Impact of Nutritional Management Regimen and Residual Feed Intake on Cow Performance during Mid to Late Gestation and Pre-weaning Calf Performance

By

Katelyn Marie Spence

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ABSTRACT

IMPACT OF NUTRITIONAL MANAGEMENT REGIMEN AND RESIDUAL FEED INTAKE ON COW PERFORMANCE DURING MID TO LATE GESTATION AND PRE-WEANING CALF PERFORMANCE

Katelyn Marie Spence
University of Guelph, 2017

Advisor:
Dr. Ira B. Mandell

This study examined the impact of strategic supplementation of straw-based diets with an energy-protein supplement and previously established residual feed intake (RFI) classification on beef cow performance (body weight, condition, feed intake, reproductive performance) in mid to late gestation and pre-weaning calf performance. Nutritional management regimens included nutrient adequate and deficient diets, along with examining frequency of supplementation to correct nutrient deficient diets. RFI classification was used to measure feed efficiency. RFI classification changes between years, and second and third trimesters were evaluated to establish influence of nutritional management regimen. Blood parameters were evaluated to assess effects of strategic supplementation in late gestation. The overall objective of the study was to evaluate how supplementation of low quality feed stuffs affects cow performance. The overall goal was to reduce the cost of production in beef cow-calf operations, with the use of more feed efficient cows and low quality feed stuffs.

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List of Abbreviations

ADF	**Acid detergent fiber**
ADG	**Average daily gain**
AI	**Artificial insemination**
BCS	**Body condition score**
BHB	**B-hydroxybutyrate**
BW	**Body weight**
CGM	**Corn gluten meal**
CP	**Crude Protein**
DDGS	**Dried distillers grains with solubles**
DIP	**Degradable intake protein**
DM	**Dry matter**
DMI	**Dry matter intake**
EBRS	**Elora Beef Research Station**
FCR	**Feed conversion ratio**
G:F	**Gain : Feed**
MBWT	**Metabolic body weight**
ME	**Metabolizable energy**
MEI	**Metabolizable energy intake**
NDF	**Neutral detergent fiber**
OM	**Organic matter**
RFI	**Residual feed intake**
RMEI	**Residual metabolizable energy intake**
TMR	**Total mixed ration**
UIP	**Undegradable intake protein**
VFA	**Volatile fatty acids**

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1.0 Introduction

In the beef industry, the greatest cost of production is the cost of feed. Cow-calf producers can utilize pasture grazing to reduce feed costs, as cows harvest the forage themselves, eliminating the cost of harvesting and labour. However, in the northern climate of Canada it is not always possible for cattle to have access to quality grazing year round. Therefore low-cost nutritional regimens are required during the winter months. Cow-calf producers often rely on harvested forages such as hay and(or) haylage to maintain cows during the winter. The costs of maintaining the cow herd are substantial as 65-85% of the total energy required for beef production is used by the breeding herd (Berry 2008). In beef cows, 70-75% of dietary energy intake is utilized for maintenance requirements alone (Ferrell and Jenkins 1985). During gestation, energy is the first limiting nutrient; thus if there is not adequate energy provided, dietary protein will be utilized to meet energy requirements before being utilized for protein requirements (Clanton and Zimmerman 1970). Rumen microbes in the reticulo-rumen allow the cow to utilize plant cell structures that cannot be used by mammalian digestive enzymes. The breakdown of these cell structures produces volatile fatty acids (VFA) that are used for energy. The products of protein degradation in the rumen are used by the rumen microbes to build the microbial biomass, meet maintenance requirements and synthesize microbial protein (Moorby et al. 2008). The ability of the cow to utilize dietary protein can be limited by the rumen microbes due to excessive catabolism of high-quality protein coupled with inadequate amounts of readily fermentable carbohydrate for microbial protein synthesis. The microbial protein that passes into the small intestine is generally available to be utilized and absorbed by the ruminant.

The ability of cattle to ferment feedstuffs in the reticulo-rumen make them more compatible for the use of lower quality feedstuffs with the growing population of the world and modernization. There is an increased demand for feedstuffs such as corn for human consumption and ethanol production. In the United States alone, the production of corn ethanol has tripled since the start of the 21st century (Berry 2008). Less corn is being used as a feedstuff for animal production, and more quality agricultural land is being used to grow corn for ethanol or human consumption (Berry 2008). This also decreases land for grazing and forage production while increasing reliance on ‘by-product’ feedstuffs such as cereal straws and stover that will require protein supplementation with feed ingredients such as soybean meal and corn-gluten meal. Many past studies (Stalker et al. 2007; Larson et al. 2009; Bohnert et al. 2013; Mathis et al. 1999; Wood et al. 2010a; Wood et al, 2010b; Huston et al. 1999) have evaluated the use of low quality forages (low in CP, high in NDF and lignin) during late gestation plus various protein and(or) energy supplements to meet nutrient requirements for beef cows in late gestation. These studies have shown that these approaches do not impact the cow’s ability to produce and wean a calf. However most of these studies provided supplements daily, which increases the cost of labour for cow-calf producers.

Another method to reduce the cost of production for cow-calf producers is to select more feed efficient animals for the breeding herd. There are limitations with measuring feed efficiency in cows as they are no longer growing once attaining physical maturity, and any gains or losses in body weight when in good body condition outside of pregnancy represent inefficient use of nutrients. Although increases in body weight may provide additional body stores to use in harsh winter months or during early lactation to meet high energy demands. In the past, beef researchers assessed feed conversion ratio, a measure of the amount of feed required to meet one unit of gain in weight. The feed conversion ratio is also influenced by breed and mature body weight. A cattle breed or animal with a heavier mature body weight will have a more desirable feed conversion ratio. Thus selection for feed efficiency using feed conversion ratio will result in larger framed cows with higher maintenance requirements; this increases total feed requirements on a daily basis (Crews 2005).

Residual feed intake (RFI), another measure of feed efficiency is the difference between the actual feed intake and the predicted feed intake for a given animal based on the regression of performance traits on dry matter intake (DMI) measured over a 128-day test period (Koch et al. 1963). The base RFI model is a regression of DMI on average daily gain and mid-test metabolic body weight, which yields a predicted dry matter intake; this value is subtracted from the actual feed intake to determine residual feed intake (Koch et al. 1963). Cows are classified as low RFI cows if they consume less feed than expected, while they are classified as high RFI cows if they consume more feed than expected. RFI is more heritable (h = 0.39) than feed conversion ratio (h = 0.29) (Arthur et al. 2001), making RFI a better selection trait to assess feed efficiency in the breeding herd. Since there is a large amount of labour and cost associated with data collection for determining RFI classification, it is not practical for most cattle operations to calculate this efficiency trait. To use RFI in the beef industry, it would be best implemented in the breeding herd as there is a high heritability for RFI, indicating that feed efficiency would be passed onto offspring entering the feedlot. This could reduce feed inputs and costs for the beef sector as a whole.

There are a vast number of demands impacting livestock agriculture in Canada; these include that livestock production should be sustainable, efficient and environmentally friendly. A solution to meet these demands for the beef industry is to have low-RFI breeding herds that can utilize low-quality feedstuffs in late gestation. In order to do this, RFI needs to be fully evaluated for beef cows to examine the impact that selection for feed efficient animals can have on various aspects of beef production such as reproduction and meat quality. In addition, there is a need to evaluate the effects of different nutritional management regimens on feed efficiency. The objectives of this study were to 1) to determine the effects of strategic supplementation of low-quality, forage-based diets on cow performance in second and third trimesters of gestation, 2) evaluate the effects of nutritional management regimen on RFI classification during second and third trimesters, and 3) determine changes in RFI classification between years and between trimesters, and how they are affected by nutritional management regimens that change the amounts of nutrients supplied to gestating beef cows.

2.0 Literature Review

2.1 Nutrient Requirements for Gestating Beef Cows

Nutritional requirements constantly change throughout a cow's life cycle. During gestation the cow has the lowest nutritional requirements in second trimester once the previous calf has been weaned and there is little fetal growth. This drastically changes as gestation progresses into third trimester and the fetus begins to grow. Third trimester in North America often coincides with harsh winter climates that further increase the nutritional requirements and energy need for the cow. Complicating this is the variation in maintenance requirements among mature cows with varying genotypes, due to differences in mature body size (NRC 2000). Laurenz et al. (1991) found that Angus cows required 21 % less metabolizable energy (kcal/$BW^{0.75}$) than Simmental cows. For a 50% Angus cow, it is estimated that the metabolizable energy requirements are 104 kcal/$BW^{0.75}$ (NRC 2000). As cows transition from gestation to lactation, maintenance energy requirements increase by 20% (NRC 2000). To maintain and maximize production in the beef cow, it is critical to meet maintenance energy requirements at various stages of production and environmental seasons.

2.2 Low-Quality Diets for Gestating Cows

Ruminants utilize microorganisms (bacteria, protozoa, fungi) in the reticulo-rumen and cecum of the hindgut to ferment feedstuffs. Microbial fermentation in the reticulo-rumen is an advantage for ruminants, in that it allows the components of the feedstuff such as cellulose and hemicellulose to be digested before the small intestine. These fermentation processes (pre-gastric and hindgut) produce volatile fatty acids (VFA) including acetic, propionic and butyric acids that can be used to meet energy demands for the animal. In addition, propionic acid is important for the production of glucose in the animal. Microbial fermentation in the reticulo-rumen can be a disadvantage for ruminants, because the microbes responsible for fermentation utilize dietary nutrients before the ruminant does. This includes utilization of high-quality feedstuffs that would otherwise be available for digestion in the ruminant abomasum and small intestine. Microbial fermentation can decrease the quality of high-quality feedstuffs such that the products of microbial fermentation are inferior in nutrient composition than what was present in the undigested feedstuff.

Clanton and Zimmerman (1970) found that energy is the first limiting nutrient for beef cattle, and not protein. If energy becomes limiting, then protein will be catabolized to meet energy requirements first and then any surplus protein can be used to meet protein requirements (Clanton and Zimmerman 1970). When feeding low quality forage diets containing high amounts of neutral detergent fiber (NDF), both dietary energy and protein can be limiting due to nutrients being inaccessible within plant cell walls. A low-quality forage would be a forage with greater than 50-60% NDF and less than 10% crude protein (CP). In order to meet nutrient requirements, the diet can be supplemented with more concentrated sources of energy such as grain, good-quality haylage (less than 50-60% NDF) and(or) protein supplements such as soybean meal or corn gluten meal. Another approach is to provide a feedstuff that can provide both energy and protein such as dried distillers grains with solubles (DDGS) (Ham et al. 1994). Supplementation of low-quality diets allows producers to maintain low costs of feed, reducing their costs of production. Feeding low-quality feedstuffs such as straw can be beneficial when the cow has low energy demands such as in the second trimester of pregnancy. However, straw-based diets will require supplementation during periods of increased energy demands such as the third trimester of gestation or during lactation. In late gestation, beef cows have increased demands for energy and protein; this is due to the dramatic increase in growth of the conceptus while late gestation often occurs during cold winter months when added energy is needed to overcome the harsh environment.

2.1.1 Energy Supplementation for Gestating Cows

Ruminants absorb limited amounts of glucose from their gastrointestinal tract, as glucose is utilized by microbes in the reticulo-rumen for fermentation. Ruminants rely on gluconeogenesis to supply their glucose requirements (Wiltrout and Satter 1972). Propionate (propionic acid), a VFA produced during fermentation in the rumen, is converted to glucose through gluconeogenesis. This process occurs primarily in the liver. There are two main pathways in which propionate is converted into glucose by gluconeogenesis. Propionate can be converted to succinyl-CoA, where it can enter the citric acid cycle and be converted into pyruvate to produce glucose directly, or propionate can cycle through the citric acid cycle once before producing glucose. Some ruminants are more efficient at utilizing propionate to produce glucose when fed a high-roughage diet (Wiltrout and Satter 1972). A propionate supplement such as calcium propionate can be included in ruminant diets to increase the energy content of the diet as the supply of propionate is increased in the rumen and small intestine where it can be utilized by either the rumen microbes or the ruminant. Wiltrout and Satter (1972) compared the effects of ruminal infusion of propionate, acetate and butyrate on the production of glucose in both dry and lactating dairy cows during gestation. The authors found 32% of glucose carbons were derived from the ruminally infused propionate as compared to 8 and 11% respectively for glucose carbons derived from ruminally infused butyrate and acetate. In dairy cows supplemented with calcium propionate during the transition period, there was a trend for increased feed intake before calving followed by a significant increase in intake post-calving (McNamara and Valdez 2005). The addition of calcium propionate had no effect on lipogenesis (fat synthesis), when cows were in a positive energy balance pre-calving. However, post-calving dairy cows fed calcium propionate had increased lipogenesis and feed intake, at a time when there is a dramatic increase in energy demands (McNamara and Valdez 2005). This suggests that propionate can be supplemented to provide readily available glucose to reduce the negative energy balance for late gestation beef cows fed lower quality diets.

There are other feedstuffs such as corn gluten meal, which can be added to the diet to increase the dietary energy content. Corn gluten meal (CGM), a co-product of the wet corn milling industry, is a high-fiber, low-starch energy source that is also very high in protein and sulphur (Cordes et al. 1988; Scaglia et al. 2013). CGM is produced in the final stages of wet corn milling, where corn is steeped in sulphur dioxide at high temperatures prior to the grinding of the corn germ; the mixture is then centrifuged to separate the starch and the corn gluten, resulting in CGM. The sulphur dioxide steeping process results in CGM having increased levels of sulphur. This can be an issue where high levels of CGM are included in the diet as sulphur levels may become toxic to livestock. Cordes et al. (1988) found CGM produced greater 72-hour organic matter (OM) and NDF digestibility values than soybean hulls and corn bran in vitro. In in-vivo studies, CGM supplementation had no negative impact on the digestion of hay and increased the OM intake of hay; however, it did not increase the digestibility of the hay when compared to corn-urea supplementation (Cordes et al. 1988). CGM can be included in diets to provide an additional protein and energy source, and increase the intake of forages, although caution needs to be taken to avoid sulphur toxicity. Therefore supplementation of CGM in late gestation can increase the energy content of the diet.

Corah et al. (1975) compared the performance in heifers fed an energy-deficient diet (65% of the recommended NRC [1970] levels) 100 days prior to calving versus heifers fed a diet meeting energy requirements. The restricted heifers lost weight and fat stores (based on changes in subcutaneous rib fat depth) and produced calves with lighter birth and weaning weights than heifers fed to meet energy requirements. These results are not consistent as DeRouen et al. (1994) found no difference in calf birth weights when heifers were fed varying levels of energy during gestation. Study-to-study differences in calf performance may be due to differences in diet pre and postpartum, season, location, duration of trial, management and breed. Since the energy-deficient and energy-sufficient diets contained equal amounts of dietary protein in the Corah et al. (1975) study, reduced calf birth weights in dams fed the energy-deficient diets may have been due to protein being used as a source of energy rather than meeting protein requirements (Clanton and Zimmerman 1970). The pre-partum nutrient-deficient diet showed no impact on return to estrus, indicating that the cows were able to overcome the pre-calving nutrient deficit (Corah et al. 1975). In a similar study for heifers fed low, intermediate and high levels of energy during late gestation, no plane of energy was enough for high body condition score (BCS) heifers (range of 6 to 7 BCS) to maintain BCS (DeRouen et al. 1994). Corah et al. (1975) compared performance of cows fed a restricted diet throughout gestation to cows fed a nutrient-restricted diet until the last 30 days of gestation followed by feeding a high-energy diet until calving. Body weight (BW) losses were reduced by feeding the extra energy in late gestation. Mature cows that were fed an energy-restricted diet in the last 100 days of gestation had greater losses in fat coverage, increased calf mortality and greater incidence of scours than cows fed to meet nutrient requirements in late gestation (Corah et al. 1975). It is possible there was less of an effect on calves from second-parity cows as those cows would have reached full maturity when compared to first-parity cows as they have the added nutritional demands of their own growth during gestation. The use of low quality forage based diets in late gestation often fail to meet energy nutrient requirements and can have detrimental impacts on the cow and subsequent calf performance. This shows that energy is an important nutrient especially in late gestation. The past studies show that a diet restricting energy can result in loses in the fat reserves and BW during late gestation. While these losses are often accompanied by lighter birth and weaning weights for calves, this response is not necessarily consistently reported.

