number of days for steers to reach their target slaughter weight ($P = 0.42$; Table 2). Steer weight did not differ at feedlot entry or at slaughter and ADG did not differ for any period during the study ($P \geq 0.93$); however,

steers whose dams were fed DDGS tended (P = 0.09) to be heavier on d 85 than those from SBM fed dams (Table 3). Maternal diet had no effect on glucose clearance ($P \geq 0.17$; Figure 1) or insulin secretion ($P \geq 0.16$; Figure 2) as measured by the IVGTT. Glucose (P = 0.27) and insulin (P = 0.37) area under the curve did not differ between treatments (Table 4), nor did the glucose to insulin ratio (P = 0.40).

Carcass characteristics are presented in table 5. Hot carcass weight (P = 0.54), dressing percent (P = 0.50) and LM area (P = 0.17) were not altered by maternal treatment. Kidney, pelvic, and heart fat (P = 0.31), back fat (P = 0.71), and yield grade (P = 0.19) did not differ between treatments, but marbling score (P = 0.04) was decreased by maternal feeding of DDGS. The decrease in marbling did not influence the percentage of steers that graded choice and better (P = 0.39).

3.5 Discussion

3.5.1 Post-weaning growth and feedlot performance

The objective of the current study was to identify differences in post-weaning growth, glucose tolerance, and carcass characteristics of steers whose dams were fed DDGS from calving until mid-lactation. Although steers whose dams were fed DDGS in this study were heavier than steers whose dams were fed SBM at the termination of dietary treatments (129 d of age) and at weaning (219 d of age; Chapter 2), there were no differences in days to achieve a similar slaughter weight. Similarly, when DDGS was fed to 2 yr old cows only during late gestation (Radunz et al., 2012), or from late gestation through early lactation (Gunn, 2013), researchers observed that calves were

heavier at both birth and weaning compared to calves whose dams were not fed DDGS, but there were no differences in weight at slaughter. In contrast, Radunz et al. (2011a) observed that limit-feeding ewes DDGS or corn from mid-gestation until parturition increased birth weights compared to those fed haylage, and while maternal diet had no effect on pre-weaning performance, progeny from ewes fed DDGS were heavier at slaughter than those fed haylage (Radunz et al., 2011b). It is important to note that differences in timing of placental and fetal growth between species (Greenwood and Café, 2007), possibly explaining differences among studies and why nutrition during fetal or neonatal phases is more pronounced in sheep (Greenwood and Cafe, 2007). Dry matter intake, feed efficiency, ADG, and days on feed were not affected by maternal diet during lactation in the present study, similar to other studies that have fed DDGS during gestation and/or lactation (Gunn et al. 2012b; Radunz et al., 2012; Wilson, 2012).

Distiller's grains are high in fat and protein, and other studies have shown that supplementing protein can have a programming effect on offspring. Underwood et al. (2010) reported increased live weight at slaughter and improved tenderness when dams grazed improved pastures that contained greater protein from mid to late gestation (Underwood et al., 2010). In another study, supplementing protein to cows grazing subirrigated meadow or fed hay during late gestation increased steer calf weight at the beginning of the finishing period, but had no effect on DMI, feed efficiency or carcass characteristics at slaughter (Stalker et al., 2006). Marbling and percentage of carcasses grading Choice or better was increased in progeny whose dams grazed winter range or corn residue supplemented with protein during late gestation (Larson et al., 2009).

3.5.2 Glucose tolerance test

Feeding 150% of NRC requirements for protein and energy to ewes during the second half of gestation decreased fetal pancreatic β-cell numbers and insulin concentration (Zhang et al., 2011), increased adiposity at term (Long et al., 2012), and increased adiposity as an adult (Long et al., 2010). Overnutrition during the second half of gestation can cause a decrease in fetal growth and β-cell numbers, which could lead to glucose intolerance in later life (Zhang et al., 2011). When ewes were fed DDGS from mid-gestation until parturition, progeny had an increased initial insulin response to an IVGTT, but there was no difference in the insulin:glucose AUC (Radunz et al., 2011b). It was suggested that progeny might have been insulin resistant compared to progeny whose dams were fed corn or hay (Radunz et al., 2011b). In the current study, steers whose dams were fed DDGS were exposed to greater concentrations of milk PUFAs. Polyunsaturated fatty acids can improve insulin sensitivity through changes in membrane composition, the formation of secondary messengers, and through alterations in gene transcription (Clarke, 2000; Kopál et al., 2013). However, there were no differences in glucose clearance or insulin secretion between steers whose dams were fed DDGS or SBM during lactation. These data agree with that of Radunz et al. (2012) and Gunn (2012b), who observed no differences in glucose clearance or insulin sensitivity to an IVGTT when steers' dams were fed DDGS during late gestation (Radunz et al., 2012) or late gestation through early lactation (Gunn, 2013). The development of insulin resistance in sheep and the absence in cattle may be due to the timing of feeding

DDGS, since organ, β-cells and endocrine system development take place prior to late gestation, or it may have been due to a species effect.

3.5.3 Carcass characteristics

Feeding DDGS to dams negatively affected intramuscular fat deposition, but had no other effects on carcass characteristics. Previous studies have observed no differences in marbling or quality grades when cows were fed DDGS during gestation and/or throughout early lactation (Gunn et al., 2012b; Radunz et al., 2012; Wilson, 2012). It is plausible that the greater levels of PUFA and CLA in the milk of DDGS-fed cows compared to control cows (Chapter 2) altered the FA composition in the tissue of DDGS-fed progeny in such a way that hindered adipose development. The esophageal groove of neonatal ruminants allows milk to bypass the rumen and calves are able to deposit the unaltered dietary fatty acids into tissue fatty acids. Paradis et al. (2008) observed an increase in the CLA content of subcutaneous adipose tissue of suckling beef calves when milk contained higher levels of CLA due to maternal supplementation of raw versus extruded soybeans. While the exact mechanism is unknown, it is thought that CLA may decrease body fat through increased energy expenditure, regulation of adipocyte metabolism by way of adipokines and cytokines, and through increased fatty acid oxidation (Reviewed by Park and Pariza, 2007). Polyunsaturated fatty acids also suppress lipogenesis through the down regulation of transcription factors such as sterol regulatory element-binding proteins (SREBPs; Worgall et al., 1998), liver X receptors (LXR; Yoshikawa et al., 2002) and are potent activators of peroxisome proliferator-

activated receptor gamma (PPARγ). Peroxisome proliferator-activated receptor gamma is a ligand-activated transcription factor that, when activated, up-regulate genes involved with the release of free fatty acids (lipoprotein lipase), the uptake of free fatty acids (fatty acid transport protein 1), transport of free fatty acids within the cell (fatty acid-binding protein 4), free fatty acid activation (acyl-CoA synthase), and esterification (phosphoenolpyruvate carboxykinase 1; Christodoulides and Vidal-Puig, 2010).

Gunn (2013) also supplemented maternal diets with DDGS and reported an increase in milk CLA and PUFA concentration but, in contrast to the present study, observed no differences in marbling at slaughter (Gunn et al., 2012b). The finishing diet in the present study contained 60% DDGS, whereas previous studies (Gunn et al. 2012b; Radunz et al., 2012; Wilson, 2012) removed DDGS from the finishing diet. Dried distiller's grains with solubles has been shown to decrease marbling deposition when fed above 29% DDGS (Mateo et al., 2004; Corah and McCully 2006*;* Gunn et al., 2009*)* and exposure to DDGS prior to finishing with a DDGS-based diet may compound any negative effects DDGS in the finishing period has on marbling. Dried distiller's grains with solubles is much lower in starch (Schoonmaker et al., 2010), which when fermented to propionate is the primary precursor for glucose, which is the preferred substrate for intramuscular fat deposition (Smith and Crouse, 1984). Schoonmaker et al. (2010) also observed that increasing concentrations of DDGS in the diet of finishing steers increased PUFA and CLA content of the LM and also decreased marbling content. Collectively, the effects of maternal DDGS supplementation may be reversed if DDGS is removed from the feedlot diet. However, if DDGS continues to be fed, it appears to

exacerbate the inhibition of adipose deposition during the neonatal stage throughout the feedlot phase.