2.1.2. Protein Supplementation for Gestating Cows

If energy is the first-limiting nutrient, then protein in the diet can be utilized to meet the energy requirements (Clanton and Zimmerman 1970). Protein supplementation for pregnant cows grazing dormant pastures increased BCS and BW pre-partum more than cows that were not supplemented on pasture (Stalker et al. 2007; Larson et al. 2009). Multiparous cows supplemented with protein during the winter months had increased intakes of hay when the forage was low in protein; thus supplementation of protein may increase feed intake for cattle fed low protein forages (Clanton and Zimmerman 1970). These authors found that non-pregnant cows supplemented with protein gained weight more uniformly in the winter months than cows that were not supplemented; although non-supplemented cows gained more weight during the summer months to have comparable weight gains (Clanton and Zimmerman 1970). In cows pastured on winter range land and supplemented with protein, thus reducing crude protein deficiency, in the last trimester resulted in cows calving earlier in the calving season than non-supplemented cows (Larson et al. 2009). This contrasts to Stalker et al. (2006), where protein supplementation resulted in cows calving later in the calving season. Cows in the Larson et al. (2009) study remained on the same dietary treatment for 3 years so their results may be due to the effects of continuous nutrient restriction, whereas the cows in the Stalker et al. (2006) study changed dietary treatments between years.

Corn dried distillers grains with solubles (DDGS), a co-product of the ethanol industry, can be used as an energy and protein supplement (Winterholler et al. 2012). The use of DDGS as a protein supplement for cows during gestation decreases losses in BCS and BW when fed at 0.9 kg/day (Bohnert et al. 2013), and as the amounts of DDGS fed in the diet increased (Winterholler et al. 2012). Kennedy et al. (2016) reported greater gains in cows fed corn stover with DDGS in late gestation when compared to cows not supplemented with DDGS. These authors noted an interaction between stage of production and dietary treatment for forage dry matter intake (DMI). Cows supplemented with DDGS consumed more forage in the last 30 days of gestation compared to cows fed the same diet without supplementation. However, this supplementation in gestation did not affect the DMI and BW post-calving as both supplemented and non-supplemented cows lost weight with no differences in DMI during lactation. Cows supplemented with DDGS have greater BCS at time of weaning than cows that were not provided a supplement during late gestation (Bohnert et al. 2013; Stalker et al. 2007).

Bandyk et al. (2001) examined the effects of infusing the milk protein, casein on voluntary feed intake in steers fed low-quality forages. Voluntary feed intake increased more when casein was infused directly into the rumen versus infusion into the small intestine. Ruminal infusion of degradable intake protein (DIP), casein, increased digestible OM intake likely due to digestibility and rate of passage of the casein. The increased intake hich resulted in an increase in rumen VFA concentrations. These same steers had greater rumen concentrations of ammonia nitrogen than steers not infused with casein when fed the same low- quality forage diet. The feeding of DIP may increase feed intake versus feeding an undegradable protein supplement, as rumen ammonia nitrogen concentrations were greater when casein was infused into the rumen, in comparison to infusing casein postruminally. Ruminal infusion of casein increased the amount of ruminally available nitrogen (Bandyk et al. 2001), which will increase the amount of microbial protein produced by the rumen microbes. Past studies have found that DIP is a limiting nutrient when cattle are fed a diet low in protein (less than 10% CP) or nitrogen (Bandyk et al. 2001; Winterholler et al. 2012).

Mathis et al. (1999) evaluated the effect of increasing the amount of soybean meal in diets for late gestation cows that were winter grazing. Increasing the amount of soybean meal decreased losses of BW and body condition until supplementation reached 0.3% BW; BW plateaued with increased levels of soybean meal provided in the diet. There were no differences in calf birth weights from cows fed varying levels of soybean meal throughout gestation. Mathis et al. (1999) concluded that since winter grazing pastures were low in nitrogen, the DIP found in soybean meal had a greater impact on digestible OM intake than supplementing with undegradable intake protein (UIP). The latter would have to be degraded in the small intestine and recycled back to the rumen, making it less effective than DIP for supplying nitrogen to the rumen microbes. When DIP is not supplied on a regular basis it can result in a surplus of ammonia produced by the rumen microbes. This excess ammonia is absorbed into the bloodstream and is converted to urea in the liver before being recycled back to the rumen or excreted in the urine (Bohnert et al. 2002; Leng and Nolan 1984). In the small intestine, UIP is absorbed into the bloodstream as free peptides and amino acids, which can be used directly by the animal or converted to urea. Bohnert et al. (2002) suggested that UIP makes a better supplement if supplemented frequently as it has the least effect on nitrogen efficiency and increased DMI as level and frequency of supplementation increased. In wethers, UIP supplementation increased NDF digestibility better than supplementation with DIP (Bohnert et al. 2002). When cows were supplemented with DIP and UIP at varying frequencies, any form of supplementation decreased BW losses post-calving (Bohnert et al. 2002).

Huston et al. (1999) supplemented gestating cows on dormant pastures with cottonseed meal (a source of protein with up to 42 to 50% UIP), at varying intervals; pre-calving BW losses decreased versus non-supplemented cows. However, these authors found that changes in BW were not affected when comparing non-supplemented cows to cows supplemented once a week with cottonseed meal. Hunt et al. (1989) found that intakes of DM and NDF increased when steers were supplemented with cottonseed meal. Supplementation with cottonseed meal increased in situ disappearance of NDF and acid detergent fiber (ADF) in cannulated steers and increased concentrations of ruminal VFA (Hunt et al. 1989). Total DM intake and digestibility increased in steers when supplemented with soybean meal and rolled sorghum regardless of the level of supplementation (Del Curto et al. 1990). These authors reported decreased NDF digestibility in steers supplemented with low levels of protein; the depression in digestibility may have been due to increased starch content or low nitrogen availability of the supplement. Protein supplemented steers had as much as a 30% increase in VFA concentrations in the rumen. When steers were supplemented with energy or protein, forage intake decreased in steers supplemented with greater amounts of energy (Del Curto et al. 1990). With energy being the first-limiting nutrient, protein is utilized to meet energy demands when energy is limited, thus supplementation with protein can be beneficial in late gestation. Several studies have found that increased protein supplementation results in reduced losses in BW and BCS, especially when fed a low-quality diet. However, there have been contradicting reports on the effect of protein supplementation on the length of gestation.

2.1.3 Effect of the Diet on Cow and Calf Performance

The nutrient content of the diet can have an impact on cow performance and subsequently calf performance. As a cow progresses through gestation, energy and protein requirements increase which can result in the cow mobilizing fat and protein stores to meet increased nutrient demands if they can not be met by the diet. When evaluating body energy reserves in mature cows, body condition scoring is an adequate predictor for assessing body composition (Wagner et al. 1988). There can be up to a 25% change in BW, including conceptus weight, in cows with high body condition (range of 6 to 9 BCS), without influencing productivity of the cow (Huston et al. 1999). This implies that cows can mobilize significant body reserves to meet increased demands without having negative effects on cow and calf performance.

Start of trial BCS impacted conception rates with high BCS cows (BCS of approximately 6) having greater conception rates than cows with low BCS (BCS of approximately 4) (Bohnert et al. 2013). Cows with higher BCS had greater percentage of calves live at birth and at time of weaning, with heavier birth weights than calves from cows with lower BCS (Bohnert et al. 2013). There was no influence of cow BCS on calf weaning weight, but Bohnert et al. (2013) found that cows supplemented in late gestation weaned heavier calves. This is also supported in other studies (Larson et al. 2009; Stalker et al. 2006; Stalker et al. 2007). Richards et al. (1986) found that even with varying planes of postpartum nutrition, cows that had a BCS of five or greater at the time of calving returned to estrus earlier than those with lower BCS. Cows with a BCS < 4 at calving had a longer interval to estrus and pregnancy despite being fed at high levels of nutrition post-partum. Richards et al. (1986) fed a low plane of nutrition designed to cause weight loss postpartum; cows with high BCS had greater pregnancy rates versus cows with low BCS, regardless of post-partum diet. First-parity cows with higher BCS at calving (range of 6 to 7) had greater conception rates and shorter interval to conception than cows with lower BCS (range 4 to 5) (DeRouen et al. 1994).

Cows with a high BCS at time of calving are more productive post-calving, demonstrating how important it is to maintain high BCS during gestation. Dunn and Kaltenbach (1980) demonstrated that, of cows that did not fluctuate in BW pre-calving, 91% showed estrus by 60 days post-calving and the number of cows showing estrus decreased by 0.5% for every kilogram of BW lost. These authors developed a regression equation, y = 46.9 - 0.17 (x), where y is the postpartum interval to first estrus in days and x is the BW change pre-calving in kilograms in the last 100 days of gestation. The equation predicts the interval to first estrus based on the amount of weight lost in last gestation.

There was no effect of protein supplementation in cows grazing pasture during the last trimester on conception rates (Larson et al. 2009; Stalker et al. 2006, Winterholler et al. 2012). Cows supplemented pre-partum with 42% crude protein and 73.3% TDN were able to maintain weight and increase BCS during gestation; this gain in BCS during the pre-partum period was still present at the start of the breeding season (Stalker et al. 2006). The non-supplemented, pre-partum cows gained body condition after calving, which may be the reason why there was no difference in conception rates when compared to supplemented cows. Past studies have recommended a BCS of 5 (on a scale from 1 to 9) to attain optimum conception rates (Richards et al. 1986; Morrison et al. 1999). However, Stalker et al. (2006) found that BCS slightly under the recommended rate of 5 had no significant impact on conception rates. The same study found heavier weaning weights and greater average daily gains (ADG) prior to weaning in calves from cows supplemented with a crude protein supplement during gestation, possibly because the cows were not nutrient deficient during gestation.

Studies have been inconclusive about the impact of protein supplementation during late gestation on subsequent calves' birth weights; some studies suggest that protein supplementation will increase birth weight (Clanton and Zimmerman 1970; Larson et al 2009; Winterholler et al 2012) while other studies found that protein supplementation did not affect birth weights (Stalker et al 2006; Martin et al 2007). When a protein supplement was provided to cows in late gestation, there was no difference in birth weights of heifer calves compared to unsupplemented cows (Martin et al. 2007). However, heifers from cows fed a protein supplement had greater conception rate and were more likely to calve early in the calving season (Martin et al. 2007).

Studies have shown that cows with higher BCS at calving have an increased number of calves born alive and reduced pre-weaning mortality with increased calf weights. These cows also lose less BW post calving and have increased conception rates. Although protein supplementation reduces weight loss during gestation, supplementation does not always result in heavier calf weights and greater conception rates. This may be related to differences in BCS in mid gestation combined with not enough energy being provided to improve poorer BCS during gestation.

2.1.3.1 Conceptus Nutrient Demands and Utilization

The fetus utilizes glucose and amino acids for its metabolism and growth (Bell 1995). In late gestation, only 32% of the amino acids taken up by the fetus are deposited in protein tissues, indicating that fetal requirements for amino acids are three times greater than net fetal retention. In late pregnancy, 20% of the gravid uterus is comprised of the uteroplacental tissues (myometrium, endometrium and placentomes), which are responsible for the use of 65% of the glucose utilized by the uterus in cows. The placenta is responsible for the greatest consumption of glucose and oxygen by the uterus and not the fetus itself (Bell. 1995).

In cows, the maternal supply of glucose to the fetus is 1476 grams per day, well exceeding the supply of amino acids at 998 grams per day; only 666 grams per day of glucose and 718 grams per day of amino acids are taken up by the uterus (Bell 1995). Fetal plasma concentrations of urea increase because of maternal undernutrition as there is less glucose available, so available amino acids in circulation are utilized as an energy source for the fetus (Breier 2006). Since the transport of glucose to the fetus is the result of facilitated diffusion based on the concentration gradients of the maternal-fetal plasma glucose concentrations, the transport of glucose is sensitive to changes in maternal plasma glucose concentrations (Bell 1995). The gestating cow undergoes changes in protein, carbohydrate and lipid metabolism in order to meet the fetal requirements. Bell (1995) noted that rates of gluconeogenesis increase in gestating ewes, even when nutrient restricted. In late gestation, nonesterified fatty acids and ketone concentrations increase in animals as maternal glucose and amino acids are utilized by the conceptus (Bell 1995). This shows as gestation progresses the cow changes metabolism to maintain the growing fetus.

2.2 Feed Efficiency

Feed efficiency cannot be directly measured but can be calculated as a function of time, feed consumed and gain in body weight (Koch et al. 1963). Feed intake has a stronger correlation with residual feed intake (RFI) than feed conversion ratio (FCR) (Arthur et al. 2001). Variation in feed efficiency can be the result of different environments in which the animals were evaluated (Koch et al. 1963). The FCR is a ratio of gain to feed, measuring the amount of feed required to meet gains in weight. Therefore, FCR can result in increased mature BW as it is unclear if the ratio is selecting for increased gain or feed (Crews 2005). A multi-year study found the heritability of residual feed intake to be 0.39 while the heritability of FCR was 0.29 (Arthur et al. 2001). Selection for decreased FCR can result in increased mature BW, growth rates and maintenance requirements at maturity (Crews 2005). Increasing the final mature BW of an animal will not always result in the animal utilizing the feed in the most efficient manner as it results in increased nutrient requirements. There is a negative correlation between ADG and internal fat depots suggesting that the amount of internal fat in steers has a negative impact on ADG (Mader et al. 2009). Changes in fat and lean deposition influence efficiency during growth, as lean deposition requires less energy from the diet than fat deposition (Mader et al. 2009). The positive relationship between gain: feed (G:F) ratio in steers and the amount of bone and lean in the rib suggests that selection for G:F favours steers that are less mature, having less calcification of bones; thus physical maturity affects FCR (Mader et al. 2009).

RFI or net feed efficiency is the difference between the predicted feed intake and production level requirements and actual feed intake (Koch et al. 1963). Animals that consume less than predicted are considered feed efficient and are classified as low RFI. In contrast, animals that consume more than predicted are considered less feed efficient and are classified as high RFI. Feed efficiency can be influenced by genetic variation. RFI and FCR are positively correlated in both Angus and Charolais steers (Mao et al. 2013). In growing steers and bulls, higher FCR was found in cattle sired by Charolais sires than those sired by University of Alberta Hybrid sires (composited of Angus, Charolais, Galloway, Hereford, Holstein and Brown Swiss) (Nkrumah et al. 2004). Partial efficiency of feed utilization for growth was correlated to increases in back fat, lean meat yield, grade fat and yield grade in growing steers and bulls (Nkrumah et al. 2004). In trying to select for feed efficiency, there can be negative effects on other performance traits based on how feed efficiency is determined. For example, the FCR can influence the mature body weight of the animal, along with fat depths. Therefore, care needs to be taken to avoid negative outcomes.

2.2.1 Residual Feed Intake

Residual feed intake (RFI) is the difference or residual between the actual feed intake and the predicted feed intake for production level requirements. RFI is independent of production traits that are used to calculate feed intake; thus RFI can be used to evaluate animals at different stages of production (Herd and Arthur 2009). Herd et al. (2004) proposed that variations in RFI can be explained by 5 biological factors, 1) feed intake, 2) how feed is digested, 3) metabolism and body composition, 4) physical activity and 5) thermoregulation. The original RFI model proposed by Koch et al. (1963) is:

$$Y = \beta_0 + \beta_1(ADG) + \beta_2(MBWT) + RFI \text{ (residual portion)}$$

where Y is the average daily DMI measured over 154 days, β_0 is the regression intercept, β_1 is the partial regression of daily intake on ADG, and β_2 is the partial regression of daily intake on mid-test metabolic body weight (MBWT). Coefficients of determination (R^2) for the base RFI model ranged from 0.52 to 0.79 (Black et al. 2013; Durunna et al. 2012; Hafla et al. 2013). Black et al. (2013) found that adding breed, changes in back fat depth, and stage of lactation to the RFI models accounted for 33.4, 16.4 and 12.2 to 14.4% respectively of the variation in RFI. Basarab et al. (2007) observed there was extensive variation in RFI for gestating cows and concluded this to be due to the fact the gestating cows are not growing and that ADG is not calculated as a regression, as it is calculated as the difference in start and end of trial BW. Kelly et al. (2010b) found in heifers that concentrations of urea, insulin and β-hydroxybutyrate (BHB), amount of kidney fat accretion and number of daily feeding events explained 54% of the variation observed in RFI with the following RFI mode: RFI = -5.41 + 4.23 × (BHB) + 0.19 × (urea) + 0.06 × (insulin) + 0.02 × (number of daily feeding events) + 7.25 × (mm of kidney fat accretion/d).

Cows from a low-RFI breeding line were leaner than cows from a high-RFI breeding line (Arthur et al. 2005), although it is not clear if being leaner results in the cow being more feed efficient or if being feed efficient results in the cow being leaner. Low-RFI steers, heifers and mature cows consume less feed than their high-RFI counterparts (Basarab et al. 2007; Black et al.

2013; Durunna et al. 2011b; Fitzsimons et al. 2014; Hafla et al. 2013; Kelly et al. 2010a; Lawrence et al. 2011; Manafiazar et al. 2014; Richardson et al. 2001). Low-RFI cattle spend less time eating their daily feed allotment than high-RFI cattle (Basarab et al. 2007; Fitzsimons et al. 2014; Hafla et al. 2013); this may indicate that low-RFI cattle use less energy consuming feed which provides more energy for maintenance and production. Reduced feed consumption was observed in low-RFI ewe and yearling lambs (Redden et al. 2014). The addition of feeding behaviour variables (feeding duration, feeding frequency, non-feeding time at feeder, eating rate) to the RFI model increased the amount of variation accounted for by the RFI model (Durunna et al. 2011b; Fitzsimons et al. 2014). High-RFI cows consumed more in the five hours after feeding than low-RFI cows. This 5-hour assessment period was the first period in the day that the RFI × time interaction, had a significant effect on DMI showing that low-RFI cattle spend less time and energy eating throughout the day (Fitzsimons et al. 2014). High-RFI growing heifers consume larger meals and have faster eating rates (Hafla et al. 2013, Kelly et al. 2010a) than low-RFI heifers (Hafla et al. 2013; Kelly et al. 2010a). When RFI was evaluated in heifers and again as mature cows, low RFI heifers consumed less forage as mature cows (Hafla et al. 2013). From the growing phase to fully mature animal, the rank of feed efficiency is maintained throughout the animal's productive life cycle. Hafla et al. (2013) suggested cattle may only need to be evaluated for feed efficiency once in their life for an accurate assessment of feed efficiency at all stages of production. However, the diet may play an important role in assessing feed efficiency.

When evaluating both gestating and lactating cows of known RFI classification on pasture, there was no difference in the area of pasture needed to maintain high- and low-RFI cows (Meyer et al. 2008). Specific RFI classifications did not affect DMI on pasture during gestation or lactation (Meyer et al. 2008). The findings of Hafla et al. (2013) support this; low

RFI classification cows maintained a lower forage DMI as a mature cow. There is no relationship between RFI classification and age at puberty (Basarab et al. 2011). Hafla et al. (2013) evaluated RFI in heifers and subsequently as first- and second-parity cows and found no interaction between parity and RFI classification.

Phenotypic RFI classification for steers was not correlated to metabolic BW, ADG, final BW and slaughter weight (Nkrumah et al. 2007). In high-RFI steers, there was 28% more methane production than in low-RFI steers (Nkrumah et al. 2006). Heat production was also 21 and 11% greater. Respectively, in high- and medium-RFI steers as compared to low-RFI steers, and energy retention was reduced (Nkrumah et al. 2006). High-RFI cattle are not efficient at utilizing energy absorbed from the diet or produced through metabolic processes. In steers, there is a negative association between RFI and the digestibility of crude protein (CP); DM and NDF digestibility values were numerically greater in low- versus high-RFI steers (Nkrumah et al. 2006).

Of the current methods to quantify feed efficiency, RFI provides the best measurement of feed efficiency in mature cows. Although it was not designed to be used in non-growing animals, RFI allows for selection without influencing the mature body weight of the animal. However, past studies have been inconclusive about the relationship of RFI and cow performance.

2.2.1.1 Relationships between Residual Feed Intake Classification Group and Cow Reproduction

The effect of RFI on calving date is inconclusive (Arthur et al. 2005; Basarab et al. 2007; Hafla et al. 2013); these studies found low RFI cows calved later in the season than high-RFI cows. In growing heifers, meeting sufficient nutrient requirements and body reserves is critical for the onset of puberty (Hafla et al. 2013). Basarab et al. (2007) found an interaction between RFI and animal age showing that heifers that calved later in the calving season continued to exhibit late calving for the remainder of their productive lives. It is possible that the difference in calving dates between high- and low-RFI cows will become further apparent after more generations of selecting for RFI, as the phenotypic traits will become inflated (Arthur et al. 2005). Hafla et al. (2013) evaluated the effects of RFI classification in Bonsmara cattle, a South African cross between British breeds and the Afrikaners breed. There was a trend for low RFI heifers to be younger at the initiation of the RFI classification evaluation period with heavier weaning weights than the high RFI heifers. This data indicates that low-RFI heifers will physically mature later than high-RFI heifers.

Basarab et al. (2007) observed no differences in conception, calving and weaning rates between animals of difference RFI classifications. However, high-RFI cows had a greater rate of twinning and calf death loss when compared to low- and medium-RFI cows (Basarab et al. 2007). There were no differences noted in birth weights, ADG and weaning weights between cows of different RFI classification (Basarab et al. 2007; Black et al. 2013; Fitzsimons et al. 2014; Meyer et al. 2008). RFI classification did not affect calf birth weight for gestating heifers fed haylage (Lawrence et al. 2011). This contrasts to Hafla et al. (2013) where lighter calf birth weights were found with first-parity, low-RFI cows when compared to their high-RFI counterparts; there was no effect of RFI classification on calf birth weights from second-parity cows in the same study. In heifers, there were no relationships between DMI, BW fat depths and milk production and RFI classification in early calving heifers (Lawrence et al. 2011). Low-RFI cows and heifers have lower conception rates at the beginning of the breeding season when compared to high-RFI cows (Basarab et al. 2011). This results in fewer low-RFI cows and heifers conceiving early in the breeding season and calving early in the calving season (Basarab et al. 2011). Low-RFI steers were more likely to be the offspring of low-RFI parents than high RFI parents (Richardson et al. 2001). There is inconclusive evidence from past studies regarding the effects of RFI on length of gestation, conception rate, calf pre-weaning mortality and calf birth weights.

2.2.1.2 Relationships between Residual Feed Intake Classification Group and Cow Performance Traits

There are a number of factors that can influence RFI classification and body mass. Studies examining the effects of RFI classification on back fat depth, rump fat depth, BCS and muscle scores have been inconclusive. Basarab et al. (2007) and Manafiazar et al. (2014) found that RFI classification is negatively correlated with back fat depths and BCS in young cattle and replacement heifers. A multi-year study found that low-RFI cows that produce low-RFI offspring had greater back-fat thickness (2-3 mm increase) and maintained weight better during lactation than dams producing high- and medium-RFI offspring (Basarab et al. 2007). Low-RFI heifers on pasture had more back fat than high-RFI heifers (Manafiazar et al. 2014). Increased back-fat thickness resulted in greater BCS in low-RFI cows (Basarab et al. 2007).

Researchers (Lawrence et al. 2011; Richardson et al. 2001; Redden et al. 2014) concluded there were no significant differences noted in performance traits between RFI classification groups. In heifers fed haylage throughout gestation, there were no differences in BW, ADG, BCS and fat thickness between RFI classification groups (Lawrence et al. 2011). There was less rib and rump fat in low- versus high-RFI steers at the start of a 140-day trial but no differences were noted at the end of the trial (Richardson et al. 2001). Redden et al. (2014) found no differences in performance traits, ADG, back fat, rib eye area and BW in ewe-lambs as affected by RFI classification; these relationships carried over when RFI was revaluated on lambs as yearlings.

Past studies (Fitzsimons et al. 2014; Hafla et al. 2013; Kelly et al. 2010a; Nkrumah et al. 2007) established that high-RFI cattle had increased fat depths and greater BCS than low-RFI cattle, contrasting Basarab et al. 2007, who found low-RFI cows had greater fat depths. RFI was positively correlated with the change in back fat, while the change in muscle depth was negatively correlated with RFI (Fitzsimons et al. 2014). Durunna et al. (2012) found low RFI heifers had less back fat than high RFI heifers at the start of an approximate 120-day trial but there were no differences across RFI classification groups by the end of the trial, concurring with Richardson et al. (2001). This contradicts Black et al. (2013), where high-RFI cows had greater back fat thickness at the start of their trial than low-RFI cows. Hafla et al. (2013) and Kelly et al. (2010a) found that high-RFI heifers had increased gains in back fat which supports the findings of Durunna et al. (2012). In high-RFI heifers, there was an increase in rump fat gains compared to low-RFI heifers (Kelly et al. 2010a). High- and medium-RFI cows fed a haylage diet during gestation had greater gains in back fat during gestation than low-RFI cows (Fitzsimons et al. 2014). In steers and bulls, RFI is correlated to back fat, yield grade and carcass grade fat (Nkrumah et al. 2004). In a Canadian study, high-RFI steers were found to have the greatest overall gains in back fat depth and subsequently carcass grade fat than medium- and low-RFI steers (Nkrumah et al. 2007). However, in another study (Lawrence et al. 2011), muscle depth was negatively correlated with RFI classification group. Based on evaluating the round in the hindquarter, muscle score was lower in high-versus low- and medium-RFI heifers during gestation (Lawrence et al. 2011). Depending on the study, there have been reports of decreased, unaffected and increased body fat reserves in low- versus high- RFI cattle. It should be noted that in evaluating RFI classification, the biological significance of differences in body fat measurements and body condition scoring the may be questionable.

2.2.1.3 Relationships between Residual Feed Intake Classification Group and Genetics

When evaluating replacement heifers for the breeding herd, post weaning feed efficiency carries over to the mature heifer maintaining said feed efficiency during gestation (Arthur et al.

1999). In cattle selected for high-or low-RFI, the RFI measure is phenotypically independent of live weight even in mature cows (Arthur et al. 2005; Archer et al. 1997; Basarab et al. 2007). Selecting for feed efficiency with the use of RFI classification will not affect mature BW as RFI is calculated independent of BW. When selecting for RFI, there were no differences in conception rates based on RFI classification group (Arthur et al. 2005). Based on using cows from low and high-RFI selection lines, there were no effects of RFI selection on calf performance, birth weights and post-weaning ADG (Arthur et al. 2005) or calf birth weights (Basarab et al. 2007; Black et al. 2013; Fitzsimons et al. 2014; Meyer et al. 2008).

Durunna et al. (2011a) reported a genotype by environmental interaction on RFI classification with greater genetic variation in the finisher phase versus the grower phase when RFI classification was evaluated in the grower and finisher phases for 3 years. In contrast, the environmental effect had a greater effect on RFI classification in the grower phase than in the finisher phase (Durunna et al. 2011a). In steers, the basic RFI model accounts for an average of 65.6% of the variation in DMI for Angus cattle and 73.0% of the variation in DMI for Charolais cattle (Mao et al. 2013). However, when back fat was added to the model, the amount of variation in DMI accounted for an increase to 66.1% in Angus and 75.3% in Charolais steers (Mao et al. 2013). A review by Pryce et al. (2014) found that heritability of RFI in beef cattle ranges from 0.14 in post weaning purebred Angus and Hereford bulls to 0.68 in Charolais steers. It is estimated that the heritability of RFI in Canadian beef cattle is 0.20 (Khansefid et al. 2014). In Canadian steers, the heritability of phenotypic RFI was 0.21, while the heritability of genetic RFI was 0.54 (Nkrumah et al. 2007). In Canadian cross breed steers with Angus and Charolais breeding, the heritability of DMI was 0.54 (Nkrumah et al. 2007). A multi-year study found RFI to have a heritability of 0.39 (Arthur et al. 2001). These studies demonstrate the effect of different breeds and effect of RFI selection in breeding programs

2.2.1.4 Factors affecting changes in RFI Classification

Black et al. (2013) evaluated RFI in heifers during pregnancy and again in their first lactation and found no correlation between RFI values as affected by stage of production and RFI classification ranking. In feedlot studies, steers fed either high forage or high concentrate diets in the grower and finisher phases had significantly different RFI and G:F values when the diets changed between phases (Durunna et al. 2011c). This included 31% of steers changing RFI classification group by at least 1 SD (Durunna et al. 2011c). When heifers were fed the same diet during the grower and finisher phases, 51% of heifers had different RFI classification groups in both feeding phases (Durunna et al. 2012). These authors found DMI to increase during the finisher phase due to the associated increases in heifer BW and maturity (Durunna et al. 2012). Manafiazar et al. (2014) determined RFI classification group in heifers fed in drylot and then evaluated feed efficiency on pasture; these authors found the low-RFI heifers were more feed efficient as pregnant two-year-old heifers. In lactating dairy cows switched from high to low starch diets, 56% of the cows maintained RFI classification group over the diet changes, with only a small percentage of cows switching from high to low-RFI classification group or from low- to high-RFI classification group (Potts et al. 2015). There may be bias in this study as cows fed the high starch diet had greater DMI than cows fed a low starch diet (Potts et al. 2015). The same study found that RFI classification within a treatment period was repeatable across diets ($r = 0.73$) (Potts et al. 2015). These studies demonstrate that changes in diets have an impact on the feed efficiency of cattle.

2.3 Blood metabolites in Serum as Indicators for Performance In Pre-partum and Post-partum Cows

Blood metabolites can be influenced by a number of factors such as diet, stage of production, environment, temperature, feed efficiency and age. For instance Metabolic rate in dairy cows decreases with age (Shaffer et al. 1983). The serum concentrations of calcium and phosphorus decrease as the bovine’s age increases (Doornenbal et al. 1988). Lower concentrations of phosphorous, potassium and iron were found in gestating ewes during the winter months when compared to mineral concentrations in gestating ewes during the summer months (Antunovic et al. 2002). High-RFI steers have lower triglycerides than low-RFI steers; this is the result of high protein turnover and higher fat content (Richardson et al. 2004). These metabolites have varying roles in metabolic processes; therefore, it is important to understand the impact of feed efficiency and low quality diets on these metabolites.

2.3.1 Glucose

Glucose, a monosaccharide, is derived by the hydrolysis of disaccharides and polysaccharides, or by synthesis in the ruminant, mainly in the liver (Ostrowska et al. 2015). Ruminants can synthesize glucose though gluconeogenesis. The most vital substrate for gluconeogenesis is propionate (Drackley et al. 2011). Increasing the supply of propionate to the rumen increases the conversion of propionate to glucose in the liver (Drackley et al. 2011). Glucose supplied by the diet can result in circadian rhythms in blood glucose and insulin levels. The feeding of lactating dairy cattle at 0600 h resulted in glucose concentrations decreasing starting at 1100 h with the lowest concentrations of glucose attained at 1500 h (Shehab-El-Deen et al. 2010). Age did not affect serum glucose concentrations in mature cattle in a study, which assessed Shorthorn beef cows over 2 years of age (Dorrnenbal et al. 1988). Decreases in plasma glucose concentrations pre-partum indicate that cows are mobilising fat stores during gestation to help meet their energy demands (McGee et al. 2005). Wood et al. (2014) found serum glucose concentrations were not correlated with RFI, ADG and DMI, although serum glucose concentrations were positively correlated to the mid trial BW in gestating beef cows. Age of cow does not affect serum glucose concentrations during gestation but the mobilization of fat and subsequent loss of BW can.

2.3.2 Urea

Once urea is produced in the body, it can be recycled in ruminants back to the ruminant gastrointestinal tract. The urea nitrogen can be used as a source of non-protein nitrogen by the bacteria for microbial protein synthesis to provide high quality protein and amino acids for utilization by the animal (Sejrsen et al. 2006). Hepatic urea synthesis uses 7.1% of total oxygen consumption by the liver (Brown 2005). In fasting lambs and bulls, serum concentrations of urea increased due to protein being mobilized from tissues to provide amino acids to be used as an energy source (Cameron 1992; Robinson et al. 1992). In steers, the RFI classification of steers entering the feedlot was positively associated with serum urea concentrations; this relationship was not present at the end of the feedlot period when examining serum urea levels and RFI classification (Richardson et al. 2002). In bulls on test, urea concentrations were positively correlated with DMI and ADG, but there was no correlation with RFI classification (Kelly et al. 2011). Urea concentrations were greatest in early gestation regardless of RFI status, although plasma urea levels for low-RFI heifers are greater in late gestation (Gonano et al. 2014). In cows fed both restricted and *ab lib* haylage, the plasma urea concentrations increased pre-partum and decreased post-partum (McGee et al. 2005). The increase in plasma urea concentrations indicates that protein was being metabolized for energy during gestation (McGee et al. 2005). Richardson et al. (2004) suggested the association between RFI and blood urea concentrations could be due to the mechanisms of protein breakdown, feed intake and body composition. In young heifers, there is a positive correlation between plasma urea and RFI and DMI, along with serum BHB concentrations being positively associated with RFI and DMI (Kelly et al. 2010b). In Shorthorn beef cows over the age of two; there was no influence of age on serum urea concentrations (Dorrnenbal et al. 1988). Wood et al. (2014) found in a study of 227 mature cows that serum urea concentrations were positively correlated to RFI, and that the addition of urea concentrations to the RFI model increased the R^2 of the RFI model by 0.12. When serum urea and NEFA concentrations were added to a RFI model including ADG and MBWT, the R^2 increased by 0.16 which provided the greatest improvement to the model over other physiological traits (Wood et al. 2014).