Gunn et al. (2012b) reported that dressing percentage tended to be greater in steers whose dams were fed DDGS during late gestation and early lactation. The increase in dressing percentage reported by Gunn et al. (2012b) was due to an 11 kg increase in HCW of the DDGS steers, and indicates that maternal DDGS may have programmed progeny to partition energy from non-carcass to carcass components. Schoonmaker et al. (2013) reported a similar effect of DDGS on carcass weight and dressing percentage when DDGS was fed to early-weaned steers. In contrast, Radunz et al. (2012) observed an 11 kg decrease in HCW and a decrease in dressing percentage in progeny when dams were fed DDGS during late gestation. Dressing percentage was also decreased in progeny of ewes fed DDGS from mid-gestation until parturition (Radunz et al., 2011). Wilson (2012) observed no effect of maternal diet on progeny HCW when cows were fed hay or a diet of DDGS, corn bran and cornstalks from late gestation until parturition. This may have been the result of lower DDGS inclusion level in maternal diets, since Gunn et al. (2012b) fed cows DDGS at 43% of the diet DM, Radunz et al. (2012) fed cows DDGS at 66.5% of the diet DM, and Wilson (2012) fed cows DDGS at only 23% of the diet DM. The current study included DDGS at 53% of the maternal diet DM, but feeding DDGS during lactation may have lessened the impact on carcass components compared to feeding DDGS during late gestation.

In conclusion, feeding DDGS to dams from calving until mid-lactation did not alter feedlot performance since body weight, ADG, gain:feed and the number of days for

progeny to reach a targeted slaughter weight did not differ. Marbling was decreased in steers whose dams were fed DDGS, but other carcass characteristics were not impacted. Negative effects of early DDGS exposure on metabolism and intramuscular fat development may materialize when diets that contain high amounts of DDGS are fed during the finishing phase.

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Table 3.1 Diet and nutrient composition of steer finishing diet

Ingredient, %	
Dried distiller's grains	60.00
Corn silage	34.00
Wheat middlings	1.56
Vitamin/mineral pre-mix[a]	2.09
Limestone	2.35
Nutrient composition, %	
CP[b]	23.91
Ether extract[b]	5.67
Calcium[b]	1.37
Phosphorus[b]	0.69
Potassium[b]	1.14
Sulfur[b]	0.55
NE_m, Mcal/kg[c]	1.90
NE_g, Mcal/kg[c]	1.32

[a]Vitamin/mineral pre-mix contained (DM basis): 27.22% Ca, 0.44% Mg, 2.68% K, 0.25% S, 7.31 ppm Co, 658.76 ppm Cu, 33.36 ppm I, 751.09 ppm Fe, 0.13% Mn, 17.08 ppm Se, 0.19% Zn, 130 IU/g vitamin A, 18 IU/g vitamin D, 584 IU/kg vitamin E, 0.98 % Rumensin (176.4 g/kg, Elanco Animal Health, Greenfield, IN), 0.52% Tylan (88.2 g/kg, Elanco Animal Health, Greenfield, IN)

[b]Analyzed composition

[c]Calculated composition

Table 3.2 Progeny feed intake and feed efficiency and days on feed during feedlot finishing

	Treatment[1]			
Day	CON	DDGS	SEM	*P*-Value
Dry matter intake, kg/d				
0-85 d	9.1	9.3	0.15	0.42
86-184 d	10.9	10.9	0.24	0.83
Overall	9.9	10.0	0.17	0.77
Gain:feed				
0-85 d	0.216	0.221	0.0040	0.42
86-184 d	0.171	0.172	0.0040	0.85
Overall	0.198	0.191	0.0040	0.23
Days on Feed, d	189.3	180.6	4.24	0.15

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

Table 3.3 Effect of maternal diet from calving until mid-lactation on steer weight and average daily gain during feedlot finishing

	Treatment[1]			
	CON	DDGS	SEM	*P*-Value
Weight, kg				
Day 0	287.1	296.1	4.67	0.18
Day 85	454.7	470.3	6.35	0.09
Day 184	644.2	645.6	5.30	0.85
ADG, kg/d				
Days 0-85	1.97	2.01	0.045	0.22
Days 85-184	1.85	1.87	0.045	0.70
Days 0-184	1.91	1.95	0.045	0.39

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

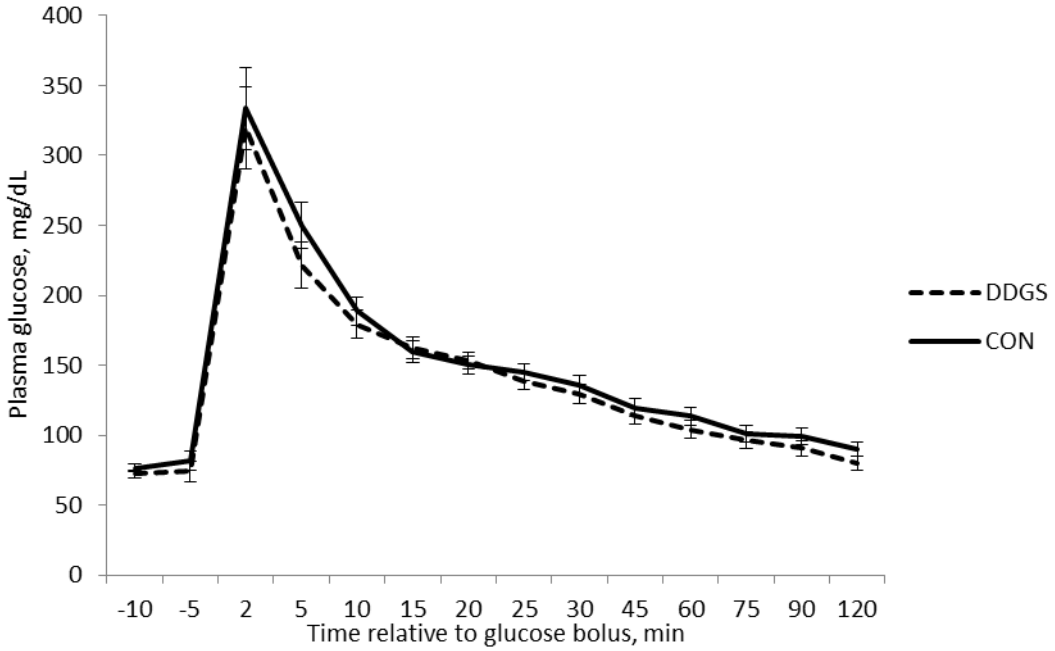

Figure 3.1 Plasma glucose concentration before and after infusion of glucose bolus 134 d after feedlot entry from steers whose dams were fed soybean meal (CON, n = 7) or dried distiller's grains with solubles (DDGS, n = 9) from calving until mid-lactation. Circulating glucose concentration *P*-Values were ≥ 0.17.