2.3.3 Nonesterified Fatty Acids

Nonesterified fatty acids (NEFA) are present in blood due to the mobilization of adipose tissues; NEFA can be used as a direct source of energy (Adewuyi et al. 2005). There was an increase in serum NEFA concentrations in fasting lambs (Cameron 1992), indicating the fat was being utilized to meet energy demands. In examining the circadian rhythm of lactating dairy cows, the highest concentrations of NEFA corresponded to the lowest concentrations of glucose (Shahab-El-Deen et al. 2010). NEFA concentrations follow a circadian rhythm similar to glucose, increasing in concentration as glucose concentrations decrease (Shehab-El-Deen et al. 2010). In growing heifers, low-RFI heifers had high concentrations of NEFA which were negatively associated with RFI and DMI (Kelly et al. 2010a). Low-RFI cattle tend to be leaner than high-RFI cattle (Kelly et al. 2011). They suggested that the increase in leanness in low-RFI cattle may be due to fat mobilization which increase serum NEFA concentrations. There was no correlation between RFI and NEFA in the pre-calving period, but RFI and NEFA were negatively correlated post-calving in first calf heifers (Lawrence et al. 2011). Circulating NEFA concentrations were found to be negatively correlated with ADG, DMI and RFI in mature gestating beef cows (Wood et al. 2014). This suggests that the low-RFI heifers and cows were mobilizing fat stores at a greater rate than their high-RFI counterparts. NEFA concentrations increased pre-partum and decreased post-partum in cows fed haylage at restricted and *ad lib* levels (McGee et al. 2005). In the same study, the increase in NEFA concentrations during gestation were lower for cows fed *ad lib* throughout gestation versus cows fed haylage at restricted levels (McGee et al. 2005). This latter group of cows along with post-calving cows, mobilized more body stores to meet energy demands (McGee et al. 2005).

2.3.4 β-Hydroxybutyrate

Beta-hydroxybutyrate (BHB) is a ketone body that is produced when the body utilizes fat stores to produce energy during fasting or if inadequate amounts of energy are being fed (Rojas-Morales et al. 2016). It is believed that BHB may play a more important role in metabolism and energy regulation for animals that are limit fed (Rojas-Morales et al. 2016). The serum BHB concentrations in lambs increased when the lambs were fasting (Cameron 1992). In feedlot heifers and steers, Richardson et al. (2004) reported a positive correlation between average daily feed intake and feed conversion ratio with serum BHB concentrations. The relationship between RFI and BHB in steers changed from being positive post-weaning to negative when entering the feedlot (Richardson et al. 2004). In heifers, there is a positive correlation between serum BHB concentrations and RFI and DMI (Kelly et al. 2010b). BHB concentrations were negatively correlated with ADG and DMI but were not correlated with RFI in mature gestating beef cows (Wood et al. 2014). In gestating cows, serum BHB levels are significantly higher than in open cows (Wood 2013). When cows were fed haylage at restricted and *ab lib* levels during gestation, BHB concentrations increased pre-partum and then decreased post-partum (McGee et al. 2005).

This study showed that restricted cows in gestation mobilized more body stores, as there was a limited increase in BHB levels for cows fed *ad lib* (McGee et al. 2005).

2.3.5 Total Proteins

Blood protein concentrations, including albumin and globulin provide a source of amino acids for protein synthesis in tissues (Clarke et al. 1996) along with a variety of other functions such as carrier proteins. Amino acids are not the primary substrate for gluconeogenesis but they account for significant gluconeogenic contributions with the amino acids, alanine and glutamine making the greatest contribution (Drackley et al. 2011). Total serum proteins and albumin are indicators of hepatic function as hepatocyte cells produce serum proteins and albumin in the liver (Sun et al. 2015). Amino acids in muscle are used for gluconeogenesis during the transition period from pre-partum to post-partum in dairy cows (Drackely et al .2011). High-RFI steers, heifers or bulls had greater total protein concentrations than low-RFI cattle of the same gender (Richardson et al. 1996). This may be due to the high-RFI cattle being less efficient in utilizing the total proteins in circulation. Doornenbal et al. (1988) found that serum protein concentrations in Shorthorn cattle increased with age; however, there was no clear association of age with changes in albumin concentrations. Peters and Anfinsen (1950) found the appearance of albumin in the liver was reliant on the supply of energy that is generated within the cell. In heifers during early gestation, albumin concentrations were greatest when comparing levels in late gestation or in open heifers (Gonano et al. 2014). In Shorthorn cattle, there was no clear association of age with changes in albumin concentration (Doornenbal et al. 1988).

2.4 Conclusion

To improve the productivity of the beef industry in Canada, the use of low-quality diets (less than 10% CP, and greater than 50% NDF) needs to be evaluated as they can allow for reduced feed costs. Providing supplementation of protein and energy to such diets when nutrient demands are high, has been shown to reduce the losses in performance (BW and BCS) in gestating cows. Providing energy to cows in late gestation has reduced the negative energy balance by providing readily available energy sources such as glucose through gluconeogenesis. What has yet to be evaluated is the effect that these diets have on RFI classification as a measure of feed efficiency. Studies have been inconclusive on the effect of RFI on the performance of gestating heifers and cows. This holds true when evaluating the effect of RFI on various blood parameters. While these differences are likely due to the difference in stage of physical maturity and genetics, RFI classification can change with stage of maturity and with changes in the diet. It is hypothesised that providing energy/protein supplementation to a low-quality forage based diet, (such as a straw-based diet) in late gestation will reduce the losses in BW and BCS compared to cows that do not receive supplementation. It is also believed there will be changes in RFI classification across time for cows regardless of maintaining or changing the diet.

3.0 Materials and Methods

3.1 Animal management

120 gestating primiparous and multiparous cows at 128 ± 31 days in gestation were used in this trial. Their average body weight was 691.5 ± 235 kg with ages ranging from 3 to 10 years. The use of animals for this work was approved by the University of Guelph Animal Care Committee based on the guidelines and principles of the Canadian Council on Animal Care (1993). The cattle were predominantly Angus and Simmental crosses and were sourced from the University of Guelph beef cattle breeding herd at Elora. The trial was conducted at the University of Guelph's Elora Beef Research Station (EBRS) in Elora, Ontario. Cows were maintained either on pasture or on dry lot during the summer of 2015 prior to the start of the trial and each cow weaned a calf at the end of October, 2015. All cows were placed in dry lot after weaning and were fed a common diet consisting of corn silage, haylage, straw and a vitamin mineral premix. The cows were evaluated by a licenced veterinarian to confirm conception through ovarian palpation per rectum prior to transitioning onto treatment (nutritional management regimen) rations on December 3rd.

The cattle (n=120) were evenly distributed to five nutritional management regimens based on age, breed composition, days in gestation and residual feed intake (RFI) classification based on values obtained during the winter of 2015, when cattle were fed a diet containing approximately 70% haylage and 30% straw (on a dry matter basis). Allocation ensured that the nutritional management regimens groups had equal average age, breed composition, days of gestation and RFI classification. The cows were allocated to pens based on nutritional management regimen and day of gestation, such that no adjacent pen contained the same nutritional management regimen, and cattle were of similar calving date within a pen and in adjacent pens. The cows were housed at EBRS with the cattle allocated into 20 pens, each 11 by

5.5 m in dimension, with a stocking density of six head per pen. Half of each pen was covered and had a straw-bedded pack for the cows to lie on. The pens were equipped with Calan gates (American Calan Inc., Northwood, NH) to allow feed intake data to be collected on an individual cow basis. The Calan gate system uses keys, placed around each cow's neck to allow the cow access to their individual feed bunk and deny them access to all other feed bunks in the pen. The cows were transitioned onto treatment diets and trained onto their specified Calan head gate from December 3rd to December 15th 2015. Feed intake data were collected from individual cows from December 15th 2015 until their respective calving date.

One cow from treatment three was removed from trial in February 2016 due to bullying from other cows in her pen. On March 28th, one cow was removed from pen 17 and placed into an isolated maternity pen as she had been observed trying to nurse off other non-lactating cows in her pen. Prior to calving, groups of three pens were amalgamated together with 18 cattle per pen, to create a creep area for the calves prior to calving on March 28th, 2016. Pens 17 and 21 did not change and calves were not provided a creep area in these pens. The creep areas were located in a straw-bedded area in the middle pen; cows did not have access to the creep areas while the creep areas provided access to water for the calves. Once calving commenced, isolated maternity pens were used for cows that were aggressive, lacked milk, had a weak or injured calf or were fostering another calf. The creep areas were also used for calving, where they would be closed off to other cows and calves allowing isolation during calving when it was required. Cows placed in creep areas to calve were placed back into the group pen approximately 4-6 hours post-calving.

The initial processing of calves conducted within the first 24 hours post-calving included weighing, scoring of calving difficulty, sex of calf identified, castration of bull calves not selected for the EBRS bull test program, placement of an ID tag in the left ear and permanent tattoo ID on the right ear, injection with Dystosel (l mL/45 kg of BW; Zoetis Canada Inc., Kirkland QC) to prevent white muscle disease and vaccination against tetanus. The earliest calving cows from each pen of 18 were removed from their pens and grouped in pairs of two in three additional pens in order to increase space available for remaining cows and reduce the spread of viruses from older to younger calves. Two cows from treatment four were removed from the trial after calving due to calving complications (prolapsed uterus, twinning and caesarean section). All post-calving data from these cows and their calves were removed from the data set. One cow from treatment five delivered a mummified calf and both pre- and post-calving data were removed. The removal of the cows resulted in 118 cows with pre-calving data and 116 cows with post-calving data. Pre-calving cow data was not removed for loss of calf post-calving.

Post-calving, cows were allocated to pasture or kept in dry lot. Sixty cows were allocated to 15 fields on pasture based on days post-calving, such that the oldest calves were selected first and there was an equal number of high-, medium- and low-RFI cows from each nutritional management regimen on each paddock. The cows were allocated such that 4 cow-calf pairs were placed on each field and that no nutritional management regimen was repeated within a field. The pasture was located at EBRS and the fields were 1.2 hectares in area, divided into eight 0.15-hectare paddocks, with a center lane to allow for rotational grazing. All cows on pasture were given free access to water and free-choice vitamin and mineral premix (Table 1). The cow-calf pairs were maintained on pasture according to EBRS pasture management practices, where the cows were moved every two days during the first two rotation cycles; during the remaining cycles, the cows were moved to a new paddock every 5-7 days dependent on the sward height and regrowth of respective paddocks. No cow-calf pair was placed on pasture prior to 45 days post-calving. The first 44 cows were placed on pasture between May 26th and May 31st, allowing the cows and calves to be trained to the electric fences prior to being placed in their respective fields. The remaining 16 cow-calf pairs were placed on pasture June 24th to June 27th in fields 2, 3, 9 and 10. To stop forage overgrowth in these fields, heifers were rotationally grazed prior to the cow-calf pairs, with the cow-calf pairs continuing on the established rotation schedule. The remaining 56 cows not allocated to pasture remained in dry lot and were fed a 100% haylage diet.

Cows were maintained on pasture until late-October 2016, where cow-calf pairs were removed from pasture between October 22nd and 28th 2016. Cows and calves were weighed when placed and removed from pasture. The cows were then placed in dry lot prior to weaning their 2016 calf. Due to drought conditions during the 2016 grazing season, cows were supplemented on pasture with corn silage starting in mid-August 2016. A field would only be supplemented after the paddock had been fully grazed to maintain the cattle on the said paddock, allowing for maximum regrowth in other paddocks for future grazing.

Half of the 16 fields were originally seeded in 1985 with a mixture of meadow brome (2.7 kg ha^{-1}) (*Bromus biebersteinii* Rom & Schult. 'Regar'), smooth brome (2.0 kg ha^{-1}) (*Bromus inermis* Leyss. 'Saratoge'), timothy (1.1 kg ha^{-1}) (*Phleum pretense* L. 'Salvo'), orchardgrass (1.3 kg ha^{-1}) (*Dactylis gloterata* L. 'Kay'), common meadow foxtail (1.3 kg ha^{-1}) (*Alopecurus pratensis* L.), common Kentucky bluegrass (1.6 kg ha^{-1}) (*Poa pratensis* L.), alfalfa (4.0 kg ha^{-1}) (*Medicago sativa* L. 'Spredro 11' and 'Roamer'), ladino white clover (2.0 kg ha^{-1}) (*Trifolum repens* L. 'Sacrmento') and birdsfoot trefoil (4.0 kg ha^{-1}) (*Loctus corniculatus* L. 'Leo'). The remaining fields were seeded with a mixture of meadow brome (5.3 kg ha^{-1}) (*Bromus biebersteinii* Rom & Schult. 'Regar'), smooth brome (2.0 kg ha^{-1}) (*Bromus inermis* Leyss. 'Saratoge'), timothy (2.2 kg ha^{-1}) (*Phleum pretense* L. 'Salvo'), orchardgrass (2.6 kg ha^{-1})

(*Dactylis gloterata* L. 'Kay'), common meadow foxtail (2.7 kg ha^{-1}) (*Alopecurus pratensis* L.) and common Kentucky bluegrass (3.1 kg ha^{-1}) (*Poa pratensis* L.).

Breeding season started on June 27th and continued until late August, 2016. Heat detection and breeding were conducted following established management practises at EBRS and were consistent for all treatments. Vasectomized teaser bulls were used for heat detection by rotating the bull through the field or pen. If any signs of estrus were observed including mucus discharge from the vulva, vulva sniffing by teaser bulls, mounting of other cows or standing to be mounted, then the cow was bred by artificial insemination (AI). Cows were bred by AI a maximum of three times, after which they were culled. Weaning of the 2016 calves took place between October 31st and November 3rd. On November 8th 2016, a licenced veterinarian assessed pregnancy status of individual cows through palpation and a post-weaning body weight was recorded.

3.2 Animal Performance

The data used for the second trimester were collected from December 1st 2015, for performance traits and from December 15th, 2015, for feed intake, data up to 207 days of gestation. The data used to evaluate performance traits in third trimester were collected from 207 days of gestation up until calving for each individual cow. Post-calving period was considered to be from after calving to weaning.

Trial Diets

The trial began in the second trimester of gestation for all animals, on December 3rd, 2015 at 121 ± 31 days in gestation. Prior to the start of the trial, the cows were fed a common diet of corn silage, straw, haylage and vitamin and mineral premix. Based on their treatment allocations they were placed on one of the two diets and fed once per day. The first diet consisted of 70%

haylage, 30% millet straw, and a vitamin and mineral premix (Table 1) (HAYL) and was fed ad libitum. The second diet consisted of haylage offered at approximately 1% of each cow's body weight on a dry matter basis along with ad-libitum millet straw and a vitamin and mineral premix (MSHAYL). The composition of the diets is presented in Table 2. While the two diets were fed from the start of the trial, designated cows started to receive an energy protein supplement starting 75 days prior to each cow's individual projected due date. The supplement contained 54.6% corn gluten meal, 23.4% soybean meal, 21.0% calcium propionate and 1.0% tallow (Table 2) and was fed once, twice, or three times per week. The five nutritional management regimens evaluated in the study were: 1) the HAYL diet, 2) the MSHAYL diet without additional supplementation, 3) the MSHAYL diet with supplementation once a week starting 75 days prior to due date, 4) the MSHAYL diet with supplementation twice a week starting 75 days prior to due date, 5) the MSHAYL diet with supplementation three times a week starting 75 days prior to due date. The supplementation schedule can be found in Table 3. The supplement was fed as a top dress on an individual cow basis, such that 0.316 grams per kg of body weight per day were provided. For example, a cow weighing 600 kg supplemented once a week would receive 0.316 grams/kg/day × 600 kg × 7 days = 1327.2 grams of supplement. The amount of supplement provided was calculated based on the most recent live body weight prior to the start of each supplementation week. The HAYL diet exceeded nutrient requirements for a gestating beef cow; while the MSHAYL plus supplement diets were designed to meet the nutrient requirements of a second and third trimester beef cow, as outlined in the NRC (2000) (Table 4). The feeding of the MSHAYL diet without a supplement was designed to not meet the energy requirements for a late gestating beef cow as outlined in the NRC (2000). Post-calving, all cows were fed the HAYL diet ad libitum until May 31st, when all dry lot cows that had calved were transitioned to ad libitum feeding of a 100% haylage diet. Cows that remained in dry lot were given free access to all bunks starting July 1st, 2016, as feed intake data were no longer being collected.

Recording of Live Body Weights and Body Condition Scoring

The cows were initially weighed on two consecutive days, and then weighed every 14 days until calving to establish changes in body weight throughout second and third trimesters. The cows were weighed 3-7 days post-calving to establish the amount of weight lost at calving. All cows were weighed every 14 days, following the pre-calving schedule until a minimum of 45 days post-calving. Cows that were placed on pasture were weighed upon entry onto the pasture, on the first week in July and every 28 days until the beginning of October, 2016. Cows on pasture were weighed upon exiting pasture at the end of October, 2016. Cows that remained in dry lot were weighed every 14 days post-calving until July and then weighed every 28 days until time of weaning their calf. All cows that weaned a calf were weighed on November 8th, 2016 post-weaning. All cows were weighed on two consecutive days on November 22nd and 23rd 2016.

Live body weights (BW) adjusted for conceptus weight were used to evaluate average daily gain (ADG) and metabolic body weight (MBWT). The conceptus adjusted weight was calculated by first calculating the weight of the conceptus, as calf birth weight (kg) × 0.01828 × $e^{[(0.02t)-(0.0000143t)t]}$, where t is the day of gestation (NRC, 2000). The conceptus weight was then subtracted from the BW to yield the conceptus-adjusted BW. ADG was calculated by subtracting initial BW from final BW and then dividing by the number of days the cow was on trial for the particular period of gestation being evaluated. MBWT was calculated as the average of all BW measures for a given period raised to the power of 0.75 (Kleiber 1961). The feed conversion ratio (FCR) was calculated as ADG during gestation divided by the average daily intake during gestation.

All cows were body condition scored initially on December 9th and 10th in 2015; then commencing in January, 2016, all cows were body condition scored at time of weighing until calving. Body condition scoring was conducted on the pre-calving schedule every 14 days until July, 2016 or when cows were moved to pasture post-calving. Cows on pasture were body conditioned every 28 days starting July, 2016. Body condition scoring for cows remaining on dry-lot was conducted on the pre-calving schedule until July, 2016 then every 28 days until time of weaning in October, 2016. Cows were body condition scored based on the following guidelines using a scale of 0 to 5 with increments of 0.5 (Lowman et al. 1976).

Score 0: Emaciated animal in which hip bones, spinous processes, tail head and ribs are projecting prominently. There is no fatty tissue to be detected.

Score 1: Able to see individual short ribs. The spinous processes, hip bones and tail head are less obvious but remain prominent. There is no fatty tissue detected around the tail head.

Score 2: When palpated individually, the spinous processes can be identified, but can not identify individual short ribs. There is fatty tissue coverage over the hip bones and tail head.

Score 3: Slight pressure needed to feel short ribs and spinous processes. Hip bones, tail head and ribs have moderate fat covering.

Score 4: Tail head and hip bones were rounded from fatty tissue coverage. Ribs can only be felt with firm palpation as fat fold beginning to form.

Score 5: Tail head and hip bones cannot be palpated though the fatty tissue. Thighs and ribs covered in apparent fat folds, impairing mobility.

The change in body condition score (BCS) was calculated as the difference in the initial BCS and the final BCS for each evaluation period. Average BCS for an evaluation period (i.e. second trimester, post-calving) was calculated using all BCS recorded in that period.

Ultrasonic Measurements of Body Composition

The cows were ultrasounded for the determination of body composition at the start of the trial (December 9th-10th, 2015), prior to calving (March 23rd-24th, 2016), prior to cows being placed on pasture (May 18th-19th, 2016) and post-weaning (November 22nd-23rd, 2016). Vegetable oil was used as a couplant, to ensure proper contact between the cow's hide and the probe, ensuring a high quality image. Ultrasound measurements were obtained for the depth of the subcutaneous fat over the *longissimus dorsi* muscle in the fourth quadrant to the ventral spine and the *longissimus dorsi* muscle area (rib eye area) at the interface of the 12th/13th ribs on the left side of the animal. The depth of subcutaneous rump fat was taken on a dorsal line between the hook and pin bones, where the *gluten medius* and *biceps femoris* muscles meet, on the left side of the animal. Ultrasound measurements were taken and interpreted by Tim Caldwell using an Aloka SSD-500 ultrasound. The ImageJ software (NIH Image, 2016) was used for interpreting the images to measure the minimum subcutaneous fat the *longissimus dorsi* muscle area. Changes in subcutaneous rib and rump fat depths as well as rib eye area were calculated by subtracting the initial measurement from the final measurement pre-calving. The average rib eye area and subcutaneous rib and rump fat depths were calculated using all ultrasound measurements taken pre-calving, post-calving and over the entire trial.

Blood Serum Collection and Analysis

Blood was collected every 28 days starting on December 1st, 2015 via jugular veinipuncture into non-heparinized tubes at approximately two hours post-feeding at 12:30 P.M. Samples were allowed to clot at room temperature for a minimum of 30 minutes before being stored on ice, then were allowed to rest at room temperature for a minimum of 30 minutes. A Thermo Scientific Legend RT + centrifuge (Thermo Fisher Scientific, Langenselbold, Germany) was used to centrifuge the blood at 3000 x g for 20 minutes. After centrifugation of the blood samples, serum was separated and frozen in a Forma™ 900 -80ºC freezer (Thermo Fisher Scientific, Langenselbold, Germany) until further analysis. Samples were analysed at the University of Guelph Animal Health Laboratory (Guelph, ON), using a Cobas 6000 c501 biochemistry analyzer (Roche Diagnosis, Laval, Quebec). The procedures used in the metabolic profile included; CA2: ACN 698 for calcium determination, PHOS2: ACN 714 for phosphorous determination, MG-2: ACN 701 for magnesium determination, Na-K-Cl for Gen.2 for sodium, potassium and chloride determination ISE indirect, TP2: ACN 678 for total protein determination, ALB2: ACN 413for albumin determination, albumin globulin ratio, UREAL: ACN 418 for urea determination, GLUC3: ACN 717 for glucose determination, GGTI2: ACN 220: assay standardized against IFCC for gamma-glutamyl transpeptidase determination, ASTL: ACN 687 for aspartate aminotransferase determination, GLDH3: ACN 588 for glutamate dehydrogenase determination, CHO2I: ACN 798 for cholesterol determination, RANBUT: D-3-Hydroxybutrate (Randox Laboratories-US, Ltd, Kearneysville, West Virginia) for beta-hydroxybutyrate determination, NEFA (Randox Laboratories-US, Ltd, Kearneysville, West Virginia) for nonesterified fatty acids determination and the haptoglobin determination was based on the works of Makimura and Suzuki (1982) and Skinner et al. (1991).

Feed intake collection

Feed refusals were weighed every 14 days until June 1st, 2016 on cattle weighing and body condition scoring dates. During the period between June 1st, 2016 and June 30th, 2016, feed refusals were weighed as needed to reduce feed spoilage. Feed refusals were done by weighing and recording the remaining feed left in each cow's individual bunk. Samples of the refused feed were taken from each cow for analysis of dry matter (DM) content. Weekly feed samples were taken for the HAYL diet, millet straw and haylage to evaluate the DM and NDF contents and for additional laboratory analyses at A & L Canada Laboratories Inc. (London, ON, Canada).

The dry matter intake (DMI) in kg/d was calculated by subtracting the feed refused from the feed presented to the cow on a DM basis and dividing by the number of days on feed. For the MSHAYL nutritional management regimens, it was assumed that supplement and haylage were entirely consumed as they were offered as a top dress and there was no visible supplement or haylage observed when collecting feed refusals. For this reason, the amount of feed DM refused was subtracted from the total amount of straw DM provided to the cow. As DMI were collected over two week intervals, second trimester DMI were collected from December 15th, 2015 until the last full feed refusal period prior to the 207th day of gestation, when cows on the MSHAYL diet began supplementation. DMI for the third trimester were collected starting from the feed refusal period, which contained the 207th day of gestation. For example, the 207th day of gestation for cow 101Y was February 2nd, 2016; collection of her feed intake data commenced on January 26th, 2016 for the third trimester. As diets changed post-calving, the data for DMI at the end of the third trimester ended at the last full feed refusal period prior to calving and the diet change. No feed intake data was collected post calving in dry-lot or on pasture.

The available energy consumption was calculated by multiplying the weight of supplement, straw, haylage and HAYL consumed by each cow during each bi-weekly feeding period by the respective total digestible nutrient (TDN) contents of each feed ingredient (NRC, 2000). This TDN intake was multiplied by 4.4 to yield the Mcal of digestible energy (DE) consumed and then multiplied by 0.82 yielding Mcal of metabolizable energy (ME) consumed for each feedstuff (NRC, 2000). The Mcal ME consumed for each evaluation period were summed and divided by the number of days in the evaluation period to yield the metabolizable energy intake (MEI) (Mcal/day).

Calf live body weight measurements

Calves that went to pasture were weighed upon entering pasture, then weighed every 28 days starting in July 2016 until exiting pasture in late October 2016. Calves were weighed exiting pasture and then weighed a final time at weaning. Calves that remained in dry lot were weighed every 28 days starting in July, 2016 and at weaning. The calves in the dry lot had access to ab lib haylage provided in a creep feeder in the respective creep areas along with free access to the cow's feed bunk.

3.3 Feed Analysis

Weekly samples of the HAYL diet, millet straw and haylage, were analyzed for DM and NDF contents and then sent to A & L Canada Laboratories Inc. (London, ON) for additional laboratory analyses. All feed refusal and diet samples were stored at -20ºC and processed at a later date. The DM content was determined by thawing samples and approximately 200 grams (wet weight) was weighed into aluminum trays. The sample trays were then placed in a Hotpack Tru-temp forced air oven (Hotpack Canada LTD, Waterloo, ON) to dry the samples at 60ºC for at least 48 hours before being reweighed to obtain the dry weight. The DM analysis was performed in duplicate for both feed refusal samples and feed samples.

The remaining portion of the diet samples were used for NDF and laboratory feed analysis. The dried samples used to calculate the DM content, were ground using a Thomas Wiley feed grinder (Wiley Mill, Arthur H. Thomas, Philadelphia, PA) to pass through a 1 mm screen. The diet samples were composited by month. Approximately 0.5 grams of ground sample were used for NDF analysis. The NDF procedure of Van Soest *et al.* (1991) was modified with the use of filter bags capable of retaining 25 micron particles and a $ANKOM^{200}$ Fiber Analyzer (ANKOM Technology, Macedon, NY). The composited diet samples were sent to A & L Canada Laboratories Inc. (London, ON) for additional laboratory analyses (CP, UIP, NDF, lignin, NE, Ca, P and crude fat).

3.4 Pasture Analysis

Three paddocks in a field were sampled during a rotational cycle to determine forage composition and nutrient content as the grazing season progressed. Within each paddock, six 1.22 m by 0.15 m quadrats were randomly taken. Pasture samples were pooled by compositing the six quadrats from each paddock taking approximately 500 g for nutrient composition analysis and 500 g for determination of forage composition. Samples for nutrient composition determination were then dried in large paper bags in a Hotpack Tru-temp forced air oven (Hotpack Canada LTD, Waterloo, ON) at 60ºC, for at least 5 days to establish the DM content. Dried samples were then ground through a 1 mm screen using a Thomas Wiley feed grinder (Wiley Mill, Arthur H. Thomas, Philadelphia, PA) and samples were composited by field for each rotational cycle. Final composited samples were analysed for NDF as described above. Based on NDF results, the fields with the highest, lowest and closest to the average NDF for each grazing cycle were sent to A & L Laboratories for the same laboratory analyses described for diet sampled above (Table 5).

Due to dry conditions during the 2016 grazing period, corn silage was supplemented on pasture starting August 1st, 2016. Corn silage was sampled once a week and was composited into one sample for analysis. The sample was processed for DM, NDF and sent to A & L Canada Laboratories Inc. (London, ON) for additional laboratory analyses following the same procedures for diet and pasture samples. The nutrient composition of the corn silage can be found in Table 6.

The forage composition samples composited by paddock were further composited by field for each rotational grazing. From the composited samples, approximately 500 g were sorted into four categories; legumes, grasses, weeds and dead material. Each category was weighed to evaluate the botanical distribution (Appendix Table 1).

3.5 Statistical Analysis

Determination of Residual Feed Intake

RFI for the 2016 data was calculated using the PROC REG (SAS Institute Inc., 2012), to perform a backward stepwise regression with an adjusted significance level of 0.05. Proc GLM was used to evaluate the fit of the RFI models, through the evaluation of Bayesian information criteria (BIC), where the model with the smallest BIC was chosen as the best fitting model. The following traits were regressed against DMI for inclusion in the model for RFI for the entire trial (RFI_{gest}); ADG, conceptus adjusted ADG, ADG post-calving, conceptus adjusted MBWT, length of gestation, days on feed, the average and change in BCS, rib and rump fat depths; end of trial conception status, if a calf was weaned, age, calf birth weight, calf weaning weight and calf ADG. The most appropriate model for the variation in RFI_{gest} had an R^2 of 0.42 and a BIC of 500.09 and was as follows:

$$DMI_j = \beta_0 + \beta_1(ADG)_j + \beta_2(BCS)_j + e_j$$

where DMI_j is the predicted DMI of the j^{th} cow, β_0 is the regression intercept, β_1 and β_2 are the coefficients of the multiple linear regression of DMI on ADG and BCS and e_j is the random error term of the j^{th} cow.

Analysis of the Effects of Nutritional Management Regimen and RFI Classification on Cow Performance

The experiment was conducted as a completely randomized design. All performance traits were evaluated for outliers using Lund's test using the critical value of 3.40 when evaluating the effects of dietary treatments and RFI_{2015} ranking. Where RFI_{2015} refers to the RFI classification that was established based on feed intake and performance data from the 2015 gestation period. PROC UNIVARIATE of SAS (SAS Institute Inc. 2012) was used to check for normality of the traits, including RFI_{2015}, by assessing the Shapiro –Wilk statistic. PROC GLIMMIX was used to evaluate the fixed effects of nutritional management regimen, RFI_{2015} classification and the regimen by RFI_{2015} classification interaction on ADG, MBWT, BCS, DMI, MEI, rib fat depth, rump fat depth, conception rate, weaning rate, calf birth weight, calf weaning weight and calf ADG. Conception rate was a binary response of yes or no as to whether the individual cow conceived during the breeding season. A linear regression model was used to calculate calf average daily gain (ADG) using PROC REG to regress observed calf weights on the days when body weights were recorded during the trial.

Orthogonal contrasts (Steele and Torrie, 1960) were used for means separation to evaluate nutritional management regimens, RFI classification, and nutritional management regimens by RFI classification interactions in Tables 7 to 9 respectively. The nutritional management regimens contrasts were as follows: Contrast 1) comparing HAYL fed cows versus all haylage limit-fed (MSHAYL) cows, Contrast 2) cows fed the MSHAYL diet without supplementation versus cows fed the MSHAYL diet with supplementation, Contrast 3) cows fed the MSHAYL diet with supplementation once a week versus cows fed the MSHAYL diet with supplementation multiple times a week, Contrast 4) cows fed the MSHAYL diet with supplementation two times a week versus cows fed the MSHAYL diet with supplementation three times a week. These contrasts were used to evaluate the effect of the straw based diets, the effect of supplementation and the varying frequency of supplementation. The RFI classification contrasts are as follows: contrast 1) medium RFI classified cows versus the average of low and high RFI classified cows, contrast 2) low RFI classified cows versus high RFI classified cows. These contrasts allowed for the evaluation of the 'extreme' RFI classifications (high and low) and to evaluate if all three classification groups differed from each other. Contrasts were not examined when the overall P-values for the main effects and the interaction were greater than 0.05.

To assess the effect of nutritional management regimens on repeated measures of blood variables, the PROC MIXED procedure of SAS (2012) was used. Days in gestation were added to the model statement along with the covariate, repeated effect of time, fixed effect of nutritional management regimen and the interaction of time with nutritional management. Least squares means were estimated to assess the means estimate and standard error of the nutritional regimens, along with a Tukey's adjustment.

Analysis of Re-Ranking in RFI Classification

Data obtained from the 2015 gestation period were combined with data from the 2016 gestation period to calculate respective RFI classification values for each year for a given cow and to evaluate changes in RFI classification between years. The fit of the RFI models was assessed using the PROC REG (SAS Institute Inc., 2012) by backward stepwise regression with an adjusted significance level of 0.05 to produce the coefficient of determination. PROC GLM (SAS Institute Inc., 2012) was used to evaluate the fit of the RFI models, through the evaluation of Bayesian information criterion (BIC), where the model with the smallest BIC was chosen as the best fitting model. The following traits were regressed against DMI for inclusion in the model (RFI_{year}); conceptus adjusted ADG, conceptus adjusted MBWT, the average and change in BCS, rib and rump fat depths and age. The best-fit model predicted DMI with an R^2 of 0.42 and a BIC of 956.85 as follows:

$$DMI_j = \beta_0 + \beta_1(ADG)_j + \beta_2(BCS)_j + \beta_3(AGE)_j + \beta_4(CRIB)_j + e_j$$

where DMI_j is the predicted DMI of the j^{th} cow, β_0 is the regression intercept, β_1, β_2 and β_3 are ehe coefficients of the multiple linear regression of DMI on ADG, BCS, age and change in rib fat depth (CRIB) on the j^{th} cow and e_j is the random error term of the j^{th} cow. The PROC MEANS (SAS Institute Inc., 2012) procedure was used to attain the respective means of zero and standard deviations to classify RFI as low (< 0.5 SD of the mean), medium (± 0.5 SD of the mean) or high (> 0.5 SD of the mean).