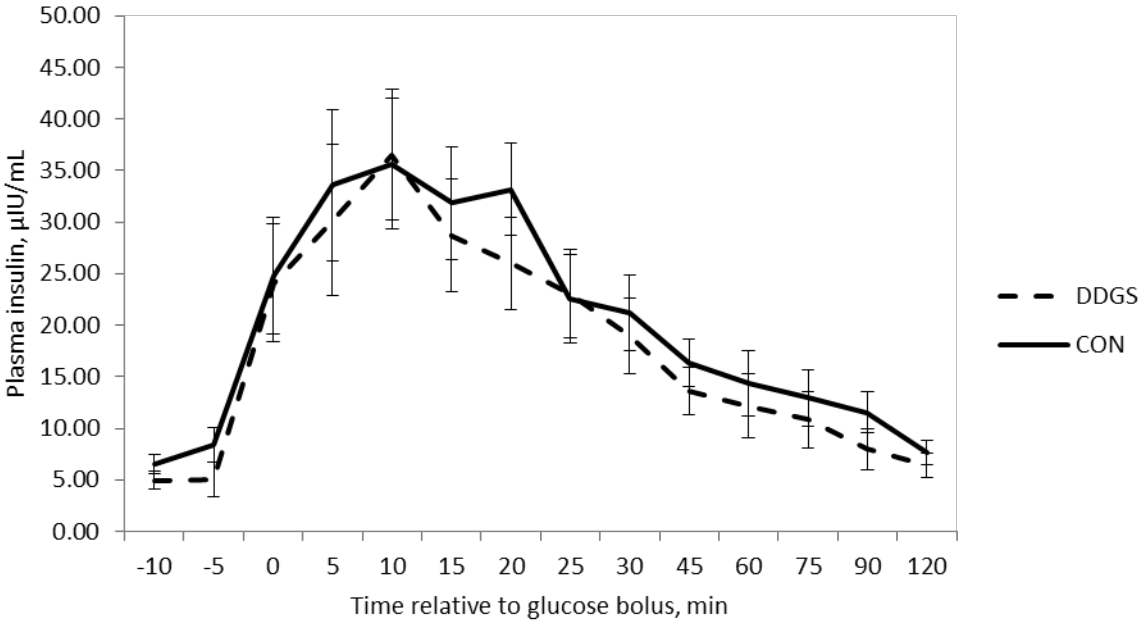

Figure 3.2 Circulating insulin concentration before and after infusion of glucose bolus 134 d after feedlot entry from steers whose dams were fed soybean meal (CON, n = 7) or dried distiller's grains with solubles (DDGS, n = 9) from calving until mid-lactation. Greatest SEM is represented and circulating insulin concentration *P*-Values were ≥ 0.16.

Table 3.4 Effect of maternal diet from calving until mid-lactation on offspring glucose area under the curve, insulin area under the curve and glucose to insulin ratio

	Treatment[1]			
	DG	SBM	SEM	P-Value
Glucose AUC	14175	15136	621.1	0.27
Insulin AUC	1750	2070	260.0	0.37
Glucose:Insulin	9.1	7.9	1.39	0.40

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

Table 3.5 Effect of maternal diet from calving until mid-lactation on steer carcass characteristics and yield grade

	Treatment[1]			
	CON	DDGS	SEM	*P*-Value
Hot carcass weight, kg	396.4	399.0	6.34	0.54
Dressing Percent	61.6	61.9	0.27	0.50
Backfat	1.35	1.30	0.09	0.71
Longissimus area, cm^2	86.65	89.16	1.271	0.17
Kidney, pelvic, heart fat, %	1.98	1.93	0.030	0.31
Marbling Score[2]	343	293	16.9	0.04
Yield Grade	3.22	2.93	0.150	0.19
Select, %	50	63	-----	0.45
Low Choice, %	25	33	-----	0.53
Choice Average, %	21	4	-----	0.12
Choice Plus, %	4	0	-----	0.98

[1]CON = Soybean meal supplemented as an energy source; DDGS = Dried distiller's grains with solubles used as an energy source

[2]USDA marbling scores: 200-299 = Slight; 300-399 = Small; 400-499 = Modest; 500-599 = Moderate.

CHAPTER 4. DIETARY INCLUSION OF CONDENSED DISTILLER'S SOLUBLES IN GESTATING AND LACTATING BEEF COW DIETS

4.1 Abstract

Two experiments were conducted to assess the performance of gestating (Exp 1) or lactating (Exp 2) beef cows fed increasing concentrations of condensed distiller's solubles (CDS). In Exp 1, Angus x Simmental heifers (n = 40) and cows (n = 8) were fed one of four diets starting on d 181 of gestation (BCS = 5.37 ± 0.23, BW = 530 ± 35 kg) until 2 weeks before calving. In Exp 2, another set of Angus x Simmental 2-yr old (n = 40) and 3-yr old (n = 8) cows were fed diets similar to Exp 1 from calving (BCS = 5.42 ± 0.49, BW = 557 ± 31 kg) until mid-lactation at 93 dpp. Diets consisted of a corn silage/haylage-based control (CON), a dried distiller's grains with solubles diet (DG; 22% Exp 1, 33% Exp 2), and two CDS diets fed at a low (LOW; 5% Exp 1, 8% Exp 2) or high (HIGH; 23% Exp 1, 27% Exp 2) inclusion. Diets were formulated to be isocaloric and isonitrogenous. Cows were allotted by cow breed, BW, age, and calf breed. Cows in Exp 2 were also allotted by calf birth weight and gender. Milk samples were collected 74 dpp (Exp 1) and 57 dpp (Exp 2) for composition analysis. A weigh-suckle-weigh was performed 77 dpp (Exp 1) and 60 dpp (Exp 2) to assess milk production. Blood samples were collected from cows and calves on 26 and 110 dpp (Exp 1) and 21 d and 93 dpp (Exp 2). Cow starting BW (*P* =

0.99), BCS ($P \geq 0.32$) and calf birth weight ($P \geq 0.77$) did not differ for either study, but by the end of Exp 1, cow BW was decreased ($P = 0.05$) and BCS was increased ($P < 0.01$) due to feeding LOW and HIGH CDS. In Exp 1, LOW decreased DMI 23.6% and HIGH decreased DMI 14.3% relative to CON ($P < 0.01$). In Exp 2, LOW decreased DMI 23.4% and HIGH decreased DMI 12.8% relative to CON ($P < 0.01$). Milk production, fat, protein and total solids did not differ ($P \geq 0.19$) among treatments for either study, but lactose ($P = 0.08$) tended to be greater in LOW cows during Exp 2. In Exp 2, maternal treatment had no effect on calf BUN at 23 or 93 days of age ($P \geq 0.47$), but increased BUN in cows fed LOW and DG ($P \leq 0.01$). Blood urea nitrogen in Exp 1 was increased on 26 dpp in LOW, HIGH and DG cows ($P < 0.001$), and was increased in HIGH and DG cows on 110 dpp ($P = 0.02$). Maternal treatment during Exp 1 had no effect at either time point on calf BUN ($P \geq 0.46$). Dietary treatment did not affect calf weight ($P \geq 0.26$) for either experiment. Calf ADG ($P \geq 0.42$) did not differ in Exp 1, but during Exp 2 ADG ($P = 0.05$) was decreased in LOW calves until the end of the maternal treatment. Timed artificial insemination ($P \geq 0.43$) and overall pregnancy rates ($P \geq 0.91$) did not differ for either study. In conclusion, CDS may need to be included at higher rates in low quality roughage diets or higher quality roughages should be included in the diet to maintain DMI at a level that matches the energy needs of the gestating or lactating cow.

4.2 Introduction

Use of corn for ethanol production is expected to decrease land available for forage (pasture, hay, and silage) production and increase cost of forage. In contrast, corn stover availability has the potential to increase, making it an economical alternative to traditional forages. Corn stover, which includes the stalk, leaf, husk, and cob remaining after corn grain production, contains approximately half of the dry weight of a standing corn plant and represents a tremendous feed resource in North America, with potential annual yields of 143 million tons (Kim and Dale, 2004).