Data from the 2016 gestation were analyzed to evaluate changes in RFI classification between trimesters. RFI was calculated as described above. The following traits were regressed against DMI for inclusion in the model for RFI for the entire trial ($RFI_{trimester}$); ADG, conceptus adjusted ADG, ADG post-calving, conceptus adjusted MBWT, length of gestation, days on feed, the average and change in BCS, rib and rump fat depths; end of trial conception status, if a calf was weaned, age, calf birth weight, calf weaning weight, calf ADG and breed. The best-fit model predicted DMI with an R^2 of 0.22 and a BIC of 1396.06 as follows:

$$DMI_j = \beta_0 + \beta_2(BCS)_j + \beta_5(RIB)_j + \beta_6(DOF)_j + e_j$$

where DMI_j is the predicted DMI of the j^{th} cow, β_0 is the regression intercept, β_2, β_5 and β_6 are the coefficients of the multiple linear regression of DMI on BCS, rib fat depths and days on feed (DOF) on the j^{th} cow and e_j is the random error term of the j^{th} cow. The PROC MEANS (SAS Institute Inc., 2012) procedure was used to attain the respective mean of zero and standard deviations to classify RFI as low (< 0.5 SD of the mean), medium (± 0.5 SD of the mean) and high (> 0.5 SD of the mean).

To test for re-ranking by year, PROC GLIMMIX was used with a multinomial distribution, along with the covariates, year and the interaction of year and nutritional management regimen to assess the number of cows that maintained a specific RFI classification (Low, medium, high) between years. PROC SORT (SAS Institute Inc., 2012) was used to sort the data by dietary treatment so that the number of cows that changed or maintained RFI rank per treatment could be evaluated with the use of PROC FREQ to perform the Friedman's test and produce Chi-square tables. The Friedman's test is a non-parametric alternative to a one-way ANOVA using repeated measures. The same procedure was followed to evaluate re-ranking by trimester with trimester replacing year as a covariate.

The following traits: ADG, conceptus adjusted ADG, ADG post-calving, conceptus adjusted MBWT, length of gestation, days on feed, the average and change in BCS, rib and rump fat depths; end of trial conception status, if a calf was weaned, age, calf birth weight, calf weaning weight, calf ADG and breed, were used to find a best-fit model for the residual metabolizable energy intakes (RMEI). Performance traits were regressed against MEI instead of DMI, producing RMEI with a R^2 of 0.28 and a BIC of 1732.96, with a model as follows:

$$MEI_j = \beta_0 + \beta_2(BCS)_j + \beta_5(RIB)_j + e_j$$

where MEI_j is the predicted MEI of the j^{th} cow, β_0 is the regression intercept, β_2, β_{10} and β_{11} are the coefficients of the multiple linear regression of MEI on BCS and rib fat depths on the j^{th} cow and e_j is the random error term of the j^{th} cow. The PROC MEANS (SAS Institute Inc., 2012) procedure, was used to attain the respective mean of zero and standard deviations to classify RMEI as low (< 0.5 SD of the mean), medium (± 0.5 SD of the mean) and high (> 0.5 SD of the mean). The same procedures were used as described above to evaluate re-ranking between trimesters.

Table 1. Chemical Composition of Cow-Calf Mineral and Vitamin Premix[1]	
Calcium (%)	12.10
Phosphorous (%)	4.10
Sodium (%)	14.0
Sulphur (%)	0.70
Magnesium (%)	1.00
Iron (mg/kg)	2,410
Fluorine (mg/kg)	373
Zinc (mg/kg)	4,004
Copper (mg/kg)	843
Manganese (mg/kg)	3.202
Iodine (mg/kg)	48.30
Cobalt (mg/kg)	47.70
Selenium (mg/kg)	16
Vitamin A (IU/kg)	604,000
Vitamin D (IU/kg)	100.700
Vitamin E (IU/g)	20,007
[1]Premix fed at 18.3 grams per kg DM per day.	

Table 2. Nutrient Composition of the Haylage Based Diet (HAYL), the Haylage Restricted Straw Based Diet (MSHAYL) With(Without) Supplementation and the Energy Protein Supplement[1]				
	HAYL	MSHAYL	MSHAYL with supplementation	Energy protein supplement
NE_m (Mcal/Kg)	1.36	1.42	1.42	2.23
TDN (%)	58.36	58.84	59.04	86.75
Crude Protein (% of DM)	16.45	15.71	15.94	48.53
UIP (% of CP)	17.26	20.16	21.74	42.35
NDF (% of DM)	52.67	51.84	52.20	4.62
Lignin (% of DM)	6.94	6.93	6.78	0.79
Calcium (% of DM)	1.28	1.40	1.43	5.36
Phosphorus (% of DM)	0.31	0.34	0.34	0.54
[1] Nutrient composition based on actual dry matter intakes for cows fed the specific diet.				

Table 3. Supplementation Schedule for Designated Cows on MSHAYL diet Provided Supplement[1] Commencing on the 207th Day of Gestation[2]

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	MSHAYL diet supplemented (**suppl**) 3 times per week[3]	MSHAYL diet **suppl** twice per week[4]	MSHAYL diet **suppl** once per week[5]	MSHAYL diet **suppl** 3 times per week	MSHAYL diet **suppl** twice per week	MSHAYL diet **suppl** 3 times per week

[1] Supplement composition: 54.6% corn gluten meal, 23.4% soybean meal, 21.0% calcium propionate and 1% tallow; fed at *0.316 g/Kg* of body weight per day.
[2]Note that feed refusals were collected on Mondays and Tuesdays, with weights and blood samples for the metabolic profile collected on Wednesdays.
[3]MSHAYL diet supplemented 3 times per week in which cows were supplemented three times a week on Mondays, Thursdays and Saturdays.
[4]MSHAYL diet supplemented twice per week in which cows were supplemented twice a week on Tuesdays and Fridays.
[5]MSHAYL diet supplemented once per week in which cows were supplemented on Wednesdays.

Table 4. The Recommended Dietary Nutrient Density Requirements for a 636.4 kg Beef Cow Based on the NRC (2000).

	Months Since Calving	
Item	10	12
DM (kg/d)	12.2	12.5
NE_m (Mcal/kg)	0.97	1.23
NE_m (Mcal/d)[1]	11.8	15.4
30% below NRC (2000) recommendation NE_m (Mcal /d)	8.26	10.78
30% above NRC (2000) recommendation NE_m (Mcal/d)	15.36	20.02

[1]The recommended NE_m (Mcal/d) calculated based on the predicted daily dry matter intake.

Table 5. Nutrient and Chemical Composition of Grass Pasture [1]												
	Cycle[2] 1			**Cycle 2**			**Cycle 3**			**Cycle 4**		
NDF Value	**High**	**Average**	**Low**	**High**	**Average**	**Low**	**High**	**Average**	**Low**	**High**	**Average**	**Low**
Dry matter (%)	94.68	94.35	94.21	94.93	95.01	95.12	94.92	94.60	94.30	94.47	94.42	94.11
TDN (%)	63.47	64.08	65.77	60.47	61.45	61.64	58.57	60.38	61.60	65.90	66.53	69.41
NE_m (Mcal/Kg)	1.55	1.57	1.62	1.47	1.49	1.50	1.41	1.46	1.50	1.62	1.64	1.73
NDF (%)	57.60	54.72	49.66	64.54	58.52	55.64	64.68	60.07	55.44	54.53	50.25	43.45
ADF (%)	32.64	31.86	29.69	36.50	35.24	34.99	38.93	36.61	35.05	59.53	28.71	25.02
Lignin (%)	2.77	2.85	2.89	3.60	3.36	3.17	4.82	4.63	5.02	2.65	3.21	3.43
Crude Protein (%)	15.27	14.23	16.97	12.31	11.10	11.29	8.66	11.29	12.80	20.55	20.56	22.84
UIP (Est % of CP)	30.52	26.00	30.08	24.58	26.35	28.16	30.31	27.50	28.01	33.68	35.09	30.32
Crude Fat (%)	2.81	3.50	3.12	2.17	2.38	2.47	2.51	2.38	2.22	4.09	3.40	3.55
Calcium (%)	0.44	0.52	0.71	0.41	0.55	0.55	0.56	0.59	0.84	0.62	0.70	0.75
Phosphorus (%)	0.37	0.42	0.47	0.30	0.36	0.33	0.22	0.28	0.32	0.52	0.52	0.46

[1]Nutritent composition values presented for the fields with the highest, lowest and the average NDF values.
[2]Cycle refers to the rotational grazing cycle.

Table 6. Nutrient Composition of Corn Silage Supplemented on Grass Pasture	
NE_m (Mcal/Kg)	1.72
Crude Protein (% of DM)	10.89
UIP (% of CP)	14.97
NDF (% of DM)	1.09
ADF (% of DM)	0.62
Calcium (% of DM)	0.79
Phosphorus (% of DM)	0.30

Table 7. Contrast Coefficients Used to Evaluate the Effects of Nutritional Management Regimens					
	Nutritional Management Regimen				
Contrast	HAYL	MSHAYL	MSHAYL, Supplementation once a week	MSHAYL, Supplementation twice a week	MSHAYL, Supplementation three times a week
1	4	-1	-1	-1	-1
2	0	3	-1	-1	-1
3	0	0	2	-1	-1
4	0	0	0	1	-1

Contrast 1 = cows fed HAYL vs. all limit-fed haylage (MSHAYL) diets.
Contrast 2 = cows fed MSHAYL without supplementation vs. the average of all cows fed MSHAYL with supplementation.
Contrast 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two to three times a week.
Contrast 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.

Table 8. Contrast Coefficients used to Evaluate the Effects of RFI Classification			
	RFI Classification		
Contrast	Low RFI	Medium RFI	High RFI
1	-1	2	-1
2	1	0	-1

Contrast 1 = medium RFI cows vs. the average of both high and low RFI classification groups.
Contrast 2 = low RFI vs. high RFI classification groups.

Table 9. Contrast Coefficients Used to Evaluate the Effects of RFI Classification by Nutritional Management Regimen Interactions									
		Low RFI vs. High RFI				Medium RFI vs. Low and High RFI			
Nutritional Regimen	RFI Class	HAYL vs. MSHAYL	MSHAYL non-supplemented vs. supplemented	MSHAYL supplemented once/wk vs. average of (twice/wk & thrice/wk)	MSHAYL supplemented twice/wk vs. thrice/wk	HAYL vs. MSHAYL	MSHAYL non-supplemented vs. supplemented	MSHAYL supplemented once/wk vs. average of (twice/wk & thrice/wk)	MSHAYL supplemented twice/wk vs. thrice/wk
HAYL	Low	4	0	0	0	-4	0	0	0
	Medium	0	0	0	0	8	0	0	0
	High	-4	0	0	0	-4	0	0	0
MSHAYL non-supplemented	Low	-1	3	0	0	1	-3	0	0
	Medium	0	0	0	0	-2	6	0	0
	High	1	-3	0	0	1	-3	0	0
WHSAYL, Supplemented 1/wk	Low	-1	-1	2	0	1	1	-2	0
	Medium	0	0	0	0	-2	-2	4	0
	High	1	1	-2	0	1	1	-2	0
MSHAYL, Supplemented 2/wk	Low	-1	-1	-1	1	1	1	1	-1
	Medium	0	0	0	0	-2	-2	-2	2
	High	1	1	1	-1	1	1	1	-1
MSHAYL, Supplemented 3/wk	Low	-1	-1	-1	-1	1	1	1	1
	Medium	0	0	0	0	-2	-2	-2	-2
	High	1	1	1	1	1	1	1	1
Contrast		1	2	3	4	5	6	7	8

Contrast 1 = Examining low vs. high RFI cows when fed HAYL diet vs. the average of MSHAYL diets.
Contrast 2 = Examining low vs. high RFI cows when fed non-supplemented MSHAYL vs. average of supplemented MSHAYL diets.
Contrast 3 = Examining low vs. high RFI cows when fed supplemented WHAYL once a week vs. the average of MSHAYL supplemented multiple times a week.
Contrast 4 = Examining low vs. high RFI cows when fed supplemented WHAYL twice a week vs supplemented three times a week.
Contrast 5 = Examining medium RFI vs. the average of low and high RFI cows when fed HAYL diet vs. the average of MSHAYL diets.
Contrast 6 = Examining medium RFI vs. the average of low and high RFI cows when fed non-supplemented MSHAYL vs. the average of supplemented MSHAYL diets.

Contrast 7 = Examining medium RFI vs. the average of low and high RFI cows when fed supplemented WHAYL once a week vs. the average of MSHAYL supplemented multiple times a week. Contrast 8 = Examining medium RFI vs. the average of low and high RFI cows when fed supplemented WHAYL once a week vs. the average of MSHAYL supplemented multiple times a week.

4.0 Results and Discussion

The gestation performance (average daily gain, body condition score, ultrasonic fat depth measurements, feed intake, length of gestation and conception rate) was evaluated over the second and third trimesters for cows managed on one of five different nutritional management regimens. The subsequent performance (birth weight, weaning weight, average daily gain and mortality) for calves from the cows was also evaluated from birth until weaning at approximately 200 days of age. The nutritional management regimens were expected to yield differences in both cow and calf performance traits despite the regimens being similar in nutrient composition (Table 2), as the nutritional regimens varied in palatability resulting in major differences in feed intakes. While the trial was designed for MSHAYL cows to receive 0.8% of their BW in alfalfa haylage fed as a top-dress; cows actually consumed the haylage at 1% of their BW due to limitations in the accuracy of the feed truck for delivering quantities of haylage in precise amounts. For cows receiving strategic supplementation with the energy-protein supplement, supplementation was provided once a week, two times a week and three times a week, such that all cows received the same amount of supplementation each week based on individual body weight.

For the purpose of this study, the second trimester of gestation for these cows began at the start of trial on December 15th, 2015 and ended when the individual cow was 207 days in gestation. The third trimester started at 207 days in gestation and continued until calving. Once at 207 days in gestation, 70 of the cows started on different nutritional management regimens, with the implementation of strategic supplementation for specific MSHAYL-fed cows. The evaluation period from December 15th, 2015 until time of calving will be referred to as gestation, representing the period of each individual cow’s gestation in which performance and changes were monitored for the present trial.

4.1 Effects of Nutritional Management Regimen on Gestating Cow Performance

At the initiation of the trial, there were no differences ($P > 0.48$) in cow body weight (BW), age, body condition score (BCS), subcutaneous rib and rump fat depths and day of gestation amongst the five nutritional management regimens (Table 10). This is due to the cows being allocated to nutritional regimens to try and ensure similar days in gestation, age and breed composition across nutritional management regimens at the start of the study. The RFI by nutritional management regimen interaction was evaluated for all of the performance traits and was found to be non-significant ($P > 0.05$; Appendix Table 2) for all traits.

Cow Body Weight and Average Daily Gain

The effects of nutritional management regimen on body weights and gains are presented in Table 11. There were no differences ($P \geq 0.31$) in BW across nutritional management regimens at the start of trial and post-weaning. Cow body weights at the start of the trial (after weaning their 2015 calves) were numerically lower than post-weaning BW observed for the 2016 calving season. This may be due to the number of first-parity cows in this trial (n = 20), that were still growing as they entered the 2016 calving season. Conceptus-adjusted ADG throughout gestation and during the second trimester were greater ($P < 0.001$; Contrast 1) for cows fed the control, HAYL diet versus MSHAYL. The HAYL regimen had increased gains over the MSHAYL regimens as the HAYL diet provided an average of 20.1 Mcal/d NE_m versus the MSHAYL diet without supplementation which provided 13.3 Mcal/d NE_m (Table 12). Based on the requirements for a 636.4 kg beef cow (10 months since calving), the NRC (2000) lists NE_m requirements at 11.8 Mcal/d NE_m based on the NRC (2000) predicted feed intake of 12.2 kg DM/d. Thus cows on the HAYL regimen had more energy available in second trimester to gain weight than those on the MSHAYL regimens due to dramatic differences in DMI to be discussed later. In general, there were no differences (*P* > 0.22; Contrasts 2, 3, 4) for any measure of conceptus adjusted ADG amongst cows fed the MSHAYL diet regardless of the amount or frequency of supplementation.

In the present study, there were negative conceptus-adjusted ADG values for all cows in the third trimester with no differences (P = 0.74) in conceptus-adjusted ADG across nutritional management regimens. Regardless of the amount of energy provided in the diet and the amount of DM consumed, there was not enough available energy for the cows to maintain their own BW in late gestation. This contrasts past studies (Stalker et al. 2007; Larson et al. 2009) where providing a protein supplement for cows on dormant pastures enabled cows to maintain their body weight better than cows that were not supplemented, as protein is utilized to meet energy requirements when conventional sources of energy are limited (Clanton and Zimmerman, 1970). Supplementation of cows with DDGS in late gestation reduced losses in BW for cows fed low-quality hay (Bohnert et al. 2013), heifers fed prairie grass hay (Summers et al. 2015), and cows fed restricted haylage diets fed with wheat straw (Wood et al. 2010a). The differences in the results of the present study when compared to past studies may be due to differences in CP and NE_m concentrations in the supplement and stage of maturity for the animals. The addition of the Ca propionate/protein supplement in the current study did not impact ADG and BW. This suggests that the amount of supplement fed in the present study may have been inadequate to supply adequate amounts of energy in late gestation with reduced DMI. The MSHAYL diet with supplementation provided 14.5 Mcal/d NE_m based on the 10.2 kg DMI in the last 75 days of gestation whereas NRC (2000) NE_m requirements for a 636.4 kg cow are 15.5 Mcal/d NE_m. Corah et al. (1975) evaluated the effects of restricted feeding on BW losses in pregnant, primiparous cows and found BW losses were greater in cows restricted throughout gestation as compared to cows fed a high-energy diet in the last 30 days of gestation. This contradicts the present study, where there were no differences in ADG amongst the nutritional management regimens in last gestation and between the MSHAYL regimens, although the cows were not as nutritionally restricted. In the current study, increased frequency of supplementation did not increase conceptus adjusted gains in BW. In gestating cows fed low quality prairie forages supplemented with soybean meal, Mathis et al. (1999) reported lower BW losses with increasing rate of supplementation until supplementation reached 0.3% of body weight; changes in body weight then plateaued as supplementation increases. This indicates that the supplementation in the present study was not provided at a high enough rate regardless of the frequency of supplement to elicit a change in ADG when compared to cows not provided supplementation.