Condensed distiller's solubles (CDS) is a co-product of ethanol production that is formed when the remaining stillage after distillation is further dehydrated to form a thick syrup. Condensed distiller's solubles (CDS) is high in protein and energy and may be a good supplement for low quality forages such as corn stover. Gilbery et al., (2006) and Coupe et al. (2006) noted increased intakes when CDS was mixed at increasing concentrations to roughage-based diets, but not when it was fed separately, indicating that the nutrients in the TMR may have been better synchronized for microbial needs**.** When fed to Holstein cows in mid-lactation*,* CDS included in a TMR at 5 or 10% DM increased milk production and milk protein content, slightly decreased milk fat and changed fatty acid composition (Da Cruz et al, 2005). Feeding 10% CDS to Holstein cows in mid-lactation did not influence DMI and milk yield, although it decreased milk fat and slightly decreased protein (Bharathan et al., 2008). Sasikala-Appukuttan et al. (2008) concluded that CDS is an acceptable alternative to dried distiller's grains with solubles (DDGS) when fed to Holsteins at 10 or 20% DM as it had no adverse effects on milk

production or feed intake. It was also suggested that CDS may exceed 20% of the diet DM as long as total dietary fat was below 7% (Sasikala-Appukuttan et al., 2008).

The effects of mixing CDS with low quality crop residues to beef cows during late gestation or early lactation on cow performance and calf growth is unknown. Therefore, the objective of this study was to identify the inclusion level of CDS in corn stover diets during gestation and lactation that will optimize cow reproductive efficiency and milk production, and to characterize the early development of the progeny from cows fed CDS. We hypothesized that mixing CDS with corn stover would improve reproductive performance of cows and that CDS would be an adequate alternative to hay or DDGS.

4.3 Materials and methods

The study was conducted at the Purdue Animal Sciences Research and Education Center in West Lafayette, IN and all procedures were approved by the Purdue Animal Care and Use Committee. Two experiments were conducted to determine the effect of inclusion level of CDS during gestation or lactation on cow and pre-weaning calf performance.

4.3.1 Experiment 1: Animals and diets

Angus x Simmental primiparous heifers (n = 40) and second parity cows (n = 8) were placed in 2.4 x 9.1 m individual pens in a 3-sided, bedded concrete floor barn and fed one of four diets from 181 d of gestation until 2 weeks prior to calving. One dietary treatment was randomly assigned to each pen and included: 1) a corn silage-based diet

(G-CON), 2) a corn stover-based, low CDS diet (G-LOW), 3) a corn stover-based, high CDS diet (G-HIGH), and 4) a corn stover-based, DDGS diet (G-DG). Corn stover was harvested at approximately 80% DM after corn harvest. Corn stover was chopped in a windrow and then harvested using a silage chopper equipped with a flail header and stored in an air-tight silage bag (Up North, Cottage Grove, MN) until the initiation of the trial. Cows in Exp 1 were allotted by cow breed, BW, age and calf breed. Initial and final body weight was determined by taking the average pre-prandial weights measured on 2 consecutive d. Body condition score (BCS, 1 = emaciated, 9 = obese) was determined bi-monthly by the same person (Wagner et al., 1988). The average BW and BCS for cows at the start of Exp 1 was 536 ± 5 kg and 5.37 ± 0.03, respectively. Diets were formulated to meet or exceed requirements for protein, energy, vitamins, and minerals (NRC, 2000) of a primiparous heifer in her third trimester of gestation. All diets were formulated using individual ingredient chemical composition analysis obtained by wet chemistry methods (AOAC, 1990) before the start of the trial (Sure-Tech Laboratories, Indianapolis, IN). Feed was offered once daily at 0800 h, and feed refusals were weighed, recorded, and discarded for each pen. Feed samples were taken and composited every 14 d for analysis of DM, CP, ether extract, and minerals. Dietary treatments concluded an average of 14 d prior to calving. At calving, cows were given 1 h to calve after initiation of hard labor to make progress before assistance was provided. Calving difficulty was scored as follows: 1 = no assistance; 2 = easy pull; 3 = mechanically assisted pull; 4 = abnormal presentation and 5 = caesarian-section. Calf vigor scores were based on the following scale: 1 = nursed on own immediately, 2 = nursed on own, but slow to begin; 3

= required assistance to nurse; 4 = died soon after birth. Udder scores were measured as: 1 = ideal; 2 = not ideal, but calf nursed on own; 3 = may require intervention; 4 = worst case. After calving, cows and calves in Exp 1 were placed on pasture and managed as one group.

4.3.2 Experiment 2: Animals and diets

A second set of Angus x Simmental primiparous heifers (n = 40) and second parity (n = 8) cows were placed in individual pens (2.4 x 9.1 m) in a 3-sided, bedded concrete floor barn and were fed one of four diets from within 1 week of calving until 93 ± 17 days postpartum (dpp). One dietary treatment was randomly assigned to each pen and included: 1) a corn silage-based diet (L-CON), 2) a corn stover based, low CDS diet (L-LOW), 3) a corn stover based, high CDS diet (L-HIGH), and 4) a corn stover based, DDGS diet (L-DG). Corn stover was harvested and stored as described in experiment 1. Cow-calf pairs were allotted by cow breed, BW, age, and by calf birth weight and sex. Initial and final body weight was determined by taking the average pre-prandial weights measured on 2 consecutive d. Weights of cows that had not calved by the first weighing were adjusted for gravid uterine weight (Ferrell et al., 1976). The average initial BW of cows was 557 ± 10 kg. Initial BCS (1 = emaciated, 9 = obese; Wagner et al., 1988) was taken the day before treatment initiation and the average was 5.4 ± 0.07. Subsequent BCS and BW were assessed monthly and bi-monthly, respectively. Assessment of BCS was conducted by the same investigator at all time points throughout the study. In addition, post-treatment body weight and BCS were recorded at 123 ± 17 and 217 ± 17

dpp to aid in interpretation of progeny growth between the treatment period and weaning.

4.4 Experiments 1 and 2 data collection

4.4.1 Milk

Milk samples were collected at 74 dpp (Exp 1) and 57 dpp (Exp 2). One quarter of the udder was hand-milked completely to collect milk samples from each cow. Milk was placed in a vial containing methylene blue and shipped to Dairy One Cooperative (Ithaca, NY) for analysis of protein, fat, lactose, total solids and milk urea nitrogen (MUN).

Milk production was measured on 77 ± 7 dpp (Exp 1) and 60 ± 17 dpp (Exp 2) using two, six hour weigh-suckle-weigh estimates (Buskirk et al., 1992). Calves were separated from their dams at 0000 until 0600, when they were allowed to nurse before being separated again. At 1200, calves were weighed prior to nursing and were re-weighed immediately after suckling ceased. After separation, cows were returned to their pens where they had access to feed and water. Calves were penned separately and denied dry feed and water throughout the weigh-suckle-weigh procedure. The difference in calf weight before and after suckling was calculated as the milk production for the 6 hr period. The procedure was repeated at 1800. Milk production at 1200 and 1800 were added together then multiplied by 2 for an estimation of 24 hr milk production.

4.4.2 Blood urea nitrogen

Blood samples from cows and calves in Exp 1 were taken 26 ± 7 and 110 ± 7 dpp to analyze blood urea nitrogen (BUN). Blood samples for Exp 2 were taken 21 ± 17 and 93 ± 17 d of age for calves and 93 ± 17 dpp for cows. Samples were collected in BD Vacutainer (Becton Drive, Franklin Lakes, NJ) tubes containing 158 USP Sodium Heparin. Tubes were inverted then placed on ice until they were centrifuged at 3000 x g for 20 min at 4°C. After centrifugation, plasma was separated into two aliquots and stored at -20°C until analysis of BUN with a commercial kit (Stanbio Urea Nitrogen Procedure No. 0580, Stanbio Laboratory, Boerne, TX). Samples were read at 530 nm in an Opsys MR microplate reader (Dynext Technologies Inc., Chantilly, VA). The intra-assay CV was 6.61% and the inter-assay CV for a control sample containing 30 mg/dL of urea nitrogen was 2.15%.

4.4.3 Estrous synchronization and breeding

Cows in both experiments were synchronized using 5 d CO-Synch + CIDR and time artificially inseminated in May of 2012. Ten days after artificial insemination, Exp 2 ended, and all cows (Exp 1 and 2) were commingled and placed with a bull for the remainder of the 60 d breeding season. Cows were ultrasounded (Variable MHz linear array transducer, MicroMaxx, Sonosite, Bothell, WA) 30 d after insemination to confirm conception to AI and were ultrasounded again 60 d later to determine overall season pregnancy.

4.4.4 Pre-weaning progeny performance

Calf BW was measured at birth and at 110 ± 7 (Exp 1) or 93 ± 17 (Exp 2) d of age. Calf weights were taken in conjunction with termination of the dietary treatments for Exp 2. At 164 ± 7 (Exp 1) or 147 ± 17 (Exp 2) d of age, calves were given ad libitum access to creep feed devoid of DDGS (18.2% CP and 1.39 Mcal NE_g/kg on DM basis) until weaning at 194 ± 7 (Exp 1) or 177 ± 17 (Exp 2) d of age, at which point calf BW was measured. Creep period gain, intakes, and feed efficiency were not collected as all cow-calf pairs were previously commingled and managed as a single group.

4.4.5 Statistical analysis

Timed artificial insemination and season pregnancy rates were calculated using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC). Cow BW, BCS, milk production, milk composition, BUN and calf weight, ADG, and BUN were analyzed using the MIXED procedure of SAS for repeated measures. The covariance structures autoregressive order one, heterogeneous autoregressive order one, unstructured, and compound symmetric were compared and the covariance structure with the smallest Bayesian information criterion was chosen for analysis results. The model included the fixed effects of treatment and day, as well as the appropriate treatment × day interaction. Animal served as the experimental unit. Least squared means were calculated for fixed effects. Simple effects within day were generated using the SLICE function of SAS. For all variables analyzed, a P-value ≤ 0.05 was identified as significant and 0.05> P ≤ 0.10 was identified as a tendency approaching significance.

4.5 Results

4.5.1 Experiment 1: Gestation

Cow DMI, BW, BCS and pregnancy rates for cows fed CDS during gestation are presented in Table 4.3. When fed during gestation, CDS decreased DMI. However, cows fed high levels of CDS (23%) had greater intakes than those fed low levels of CDS (5%). Although G-LOW, G-HIGH, and G-DG did not gain as much weight as G-CON cows, they had greater BCS scores ($P < 0.01$) and did not differ in timed artificial insemination ($P = 0.43$) or overall pregnancy rates ($P = 1.00$). There were no effects of treatment on calf birth weight, calving ease, calf vigor or udder score (Table 4; $P \geq 0.29$).

There were no effects of gestational treatment on milk production, milk fat percentage, milk protein percentage, lactose or total solids on 77 dpp (Table 5; $P \geq 0.42$). Milk urea nitrogen was lowest in cows fed the CON and G-LOW ($P < 0.01$) treatments. Blood urea nitrogen (Table 6; $P \leq 0.02$) was increased on 26 dpp in G-LOW, G-HIGH, and G-DG cows compared with G-CON cows and in G-HIGH and G-DG cows on 110 dpp. Calf BUN did not differ between treatments on 26 or 110 dpp ($P \geq 0.46$). Pre-weaning growth of calves did not differ ($P \geq 0.42$) among treatments (Table 7).

4.5.2 Experiment 2: Lactation

Cow DMI, BW, BCS and pregnancy data are presented in Table 8. Similar to Exp 1, CDS fed during lactation decreased DMI, although L-HIGH cows (27% of dietary DM) had greater intakes than L-LOW cows (8% of dietary DM). However, weight gain of L-HIGH

and L-LOW cows did not differ ($P > 0.22$). Dietary treatment during lactation did not affect the BW or BCS of the cows ($P \geq 0.22$). Feeding CDS had no negative effects on timed artificial insemination rates ($P = 0.83$) or overall pregnancy rates ($P = 0.91$).

Milk composition when cows were fed CDS during lactation is shown in Table 9. There was no effect of treatment on milk production ($P = 0.73$), milk fat percentage ($P = 0.77$), milk protein percentage ($P = 0.19$), or total solids ($P = 0.92$). However, milk lactose percentage tended to be greater in cows fed low ($P = 0.08$) compared with L-CON cows. Milk urea nitrogen tended to be greater in cows fed L-LOW ($P = 0.08$) compared to L-CON and L-HIGH fed cows, which also corresponded with an increase in cow BUN for L-LOW and L-DG cows on 93 ± 17 dpp ($P \leq 0.01$).

Calves from L-LOW cows gained the least and calves from L-CON cows gained the most from birth to 93 days of age ($P = 0.05$; Table 10).

4.6 Discussion

A primary goal of the current study was to determine the effect dietary concentration of CDS in gestating and lactating cow diets on cow and pre-weaning calf performance. In an attempt to eliminate body weight as a confounding factor, initial diets were formulated based on chemical composition of individual ingredients, to provide similar daily megacalories of NE_g and maintain similar BW between treatments throughout the study. However, actual DMI during gestation was 15, 35, 26, and 34% lower than predicted DMI for cows fed the G-CON, G-LOW, G-HIGH, and G-DG diets, respectively and actual DMI during lactation was 13, 4, and 19% lower than the

predicted DMI for cows fed the L-LOW, L-HIGH, and L-DG diets. Corn stover inclusion at these concentrations (70, 71, and 56% of the diet DM for G-LOW, G-HIGH, and G-DG, respectively and 50, 52, and 44% of the diet DM for L-LOW, L-HIGH, and L-DG; respectively) may have been too high and caused a decrease in palatability and digestibility. As a result, energy intake was reduced and cow weight at the termination of dietary treatments was negatively affected in CDS compared with control diets. CON diets were controlled to attempt to maintain similar weight gain to those fed LOW, HIGH and DG diets. However, increasing concentrations of CDS appeared to improve DMI, as intake increased from the G-LOW to G-HIGH diets and from L-LOW to L-HIGH diets. Coupe et al. (2008) and Gilbery et al. (2006) noted increased intakes when CDS was added to moderate or low quality roughage at increasing concentrations, but not when CDS and roughage was fed separately. The difference in response when CDS was mixed with roughage opposed to separately indicates the nutrients in the TMR may have been better synchronized to meet microbial needs (Gilbery et al., 2006) to help improve digestibility. However, in dairy studies, when mixed with higher quality forages such as alfalfa and corn silage (Da Cruz et al., 2005; Bharathan et al., 2008; Sasikala-Appukuttan et al., 2008) CDS had no effect on DMI.

It is interesting to note that while cows fed CDS during gestation did not gain as much weight as control cows, they had greater BCS scores and numerically increased conception rates compared to cows fed the control diet. With decreased energy intake for cows fed CDS or DDGS, we expected that BCS would decline in cows fed CDS or DDGS. Furthermore, in studies where DDGS is fed during gestation or lactation, BCS

either does not change (Radunz et al., 2010; Chapter 2) or decreases (Gunn, 2013) while cow weight is maintained. It may be possible that cows fed ethanol co-products such as DDGS or CDS are able to shift location of fat mobilization to cause a change in BCS. Dietary treatment during lactation in the present study did not affect the BW or BCS, which may have been due to the lower amount of corn stover (50% Exp 2 vs. 70% Exp 1) fed in the lactation diets.

The fact that CDS and DDGS did not negatively affect conception or pregnancy rates in the present study is consistent with previous reports where DDGS was fed to gestating and lactating cows. Dried distiller's grains with solubles has been shown to have no negative effects on TAI or pregnancy rates when fed during gestation (Radunz et al., 2010) or during early lactation (Shike et al., 2009). Data from Chapter 2 indicates that DDGS improves conception rates, but not overall pregnancy rates when fed during lactation. Other studies have observed that feeding DDGS increases follicular growth during postpartum anestrus (Gunn, 2013) and may reduce the postpartum interval (Engel et al., 2008; Gunn, 2013).