Feed Intake

The effects of nutritional management regimen on feed intake are presented in Table 12. DMI throughout gestation and second and third trimesters differed ($P < 0.001$) amongst nutritional management regimens. Cows receiving HAYL had greater DMI versus cows fed MSHAYL diets throughout gestation and second and third trimesters ($P < 0.001$; Contrast 1). There were differences in metabolizable energy intake (MEI) amongst nutritional management regimens during second and third trimesters of gestation ($P < 0.0001$). Similar to DMI, cows receiving HAYL had greater MEI versus cows fed MSHAYL diets throughout gestation and in both second and third trimesters ($P < 0.001$; Contrast 1). Providing a supplement to cows fed MSHAYL tended to increase MEI ($P < 0.06$; Contrast 2) during third trimester versus MEI for MSHAYL cows that did not receive a supplement. While this trend was not found in second trimester ($P > 0.53$; Contrast 2), supplementation tended to increase MEI throughout gestation versus MSHAYL cows that were not supplemented ($P < 0.07$; Contrast 2). This indicated that the supplement was able to slightly increase the MEI for cows fed the MSHAYL diet when supplementation commenced at 207 days in gestation. The NE_m contents for the HAYL and MSHAYL diets are similar (Table 2), although there were major differences in DMI which impacts Mcal of NE_m consumed per day in which 20.1 Mcal/d NE_m were consumed by cows fed HAYL versus 13.3 Mcal/d NE_m consumed by cows fed MSHAYL without supplementation. The HAYL diet also contained the greatest amount of CP (DM basis) at 16.5% as compared to 15.7% CP for the MSHAYL diet without supplementation.

The greater DMI values for cows receiving the HAYL vs. MSHAYL diets may be due to diet differences in palatability and(or) gut fill. For cows fed MSHAYL diets, it was observed that cows ate their daily allotment of haylage before consuming the millet straw that was available free choice. It is possible that DMI by cows fed the MSHAYL regimens were restricted by gut fill, especially in late gestation. The NDF content of all diets was relatively similar, ranging from 51.8% to 52.7%, with higher values for supplemented MSHAYL diets because there was increased straw intake with supplementation. Wood et al. (2010b) evaluated the digestibility of NDF in wheat straw and haylage in vitro, finding reduced digestibility for NDF in wheat straw compared to haylage. In the current study, reduced NDF digestibility for straw based MSHAYL diets may have decreased rates of passage and therefore limited intakes for cows on the MSHAYL regimens compared to cows fed the HAYL diet. As the NDF content in the diet increases, there is increased gut fill; the latter decreases as the energy content of the diet increases as they are inversely related (Mertens 1987). Eastridge et al. (2017) concluded the decrease in DMI is due to an increase in gut fill as there were no differences in rumen fermentation (concentration of propionate, acetate, butyrate and total tract apparent digestibility) with straw included in the diet. Wood et al. (2010a) found DMI was also reduced when cows were fed restricted haylage on a wheat straw based diet compared to a straight haylage diet.

Providing a supplement to cows fed MSHAYL tended to increase DMI ($P > 0.07$; Contrast 2) during third trimester versus DMI for MSHAYL cows that did not receive a supplement. This trend was not found in second trimester ($P > 0.40$; Contrast 2), as supplementation had not commenced at that time. Supplementation tended to increase DMI throughout gestation versus MSHAYL cows that were not supplemented ($P < 0.10$; Contrast 2), most likely due to the trend observed in third trimester. Past studies have found that the addition of soybean meal increases the digestibility of DM, CP, and ADF (Church and Santos 1981) and increased the disappearance of barley straw after 24 h (Tellier et al. 2004). Increased NDF digestibility was also found with the supplementation of CGM in cows fed hay (Cordes at al. 1988), cottonseed meal in cows fed prairie-grass hay (Hunt et al. 1989) and SBM and rolled sorghum (Del Curto et al. 1990). However, Del Curto et al. (1990) found forage intakes decreased when soybean meal and sorghum were used as supplements to increase energy intakes. Based on the results of past studies, it is evident supplementation with corn gluten meal and soybean meal (the two protein sources in the supplement for the current study) would likely increase DMI, resulting in increased MEI. It is also possible that supplementation in the current study may have influenced the digestibility of NDF and rate of passage allowing for more nutrients to be available to microbes and the animal itself; however, further digestibility studies would need to be conducted to fully evaluate these effects of the current study.

While gut fill may be limiting DMI for cows on MSHAYL diets, palatability issues with the millet straw are most likely responsible for low DMI for MSHAYL cows limit-fed haylage. Based on daily DMI data for MSHAYL cows weighing 680 kg BW, cows consumed an average of 3.7 kg of millet straw and 6.1 kg of haylage on a DM basis per day. This contrasts to 4.4 kg millet straw consumed per day for cows on the HAYL diet in which the millet straw was mixed with haylage and fed as a total mixed ration (TMR). Although gut fill may have played a factor, it is most likely the fashion in which the millet straw was offered to cows on the MSHAYL diets that impacted DMI. As it is likely the cows would have consumed more straw if presented in a TMR as TMRs have the ability to hide unpalatable feed as well as break down the straw further during the mixing process. The limited consumption of millet straw for cows on the MSHAYL diets also has implications for nutrient composition data presented in Table 2. While the energy and protein concentrations for the MSHAYL diets are numerically similar to values for the HAYL diet, these values are based on actual dry matter intakes for cows fed the specific diet. This is misleading as limited intakes for cows fed MSHAYL diets prevented these cows from meeting ME requirements even during second trimester, as well as the energy-protein supplement only being provided after 207 days in gestation, and possibly impacting nutritional management regimen differences in performance traits presented in tables 14 to 16. Although there is no difference (P = 859) in RFI_{2015} between the nutritional management regimens, there is a significant difference ($P < 0.001$) in the RFI_{gest} classification. There was a significant difference between ($P < 0.001$) in RFI_{gest} between cows fed the HAYL diet and the cows fed the MSHAYL diets with(without) supplementation. These differences in the RFI_{gest} classification from 2016 are likely due to the difference seen in DMI and the low palatability of the millet straw. The gain to feed ratio (G:F) was greater ($P < 0.001$; Contrast 1) for cows fed HAYL vs. MSHAYL-fed cows. This is likely due to the greater amounts of available energy due to greater DMI. As G:F is a ratio, it can be an indicator of increased feed intake or increased gain; therefore an increase in G:F in cows fed HAYL does not mean that the cows are more feed efficient. The cows fed the HAYL regimen had increased DMI and ADG; the increased in DMI was more drastic and seen throughout gestation and second and third trimesters and it thus more likely responsible for the higher G:F ratio.

Changes in Body Condition

The effects of nutritional management regimen on body condition are presented in Table 13. Body condition scoring is the palpation and visual evaluation of the cow's subcutaneous fat cover and body condition, and is used as an indicator of the available fat reserves to provide energy to the cow. Cow BCS was not affected ($P > 0.41$) by nutritional management regimen when assessed over the entire gestation or in second and third trimesters. Based on past studies (Stalker et al. 2007; Larson et al. 2009; Bohnert et al. 2013; Winterholler et al. 2012), it was expected that the nutrient supplementation in the third trimester would allow cows to maintain fat reserves better then cows not receiving supplementation. When feeding restricted amounts of haylage on a wheat straw based diet, Wood et al. (2010) found there were no differences in the final BCS when cows were supplemented with soybean meal or DDGS and when haylage was fed at a higher rate at 1% of BW. However, these authors found BCS was greater in cows fed a 100% haylage diet versus BCS for cows fed restricted amounts of haylage. The lack of improvement in BCS with supplementation of the MSHAYL diets in the current study may be due to similar MEI across MSHAYL regimens (Table 12), as energy is the first limiting nutrient for gestating cows (Clanton and Zimmerman, 1970). In past studies, protein supplementation such as SBM, DDGS and CGM was added to diets at a higher rate than in the current study, thus increasing the probability that supplementation can improve BCS and overall performance.

There were no differences in the average rib and rump subcutaneous fat depths ($P \geq 0.48$) during gestation amongst nutritional management regimens. When evaluating the change in subcutaneous fat depths from the start of trial to pre-calving, nutritional management regimen differences were present for the change in subcutaneous rib fat depths ($P < 0.0001$), but not for the change in subcutaneous rump fat depths ($P > 0.90$). There was a greater loss ($P < 0.0001$; Contrast 1) in subcutaneous rib fat from the start of trial to pre-calving for cows fed MSHAYL diets versus cows fed the HAYL diet. Increasing the frequency of supplementation reduced ($P > 0.02$; Contrast 4) losses of subcutaneous rib fat depth during gestation. One can question the biological significance of the changes in subcutaneous rib and rump fat depths, which are less than 1.5 mm and confirms the lack of differences in BCS across nutritional management regimens. Corah et al. (1975) reported losses in subcutaneous rib fat depth of approximately 2 mm for gestating heifers fed an energy deficient diet at 65% of the recommended NRC (1970) level for the last 100 days of gestation. In the current study the HAYL diets provided 20.1 Mcal/d NE_m, 8.3 Mcal/d over NRC (2000) recommendations for cows in second trimester and 4.7 Mcal/d over the requirements for cows in third trimester. The cows receiving the MSHAYL diet without supplementation consumed 13.3 Mcal/d NE_m, which provided 2.2 Mcal/d or 13.8% under NRC (2000) recommendation for cows in late gestation. These results suggest that if cows in the current study had received a more energy-restricted diet in late gestation, greater differences amongst nutritional management regimens most likely would have been present for changes in subcutaneous rib and rump fat depths and BCS over gestation.

Cow Reproductive Performance and Pre-weaning Calf Performance

The effects of nutritional management regimen on cow reproductive performance and pre-weaning calf performance are presented in Table 14. Only the length of gestation, conception rate and weaning rate were used to evaluate the reproductive performance. There were no differences in length of gestation across nutritional regimens ($P > 0.13$). This contradicts Larson et al. (2009) where providing a 28%-CP supplement to cows in the last trimester resulted in earlier calving (shorter length of gestation) versus cows that were not supplemented. Past studies have proven inconclusive regarding the effect of supplementation on the length of gestation. Stalker et al. (2006) found cows calved later in the calving season grazing winter pastures and provided with a 42% crude protein supplement than non-supplemented cows. Martin et al. (2007) found that providing a 42%-CP supplement to cows during late gestation resulted in the birth of heifers that were more likely to calve in the first 21 days of their first calving season. The variability in results across studies may be due to differences in genetics, environment, health status, age, BCS and method of breeding.

Conception rates for the subsequent breeding season were not affected ($P > 0.31$) by nutritional management regimen. These results concur with past studies (Larson et al. 2009; Stalker et al. 2006) where providing a 42% CP supplement did not affect conception rates for mature cows. However, Martin et al. (2007) reported increased conception rates when protein was supplemented to the dams of heifers. Since heifer progeny from the current study were not evaluated post-calving, it is unclear if there are any effects of nutritional management regimens on the reproductive performance of heifer offspring. It is surprising that Larson et al. (2009) and Stalker et al. (2006) did not find any effects of supplementation on conception as both studies reported losses in post-calving body condition for cows not supplemented during gestation. Richards et al. (1986) found mature cows of higher BCS (BCS ≥ 5, on a 1 to 9 scale) returned to estrus earlier regardless of nutritional regimen post-partum; while BCS at time of calving in mature cows did not influence single service conception rates. This holds true for first-parity cows with increased BCS in which there were shorter intervals to conception and greater conception rates (DeRouen et al. 1994). However, Bohnert et al. (2013) showed that conception rate was affected by BCS at the start of the trial, in which high-BCS cows post-weaning had improved conception rates the following year. The differences in conception rates and influences on conception in these various studies may be due to differences in cow body condition and fat reserves at the time of weaning prior to the initiation of the studies.

There were no differences in weaning rate amongst nutritional regimens ($P > 0.35$). Bohnert et al. (2013) evaluated BCS for cows throughout gestation; cows with low BCS (BCS averaging 4 on a scale of 1 to 9) had greater calf mortalities prior to weaning than cows with high BCS (BCS average 6 on a scale of 1 to 9). The absence of differences in BCS across nutritional management regimens in the present study may explain similar weaning rates across nutritional regimens. Adequate BCS at the time of calving for cows on all of the nutritional management regimens may be responsible for similar pre-weaning (post-calving) cow ADG ($P = 0.47$; Table 11) and calf ADG ($P = 0.88$; Table 14) across nutritional management regimens. The study conducted by Stalker et al. (2006) found greater gains in calves from cows supplemented with CP pre-calving, although it should be noted that these cows also had higher BCS than cows that were not supplemented. Calf birth weights were not affected ($P > 0.70$) by nutritional management regimens in the present study. The findings of DeRouen et al. (1994) agree with the present study, in that prepartum energy levels for pregnant heifers had no influence on calf birth weights. Mathis et al. (1999) also did not find any differences in calf birth weights from cows on pasture during gestation, supplemented with varying levels of soybean meal. Wood et al. (2010a) found no differences in calf birth weights from cows that were fed restricted amounts of haylage on a wheat straw-based diet in mid- to late-gestation. However, Corah et al. (1975) concluded that heifers fed low-energy diets during gestation gave birth to lighter weight calves that would go on to produce lighter weaning weights than calves from heifers that were fed higher energy diets.

There were also no differences ($P > 0.81$) in calf weaning weights across nutritional management regimens, which may be due to the calves having similar birth weights as Corah et al. (1975) demonstrated that calf birth weights can influence calf weaning weights. In dry lot, the lactation diet consisted of 100% haylage. Some cows remained in dry lot until weaning their calf while others grazed an alfalfa-grass pasture, with corn silage supplementation late in the grazing season when quality and quantity of grass were limited. The lactation diets were provided to meet or exceed energy requirements during lactation and reduce any possible losses in BW post-calving; thus, lactation diets should not have limited the possible pre-weaning gains for calves.

Table 10. Start of Trial Traits for Cows Allocated to the 5 Nutritional Management Regimens							
	Nutritional Management Regimens[1]						
Trait	HAYL	MSHAYL None	MSHAYL one /wk	MSHAYL twice /wk	MSHAYL thrice /wk	S.E.[2]	P-value
No. of Cows	24	24	23	24	23	-	-
Body Weight (kg)	679.8	682.4	659.0	693.7	689.0	20.50	0.793
Age (yr)	6.00	5.63	5.44	5.36	5.61	0.411	0.836
BCS	2.9	2.8	2.6	2.8	2.8	0.13	0.555
Rib fat depth (mm)	7.8	9.0	7.2	8.5	7.0	0.90	0.481
Rump fat depth (mm)	9.9	10.4	9.7	11.4	10.3	1.38	0.921
Days in gestation (d)	138.4	136.1	136.2	140.6	137.9	3.45	0.867

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.
[2] The pooled standard error of treatment means.

Table 11. Effects of Nutritional Management Regimen on Average Daily Gain and Body Weights											
	Nutritional Management Regimen[1]										
		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum						P-value for contrasts[2]			
Trait	HAYL	None	once /wk	twice /wk	thrice /wk	S.E.[3]	P-value	1	2	3	4
No. of cows	24	24	23	24	23	-	-	-	-	-	-
Body Weight (kg)	679.8	682.4	659.0	693.7	689.0	20.50	0.793	Not Applicable as nonsignificant P-values for nutritional management regimens			
End of trial body weight (kg)	716.9	712.3	678.0	739.5	705.7	20.33	0.312				
ADG throughout gestation[4] (kg/day)	0.39	-0.03	-0.07	0.05	-0.02	0.059	<0.0001	<0.0001	0.775	0.218	0.432
2nd trimester ADG (kg/day)	1.03	0.41	0.34	0.43	0.54	0.104	<0.0001	<0.0001	0.853	0.284	0.451
3rd trimester ADG (kg/day)	-0.26	-0.36	-0.24	-0.25	-0.36	0.08	0.748	Not Applicable as nonsignificant P-values for nutritional management regimens			
Post-calving ADG (kg/day)	-0.09	0.07	0.10	0.21	-0.08	0.139	0.470				
Average MBWT (kg)	133.1	129.8	129.0	132.0	131.8	2.87	0.829				

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] Contrasts: 1 = cows fed HAYL (70% haylage/30% straw diet) vs. all ad lib straw based diets (MSHAYL); 2 = cows fed MSHAYL without supplementation vs. cows fed MSHAYL with supplementation; 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two and three times a week; 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.