Blood urea nitrogen was increased on 26 dpp in cows fed low and high CDS and cows fed DDGS during gestation. This may have been due to the lower feed intakes relative to CON cows during the trial. As a result, protein may have been metabolized as an energy source, and the excess nitrogen from amino acid breakdown was excreted. We expected diets to have no long-term effect on BUN, thus it is unclear why cows fed high CDS and DG during gestation had increased concentrations of BUN on 110 dpp.

Condensed distiller's solubles when fed during gestation had no long-term effects on milk composition, but CDS fed during lactation increased milk urea nitrogen. Similar to the effect of treatment on BUN in Exp 1, the cows fed low CDS and DDGS during lactation had lower intakes, and may have used protein as an energy source to meet their energy requirements. Studies using Holstein cows have reported slight milk fat depression with CDS supplementation at 5 and 10% of the diet DM (Da Cruz et al., 2005) and at 10% of the diet DM (Bharathan et al., 2008), while others have reported no milk fat depression when fed at 10% and 20% of the diet DM (Sasikala-Appukuttan et al., 2008). However, the lack of milk fat depression observed by Sasikala-Appukuttan et al. (2008) may have been due to high ambient temperatures that decreased feed intake and milk production. In the current study, we observed no effect on milk fat depression when CDS was included at 8 or 27% of the diet DM in lactation diets.

In contrast to the present study, Gunn (2013) reported that calf birth weight and pre-weaning ADG were increased by dietary DDGS, and suggested that external fat may have been used as an energy source to increase progeny weights, or that excess dietary fat was deposited internally (Gunn, 2013). Polyunsaturated FA are able to increase insulin sensitivity (Kopál et al., 2013). It may be possible that the elevated PUFA content of CDS in the present study enabled glucose to be used more efficiently by the cow, thus allowing external fat to be preserved. Maternal diet during gestation did not affect calf growth, but calves whose dams were fed CDS and corn stover during lactation grew more slowly than those fed a control diet. Decreased ADG for calves of dams fed CDS and stover during lactation are in a large part due to inadequate energy intake of the

dam. Studies have observed an increase in birth weight when DDGS was fed to dams during gestation (Radunz et al., 2010; Gunn, 2013) and heavier weaning weights when fed during gestation (Radunz et al., 2010), gestation and lactation (Gunn, 2013) and just during lactation (Chapter 2). The high levels of corn stover in maternal diets as well as the decreased DMI by dams fed CDS may have prevented any positive effects of CDS and DDGS from occurring.

In conclusion, CDS may need to be included at greater rates when fed with low quality forages to increase intake or nutrient density of the diet in order to meet the dietary needs of a cow during late gestation or early lactation. Alternatively, higher quality forages should be included in the diet at a greater rate for CDS inclusion to have any positive effects.

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Table 4.1 Dietary ingredients, nutrient composition and dry matter intake (Exp 1)

	G-CON	G-LOW	G-HIGH	G-DG
		----------%DM basis----------		
Corn stover	-----	70.3	70.6	56.5
Corn silage	51.0	-----	-----	10.0
Grass haylage	45.6	-----	-----	-----
Gluten meal	1.4	-----	-----	-----
Corn	-----	-----	-----	10.0
Soybean meal	-----	-----	-----	-----
DDGS	-----	21.0	4.0	22.0
CDS	-----	5.0	22.8	-----
Corn oil	1.0	2.0	-----	-----
Vita Ferm	1.0	1.0	1.0	1.0
Limestone	-----	0.7	1.6	0.5
Crude protein, %	11.38	12.69	11.34	12.53
Oil, %	2.50	4.98	5.21	2.55
NE_m, Mcal/kg	1.44	1.50	1.54	1.49
NE_g, Mcal/Kg	0.83	0.91	0.95	0.90
NDF, %	46.55	52.92	49.47	49.00
ADF, %	32.76	34.67	33.28	31.38
Ca, %	0.75	0.59	0.91	0.51
P, %	0.32	0.43	0.62	0.38
S, %	0.16	0.30	0.39	0.25
Calculated nutrient intake				
DMI, kg/d	9.6	7.3	8.2	7.4
CP, g/d	1090	928	932	927
Oil, g/d	239	364	429	189
NE_m, Mcal/d	10.68	10.68	10.68	10.68
NE_g, Mcal/d	1.71	0.00	0.72	0.12
NDF, g/d	4460	3868	4066	3626

ADF, g/d	3139	2534	2736	2322
Ca, g/d	72.1	43.3	74.5	37.5
P, g/d	30.4	31.6	51.2	28.4
S, g/d	15.5	21.7	32.3	18.7

Table 4.2 Dietary ingredients, nutrient composition and dry matter intake (Exp 2)

	L-CON	L-LOW	L-HIGH	L-DG
	----------%DM basis----------			
Corn stover	-----	50.0	51.6	43.6
Corn silage	50.8	-----	10.8	16.8
Grass haylage	40.0	10.5	-----	-----
Gluten meal	-----	-----	1.0	-----
Corn	-----	-----	-----	5.0
Soybean meal	6.5	-----	-----	-----
DDGS	-----	27.6	6.5	32.7
CDS	-----	8.0	27.0	-----
Corn oil	1.7	1.7	-----	-----
Vita Ferm	1.0	1.0	1.0	1.0
Limestone	-----	1.2	2.1	0.9
Crude protein, %	12.99	15.67	13.43	15.26
Oil, %	3.14	5.90	6.43	3.32
NE_m, Mcal/kg	1.50	1.55	1.65	1.52
NE_g, Mcal/Kg	0.89	0.96	1.06	0.93
NDF, %	44.23	47.80	43.02	46.36
ADF, %	30.92	31.29	28.45	28.98
Ca, %	0.72	0.83	1.05	0.62
P, %	0.34	0.57	0.75	0.48
S, %	0.17	0.40	0.48	0.34
Calculated nutrient intake				
DMI, kg/d	14.9	11.4	13.0	10.7
CP, g/d	1940	1792	1750	1629
Oil, g/d	470	675	838	354
NE_m, Mcal/d	16.68	16.68	16.68	16.68
NE_g, Mcal/d	3.25	0.03	2.50	0.21
NDF, g/d	6607	5468	5605	4946
ADF, g/d	4620	3579	3707	3092
Ca, g/d	107.6	94.4	137.1	66.7
P, g/d	50.9	65.8	97.2	51.1
S, g/d	24.7	45.8	62.5	35.8

Table 4.3 Effect of CDS inclusion during gestation on cow weight and body condition score (Exp 1)

	Dietary Treatment[1]					
	G-CON	G-LOW	G-HIGH	G-DG	SEM	P-Value[2]
Weight, kg						
Day 0	526.7	531.1	531.9	530.8	11.07	0.99
Day 56	578.8	562.5	557.8	577.5	11.07	0.44
Day 86 (End trial)	614.9[a]	582.0[b]	573.9[b]	600[ab]	11.07	0.05
DPP 203 (Weaning)	573.7	576.7	554.9	572.2	11.07	0.37
Body condition score						
Day 0	5.30	5.33	5.47	5.36	0.079	0.46
Day 56	4.86[a]	5.11[b]	5.22[b]	5.17[b]	0.079	0.01
Day 86 (End trial)	4.86[a]	5.28[b]	5.39[b]	5.25[b]	0.079	<0.01
Timed Artificial Insemination, %	50.0	66.7	66.7	83.3	-----	0.43
Overall Pregnancy, %	91.7	100.0	91.7	91.7	-----	1.00

[1]G-CON = corn silage and haylage based diet; G-LOW= 5% condensed distiller's solubles; G HIGH = 23% condensed distiller's solubles; G-DG = 22% dried distiller's grains with solubles

[2]Within a row, means with differing superscripts were considered significant ($P < 0.05$)

Table 4.4 Effect of CDS inclusion during gestation on udder score, calving ease and calf vigor (Exp 1)

	Dietary Treatment[1]					
	G-GON	G-LOW	G-HIGH	G-DG	SEM	*P*-Value
Udder Score	1.1	1.0	1.1	1.0	0.06	0.58
Calving Ease	1.0	1.3	1.2	1.6	0.22	0.29
Calf Vigor	1.0	1.0	1.1	1.0	0.04	0.40

[1]G-CON = corn silage and haylage based diet; G-LOW= 5% condensed distiller's solubles; G-HIGH = 23% condensed distiller's solubles; G-DG = 22% dried distiller's grains with solubles

Table 4.5 Effect of CDS inclusion during gestation on milk production and composition (Exp 1)

	Dietary Treatment[1]					
	G-CON	G-LOW	G-HIGH	G-DG	SEM	*P*-Value[2]
Production, kg[3]	9.8	9.5	10.3	11.5	1.94	0.49
Fat, %[4]	0.6	0.8	0.6	0.7	0.09	0.42
Protein, %	3.2	3.1	3.2	3.2	0.06	0.49
Lactose, %	5.1	5.1	5.1	5.1	0.04	0.92
Total Solids, %	9.9	10.0	9.8	10	0.13	0.70
MUN, mg/dL	16.04[a]	15.38[a]	17.54[b]	17.55[b]	0.53	<0.01

[1]G-CON = corn silage and haylage based diet; G-LOW= 5% condensed distiller's solubles; G-HIGH = 23% condensed distiller's solubles; G-DG = 22% dried distiller's grains with solubles

[2]Within a row, means with differing superscripts were considered significant ($P < 0.05$)

[3]Measured 77 ± 7 d postpartum

[4]Fat, protein, lactose, total solids and MUN measured 74 ± 7 d postpartum

Table 4.6 Effect of CDS inclusion during gestation on cow and calf blood urea nitrogen (Exp 1)

	Dietary Treatment[1]					
	G-CON	G-LOW	G-HIGH	G-DG	SEM	*P*-Value[2]
Cow BUN, mg/dL						
26 dpp	6.7[a]	9.3[b]	8.6[b]	10.2[b]	0.62	<0.001
110 dpp	8.1[a]	8.1[a]	10.3[b]	10.1[b]	0.62	0.02
Calf BUN, mg/dL						
26 d of age	7.2	8.2	8.5	7.4	0.76	0.46
110 d of age	10.4	9.6	10.2	10.6	0.70	0.64

[1]G-CON = corn silage and haylage based diet; G-LOW= 5% condensed distiller's solubles; G-HIGH = 23% condensed distiller's solubles; G-DG = 22% dried distiller's grains with solubles

[2]Within a row, means with differing superscripts were considered significant ($P < 0.05$)

Table 4.7 Effect of CDS inclusion during gestation on calf weight and average daily gain (Exp 1)

	Dietary Treatment[1]					
	G-CON	G-LOW	G-HIGH	G-DG	SEM	P Value
Weight, kg						
Day[2] 0 (Birth)	36.0	37.6	36.4	36.5	1.13	0.77
Day 110 (End trial)	163.3	164.7	166.4	165.5	3.90	0.96
Day 194 (Wean)	244.2	244.2	251.4	248.1	5.26	0.72
ADG, kg/d						
Days 0-110	1.16	1.15	1.18	1.19	0.097	0.90
Days 111-194	0.96	0.95	1.01	0.98	0.181	0.95
Days 0-194	1.08	1.06	1.11	1.10	0.056	0.42

[1]G-CON = corn silage and haylage based diet; G-LOW= 5% condensed distiller's solubles; G-HIGH = 23% condensed distiller's solubles; G-DG = 22% dried distiller's grains with solubles

[2]Days of age

Table 4.8 Effect of CDS inclusion during lactation on cow weight and body condition score (Exp 2)

	Dietary Treatment[1]					
	L-CON	L-LOW	L-HIGH	L-DG	SEM	*P*-Value
DMI, kg/d	14.9	11.4	13.0	10.7		
Weight, kg						
0 dpp[2] (Calf birth)	557.6	554.4	558.8	556.1	9.29	0.99
60 dpp	574.4	559.3	554.0	560.0	11.08	0.60
93 dpp (End trial)	577.0	544.7	557.5	555.5	11.16	0.22
176 dpp (Wean)	561.0	544.5	546.0	553.4	10.92	0.74
BCS						
0 dpp (Calf birth)	5.47	5.58	5.33	5.28	0.127	0.32
93 dpp	5.29	5.07	5.00	5.06	0.127	0.39
Timed Artificial Insemination, %	66.7	75.0	75.0	83.3	-----	0.83
Overall Pregnancy, %	91.7	83.3	91.7	100.0	-----	0.91

[1]L-CON = corn silage and haylage based diet; L-LOW= 8% condensed distiller's solubles; L-HIGH = 27% condensed distiller's solubles; L-DG = 33% dried distiller's grains with solubles

[2]Days postpartum

Table 4.9 Effect of CDS inclusion during lactation on milk production and composition (Exp 2)

	Dietary Treatment[1]					
	L-CON	L-LOW	L-HIGH	L-DG	SEM	*P*-Value[2]
Production, kg[3]	7.4	8.0	6.8	5.2	1.88	0.73
Fat, %[4]	1.9	1.3	2.0	2.0	0.50	0.77
Protein, %	3.1	3.1	3.0	3.0	0.07	0.19
Lactose, %	4.9[a]	5.1[b]	5.0[ab]	5.0[ab]	0.06	0.08
Total Solids, %	10.9	10.6	11.0	10.9	0.46	0.92
MUN, mg/dL	12.25[a]	13.93[b]	12.15[a]	13.60[ab]	0.60	0.08

[1]L-CON = corn silage and haylage based diet; L-LOW= 8% condensed distiller's solubles; L-HIGH = 27% condensed distiller's solubles; L-DG = 33% dried distiller's grains with solubles

[2]Within a row, means with differing superscripts were considered significant ($P < 0.05$)

[3]Measured 60 ± 17 d postpartum

[4]Fat, protein, lactose, total solids and MUN measured 57 ± 17 d postpartum

Table 4.10 Effect of CDS inclusion during lactation on calf weight and average daily gain (Exp 2)

	Dietary Treatment[1]					
	L-CON	L-LOW	L-HIGH	L-DG	SEM	*P*-Value[2]
Weight, kg						
Day 0 (Birth)	35.5	35.1	35.6	35.9	5.80	1.00
Day 93 (End trial)	148.7	133.7	144.7	141.9	6.85	0.32
Day 176 (Wean)	228.8	212.5	223.0	220.0	7.59	0.26
ADG, kg/d						
Day 0-93	1.20[a]	1.06[b]	1.15[ab]	1.13[ab]	0.040	0.05
Days 94-177	0.95	0.94	0.93	0.93	0.036	0.97
Days 0-177	1.09	1.00	1.05	1.04	0.026	0.15

[1]L-CON = corn silage and haylage based diet; L-LOW= 8% condensed distiller's solubles; L-HIGH = 27% condensed distiller's solubles; L-DG = 33% dried distiller's grains with solubles

[2]Within a row, means with differing superscripts were considered significant ($P < 0.05$)

Table 4.11 Effect of CDS inclusion during lactation on cow and calf BUN (Exp 2)

	Dietary Treatment[1]					
	L-CON	L-LOW	L-HIGH	L-DG	SEM	*P*-Value
Calf BUN, mg/dL						
21 d of age	9.3	8.0	8.8	8.4	0.65	0.47
93 d of age	10.4	9.8	10.0	10.5	0.80	0.80
Cow BUN, mg/dL						
93 dpp	14.0[a]	13.6[a]	11.4[b]	13.9[a]	0.54	<0.01

[1]L-CON = corn silage and haylage based diet; L-LOW= 8% condensed distiller's solubles ; L-HIGH = 27% condensed distiller's solubles; L-DG = 33% dried distiller's grains with solubles

[2]Within a row, means with differing superscripts were considered significant ($P < 0.05$)

CHAPTER 5. CONCLUSIONS AND FURTHER DIRECTIONS

As feed costs continue to rise producers will continue searching for alternative feeds. These feeds may have an impact not only on the performance of the cows, but also the development of their calves. Thus, we investigated the effects of feeding dried distiller's grains with solubles (DDGS) and condensed distiller's solubles (CDS) during lactation and/or gestation on cow performance and calf growth. Our hypothesis was that feeding ethanol co-products would improve cow performance and reproductive efficiency while improving the pre- and post-weaning performance of their calves compared to those not fed ethanol co-products.

In Chapter 2, we demonstrated that feeding DDGS from early to mid-lactation improves cow reproductive performance and pre-weaning calf growth. Cow BW and BCS were not altered by DDGS supplementation, but cows were more receptive to TAI and may have had a shorter postpartum anestrous. Milk production was not changed, but milk composition, particularly milk fatty acid saturation and chain length, was changed by DDGS supplementation. While calves had access to the cows' feed, it is most likely that this change in milk composition was responsible for the greater ADG and weights of the calves by the end of the trial and at weaning. I hypothesize that it was the change in fatty acid composition that improved the pre-weaning weights of the calves, but the

exact mechanism how and the specific fatty acids responsible remain to be determined. It may be possible that nutritional fatty acids altered signaling pathways involved in neonatal muscle, skeletal or adipose growth or that it improved the immune function of the calves. The importance of neonatal nutrition and milk composition on long-term progeny development would be particularly beneficial to the dairy industry as heifer calves are often raised on milk replacer. In this study, we only used cows with male calves. It would be beneficial to study the effects of maternal diet during gestation and/or lactation long-term reproductive performance of female progeny as they are retained in the herd longer and programming may be more apparent in older offspring.

In Chapter 3, the feedlot performance of the steer progeny from Chapter 2 was observed. We expected the improved performance of progeny of DDGS fed dams to continue, but our hypothesis was incorrect. Feeding DDGS to dams during lactation had no effect on feedlot ADG, days on feed, or carcass characteristics except for a decrease in marbling. This decrease may have been due to elevated levels of conjugated linoleic acid and polyunsaturated fatty acids in the milk, as they have been shown to decrease adipose tissue development. Providing DDGS in the feedlot diet may have exacerbated this decrease because high levels of dietary DDGS have been shown to decrease adiposity and the cattle may have used energy to excrete the excess nitrogen. Maternal diet during lactation had no effect on glucose tolerance or insulin sensitivity. The lack of an effect compared to other studies may be due to differences between species that may make cattle less sensitive to programming, or it may be that the age at which the

glucose tolerance test was performed or the age at which steers are slaughtered is too young for glucose intolerance to occur.

In Chapter 4, CDS was added to corn stover and fed to cows during gestation or lactation to observe the effects on cow and calf performance. While high levels of corn stover decreased feed intake because of high NDF and poor digestibility, increasing levels of CDS improved feed intake. Although the decrease in feed intake caused the CDS cows to lose weight, they had adequate TAI and overall season pregnancy rates, which is interesting considering weight and BCS are important factors in assessing fertility. Milk urea nitrogen tended to be higher when CDS was fed during lactation, but no other changes in milk production or composition were apparent when CDS were fed during gestation or lactation. Feeding CDS to cows during gestation had no effect on calf birth weight or pre-weaning growth, but calves whose dams were fed CDS during lactation grew more slowly than those fed a control diet.

Chapters 2 and 4 demonstrate that feeding DDGS and CDS appear to benefit reproduction. It should be determined what exactly is beneficial to reproduction, whether it is the high levels of fat, the fatty acid composition, the high levels of protein, the relationship between RDP and RUP, or the combination of fat and protein. Feed availability and prices are volatile and ethanol co-products may not always be a viable option for producers, and knowing specifics and mechanisms can help create and provide alternatives in such situations.

In conclusion, these experiments demonstrate that ethanol co-products are an acceptable feed for beef cows. Producers should avoid feeding high levels of protein to

cows in late gestation; however, excess protein should not be of concern in lactation diets. Feeding DDGS during lactation can improve cow reproductive performance and calf pre-weaning growth, but is less effective on post-weaning calf growth. If CDS is fed to gestating or lactating beef cows, it should be included at increased levels or with higher quality forages to prevent decreased intake and performance. In an ever-changing market in which feedstuffs may rapidly become too costly or scarce, efforts should be taken to determine the nutrients in DDGS and CDS that are most beneficial to cow reproduction and calf development.

VITA

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Education

B.S., Animal Sciences, 2010, The Ohio State University, Columbus, Ohio
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Research Experience

Research Assistant; March 2011 – Present

- Conducted radioimmunoassays to determine insulin and progesterone concentration
- Isolated and purified DNA from blood and tissue, RNA from muscle tissue
- Extracted fatty acids from milk, muscle and feed and profiled via gas chromatography
- Assessed glucose and blood urea nitrogen through colorimetric assays
- Maintained inventory of lab supplies, radioactive materials and MSDS
- Responsible for statistical analysis in SAS
- Communicated with off-site testing labs, bioinformatics, technical support

Certifications

Good Clinical Practices and Good Documentation for Regulated Studies
Purdue Animal Care and Use Committee (PACUC) Qualified
Radiological and Environmental Management (REM) Certified

Animal Experience

Zinpro, Eden Prairie, MN; Volunteer, 2013

- Performed glucose tolerance tests on cattle for an FDA clinical trial conducted at Purdue University

Bos Family Farms, Fair Oaks, IN; Consultant, 2013

- Body condition scored 400+ Holstein cows over 7 months for a research trial

4 Paws For Ability, Xenia, OH; Volunteer 2010
- Fostered and helped train a seizure alert dog while educating the public on the use of service dogs

White Pine Stables Therapeutic Riding Center, Gahana, OH; Volunteer, 2008-2010
- Helped 13 children with disabilities perform tasks on horseback to improve physical, cognitive, emotional and social capabilities, mentored new volunteers

Darlington Polo Team, Darlington, PA; Employee, 1998-2010
- Caretaker and exercise rider of 12 horses

Abstracts and Publications

J. P. Schoonmaker, K. T. Korn, K. N. Condron, C. N. Shee, M. C. Claeys, and R. P. Lemenager. Effect of decreasing dietary cation anion difference (DCAD) on feedlot performance, carcass characteristics, and beef tenderness. (Submitted to J. Anim. Sci.)

C. N. Shee, R. P. Lemenager, M. C. Claeys, and J. P. Schoonmaker. 2012. Effect of feeding distiller's dried grains with solubles during lactation on cow performance, milk composition, and pre-weaning progeny performance. J. Anim. Sci. 90(E-Suppl. 2):42. (Abstr.)

C. N. Shee, M. C. Claeys, R. P. Lemenager, and J. P. Schoonmaker. 2013. Effect of feeding distiller's dried grains with solubles during lactation on feedlot performance and carcass characteristics of steer progeny. J. Anim. Sci. 91(E-Suppl. 2):52. (Abstr.)

C. N. Shee, M. C. Claeys, R. P. Lemenager, and J. P. Schoonmaker. 2013. Dietary inclusion of condensed distiller's solubles in gestating and lactating beef cows. J. Anim. Sci. 91(E-Suppl. 2):132. (Abstr.)

C. N. Shee, M. C. Claeys, R. P. Lemenager, and J. P. Schoonmaker. 2013. Effect of feeding distiller's dried grains with solubles during lactation on milk fatty acid composition. J. Anim. Sci. 91(E-Suppl. 2):129. (Abstr.)

J. P. Schoonmaker, M. Engstrom, K. N. Condron, C. N. Shee, and R. P. Lemenager. 2013. Effect of supplementing gestating and lactating beef cows with supranutritional concentrations of vitamin D on cow production and pre-weaning growth of the calf. J. Anim. Sci. 91(E-Suppl. 2):140. (Abstr.)

Activities and Affiliations

American Society of Animal Science – Member
Purdue Animal Science Graduate Student Association – Student Outreach Chair