[3] The pooled standard error of treatment means.

[4] Average daily gain measurements and metabolic body weight measurements (MBWT) are calculated based on conceptus-adjusted body weights.

Table 12. Dietary Regimen Effects on Intakes of Dry Matter (DMI) and Metabolizable Energy (MEI)											
	Nutritional Management Regimen[1]										
		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum						P-value for contrasts[2]			
	HAYL	None	once /wk	twice /wk	thrice /wk	S.E.[3]	P-value	1	2	3	4
No. of Cows	24	24	23	24	23	-	-	-	-	-	-
DMI throughout gestation (kg/d)	14.8	9.4	9.9	10.3	10.3	0.38	<0.0001	<0.0001	0.099	0.419	0.983
2nd trimester DMI (kg/d)	16.2	10.3	10.4	10.7	10.9	0.36	<0.0001	<0.0001	0.407	0.336	0.761
3rd trimester DMI (kg/d)	14.0	8.9	9.5	9.8	10.0	0.40	<0.0001	<0.0001	0.063	0.403	0.720
MEI throughout gestation (Mcal/d)	31.3	20.2	21.3	22.1	22.1	0.76	<0.0001	<0.0001	0.063	0.379	0.972
2nd trimester MEI (Mcal/d)	34.1	23.6	23.4	24.2	25.2	0.92	<0.0001	<0.0001	0.537	0.265	0.427
3rd trimester MEI (Mcal/d)	29.5	18.4	19.8	20.5	20.8	0.87	<0.0001	<0.0001	0.055	0.452	0.796
G:F	0.03	-0.03	-0.007	0.006	-0.001	0.006	0.001	<0.001	0.693	0.208	0.401
RFI_{2015}	0.29	-0.19	0.04	0.48	-0.22	0.524	0.859	Not Applicable as nonsignificant P-values for nutritional management regimens			
RFI_{gest}	2.04	-0.96	-0.19	-0.27	-0.58	0.320	<0.001	<0.001	0.101	0.535	0.495

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] Contrasts: 1 = cows fed HAYL (70% haylage/30% straw diet) vs. all ad lib straw based diets (MSHAYL); 2 = cows fed MSHAYL without supplementation vs. cows fed MSHAYL with supplementation; 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two and three times a week; 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.

[3] The pooled standard error of treatment means.

Table 13. Nutritional Management Regimen Effects on Cow Body Condition											
	Nutritional Management Regimen[1]										
		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum						P-value for contrasts[2]			
	HAYL	None	once /wk	twice /wk	thrice /wk	S.E.[3]	P-value	1	2	3	4
No. of Cows	24	24	23	24	23	-	-	Not Applicable as nonsignificant P-values for nutritional management regimens			
BCS throughout gestation[4]	2.81	2.71	2.71	2.64	2.82	0.122	0.795				
2nd trimester BCS[5]	2.77	2.61	2.66	2.64	2.79	0.121	0.799				
3rd trimester BCS[6]	2.94	2.77	2.72	2.61	2.81	0.125	0.419				
Rib Fat depth (mm)[7]	7.8	7.5	6.8	7.40	7.6	0.912	0.942				
Change in Rib fat depth (mm)[8]	0.80	-1.28	-1.24	-1.33	-0.28	0.319	<0.0001	<0.0001	0.366	0.268	0.029
Rump fat depth (mm)[9]	9.2	11.1	10.0	8.8	7.8	1.262	0.484	Not Applicable as nonsignificant P-values for nutritional management regimens			
Change in rump fat depth (mm)[10]	-0.53	-0.74	0.34	0.10	-1.21	1.194	0.901				

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] Contrasts: 1 = cows fed HAYL (70% haylage/30% straw diet) vs. all ad lib straw based diets (MSHAYL); 2 = cows fed MSHAYL without supplementation vs. cows fed MSHAYL with supplementation; 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two and three times a week; 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.

[3] The pooled standard error of treatment means.

[4] Body condition score as an average of all measurements collected throughout gestation. All BCS measurements scores on a scale from 0 to 5 with 0 = emaciated, hip bones tail head and ribs projecting to 5 = tail head and hip bones covered with fatty tissue and ribs have fat folds.

[5] Body condition score as an average of all measurements collected throughout second trimester.

[6] Body condition score as an average of all measurements collected throughout third trimester

[7] Average of all measurements of subcutaneous fat (mm) between the 12th and 13th ribs during gestation

[8] Change in subcutaneous rib fat (mm) between the initial measurement and the final pre-calving measurement.

[9] Average of all measurements of subcutaneous rump fat (mm) during gestation.
[10] Change in subcutaneous rump fat (mm) between initial and final pre-calving measurements during gestation.

Table 14. Dietary Regimen Effects on Cow Reproductive Performance and Pre-Weaning Calf Performance							
	Nutritional Management Regimen						
		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum					
	HAYL	None	once /wk	twice /wk	thrice /wk	S.E.[2]	P-value
No. of cows	24	24	23	24	23	-	-
Length of Gestation (d)	282.8	284.5	286.3	282.9	285.7	1.20	0.131
Conception rate[3] (%)	71.6	72.9	62.2	93.3	72.3	0.11	0.317
Weaning rate[4] (%)	100.0	100.0	94.4	87.8	93.9	0.05	0.352
Birth Weight (kg)	40.1	39.6	41.9	40.3	39.2	1.45	0.707
Calf ADG (kg/d)	1.13	1.12	1.11	1.08	1.10	0.040	0.883
Weaning Weight (kg)	272.4	261.9	261.9	261.0	267.4	8.17	0.811

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.
[2] The pooled standard error of treatment means.
[3] Conception rate is the percentage of cows confirmed pregnant vs. open.
[4] Weaning rate is the percentage of cows weaning their own calf vs. cows not weaning a calf due to death of calf or orphaning calf.

4.2 Effect of Nutritional Management Regimen on Blood Parameters

The effects of nutritional management regimen on serum total protein, urea, non-esterified fatty acids (NEFA) and β-hydroxybutyrate (BHB) concentrations are presented in Table 15. There were no differences in serum protein concentrations amongst nutritional management regimens ($P > 0.73$) during gestation and second and third trimesters. In contrast, serum urea concentrations were affected ($P < 0.03$) by nutritional management regimens during the second trimester. Serum urea concentrations tended to be lower ($P < 0.09$; Contrast 2) in MSHAYL cows that were supplemented versus non-supplemented MSHAYL cows. Increasing the frequency of supplementation to 2 or 3 times a week increased ($P < 0.03$; Contrast 3) serum urea concentrations in second trimester, which is surprising as no supplement was being provided in second trimester. While no nutritional management regimen differences in serum urea concentrations were found for third trimester ($P < 0.44$), feeding the HAYL diet tended to decrease serum urea concentrations throughout gestation versus feeding the MSHAYL diets ($P < 0.10$; Contrast 1). There were no consistent effects of diet supplementation on serum urea concentrations throughout gestation as more frequent supplementation tended to increase serum urea levels versus supplementing once per week ($P < 0.07$; Contrast 3), while serum urea levels were greater with 2 times versus 3 times a week supplementation ($P < 0.006$; Contrast 4). Since there were no differences in serum urea concentrations in third trimester, the trends seen throughout gestation are likely the result of differences seen during second trimester. When evaluating gestating heifers, Gonano et al. (2014) found the plasma urea levels were higher in early gestation regardless of RFI classification. The past study of Waterman et al. (2006) found greater serum urea concentrations in lactating cows fed a high UIP supplement alone compared to feeding a supplement containing UIP and propionate salts. Mulliniks et al. (2011a) also found that the addition of propionate salts had no effect on serum urea concentrations. In the current study, serum urea concentrations tended to increase as gestation progressed in agreement with McGee et al. (2005). This may be due to increased mobilization of protein stores to meet energy demands in late gestation (McGee et al. 2005; Richardson et al. 2004)

There were no differences ($P > 0.63$) in serum glucose concentrations across nutritional regimen during late gestation. Drackley et al. (2011) showed that supplying propionate to the rumen increased glucose production from propionate in the liver. In the past, infusion of propionate into the rumen resulted in 32% of glucose carbons being derived from propionate (Wiltrout and Satter 1972). Waterman et al. (2006) provided a supplement with UIP and propionate in lactating beef cows and found greater increases in serum glucose concentrations than providing a supplement with UIP alone. Mulliniks et al. (2011a, 2011b) found that as the glucogenic potential and propionate salts increased in the diet, serum glucose concentrations also increased in lactating beef cows. For the present study, it was expected there would be an increase in serum blood glucose concentrations in supplemented MSHAYL cows as compared to cows fed MSHAYL without supplementation. Wood et al. (2010a) fed a wheat straw-based diet to beef cows in mid to late gestation that were supplemented with haylage, soybean meal, or DDGS; supplementation did not affect glucose concentrations. For the present study it is unclear if the variations in when the supplement was provided to the cows, in relation to blood sampling influenced any response in serum glucose concentrations in third trimester as supplementing propionate in the past increased production of glucose in the liver (Drackley et al. 2011).

There were no differences in ($P > 0.29$) in serum BHB concentrations across nutritional regimens during gestation and second and third trimesters. However past studies (McGee et al. 2005; Cameron 1992) found that BHB concentrations increased in restricted cows when compared to cows fed ad libitum, possibly indicating faster mobilization of fat stores when restricted. Mulliniks et al. (2011a) found that as the glucogenic potential of the diet increased, serum BHB concentrations decreased. Since the gestating cow's greatest energy demands are in the third trimester, it is more likely to see nutritional regimen differences in serum BHB concentrations during this period if one or more nutritional management regimens impact energy availability qualitatively or quantitatively.

Similar to BHB data, there were no differences ($P > 0.10$) in serum NEFA concentrations across nutritional management regimens during gestation and second and third trimesters. Past studies have found serum NEFA concentrations to increase when adipose tissues are mobilized to be utilized as an energy source (Adewuyi et al. 2005; Cameron 1992). In the current study, serum NEFA concentrations tended to increase as gestation progressed, indicating there was an increase in mobilization of body fat depots as energy demands increased.

Table 18. Nutritional Management Regimen Effects on Total Protein, Urea, Glucose, β-hydroxybutyrate (BHB) and Nonesterified Fatty Acids (NEFA) Concentrations in Serum											
	Nutritional Management Regimen[1]										
		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum						P-value for contrasts[2]			
Trait	HAYL	None	once /wk	twice /wk	thrice /wk	S.E.[3]	P-value	1	2	3	4
No. of Cows	24	24	23	24	23	-	-	Not applicable as nonsignificant P-value for nutritional management regimen			
Total Protein throughout gestation (g/L)	70.4	70.8	71.4	71.3	71.8	0.79	0.733				
2nd Trimester Total Protein (g/L)	72.1	71.9	70.9	69.3	72.1	1.67	0.749				
3rd Trimester Total Protein (g/L)	70.2	71.3	70.1	73.3	73.4	2.34	0.745				
Urea throughout gestation (mmol/L)	4.3	4.4	4.4	4.7	4.4	0.08	0.052	0.098	0.481	0.064	0.058
2nd Trimester Urea (mmol/L)	3.9	3.9	3.4	3.8	3.7	0.15	0.029	0.348	0.087	0.024	0.089
3rd Trimester Urea (mmol/L)	5.08	4.6	4.9	5.3	5.2	0.27	0.437	Not applicable as nonsignificant P-value for nutritional management regimen			
Glucose throughout gestation (mmol/L)	3.2	3.2	3.2	3.2	3.1	0.04	0.627				
2nd Trimester Glucose (mmol/L)	3.2	3.1	3.1	3.1	3.1	0.09	0.702				

3rd Trimester Glucose (mmol/L)	3.2	3.3	3.3	3.2	3.2	0.11	0.904
BHB throughout gestation (µmol/L)	345.2	348.3	347.3	358.6	344.6	11.18	0.910
2nd Trimester BHB (µmol/L)	357.8	329.3	307.1	333.9	326.5	31.18	0.838
3rd Trimester BHB (µmol/L)	327.1	329.9	381.2	372.3	333.6	23.13	0.292
NEFA throughout gestation (mmol/L)	0.16	0.17	0.16	0.14	0.17	0.009	0.208
2nd Trimester NEFA (mmol/L)	0.10	0.14	0.13	0.11	0.14	0.012	0.107
3rd Trimester NEFA (mmol/L)	0.20	0.21	0.16	0.14	0.18	0.029	0.424

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.
[2] Contrasts: 1 = cows fed HAYL (70% haylage/30% straw diet) vs. all ad lib straw based diets (MSHAYL); 2 = cows fed MSHAYL without supplementation vs. cows fed MSHAYL with supplementation; 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two and three times a week; 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.
[3] The pooled standard error of treatment means.

4.3 Effects of Previously Evaluated Residual Feed Intake Classification on Cow and Calf Performance

Cows were allocated to the 5 nutritional management regimens in the current study based on RFI classification to ensure there were no differences in feed efficiency across nutritional management regimens at the start of the study. RFI for classification were calculated during mid-late gestation in 2015 when cows in the study (n = 108) were fed a 70% haylage, 30% millet straw (HAYL) TMR diet.

Feed Intake

The effects of RFI_{2015} classification on feed intake are presented in Table 16. There were no differences ($P > 0.84$) in DMI across RFI_{2015} classification group throughout gestation and second and third trimesters. Since DMI and MEI are related, similar results were found for MEI, with no differences ($P > 0.70$) in MEI across RFI_{2015} classification groups for all evaluation periods. This was not expected as RFI is calculated based on the residual difference in DMI from the expected DMI with cows that consume more DM having a higher RFI classification, meaning they are less efficient at converting feed to gain. Past studies have shown that high RFI cattle consume more than their low RFI counterparts when RFI was measured in feedlot animals (Basarab et al. 2007; Durunna et al. 2011b; Kelly et al. 2010a; Richardson et al. 2001) and breeding herd cattle (Basarab et al. 2007; Black et al. 2013; Fitzsimons et al. 2014; Hafla et al. 2013; Lawrence et al. 2011; Manafiazar et al. 2014). In the present study the high-RFI_{2015} classified cows were not consuming more than the medium- and low-RFI_{2015} classified cows and cannot be considered inefficient for converting feed to gain. As well, the low RFI_{2015} classification cows did not consume less than medium- and high- RFI_{2015} classification cows and cannot be considered inefficient in converting feed to gain. These results suggest that cows changed in feed efficiency between years and with changes in nutritional management regimen.

Cow Body Weight and Average Daily Gain

The effects of RFI_{2015} on body weights and gains are presented in Table 17. There were no differences in conceptus-adjusted ADG amongst RFI_{2015} classifications groups throughout gestation and for second and third trimesters ($P > 0.70$). Post-calving ADG (measured from calving to weaning), and cow MBWT were also similar ($P \geq 0.47$) across RFI_{2015} classification groups. Past studies (Basarab et al. 2007; Black et al. 2013; Fitzsimmons et al. 2014; Lawrence et al. 2011; Redden et al. 2014; Meyer et al. 2008) reported no differences in ADG during gestation based on RFI classification group in heifers, cows and ewes. There were no differences in G:F amongst RFI_{2015} classifications groups; since RFI and G:F are both measures of feed efficiency it would be expected there would be a significant difference in G:F between high and low RFI_{2015} classification cows. This concurs with the lack of significant difference in DMI, demonstrating that RFI is not a good repeatable measure of feed efficiency when evaluated over multiple years, especially with changes in the diet.

Change in Body Condition

The effects of RFI_{2015} classification on body condition are presented in Table 18. There were no differences ($P > 0.19$) in BCS across RFI_{2015} classification groups throughout gestation and second and third trimesters. Past studies disagree on the effect of RFI classification on BCS in cows and heifers. While Lawrence et al. (2011) concluded there was no impact of RFI on BCS in heifers, Manafiazar et al. (2014) and Basarab et al. (2007) both found BCS and subcutaneous fat cover were negatively correlated with RFI classification. Study-to-study differences on the effects of RFI classification on BCS may be due to BCS being a subjective measurement which is subjected to extensive variation and error depending on a given individual’s interpretation of the BCS scale and experience (Edmonson et al. 1989).

There were no differences ($P > 0.12$) in the average or changes in subcutaneous rib and(or) rump fat depths (mm) during gestation amongst RFI_{2015} classification groups. Past studies have generally found that subcutaneous fat depths are positively correlated with RFI classification in feedlot animals (Basarab et al. 2007; Nkrumah et al. 2007), heifers (Black et al. 2013; Durunna et al. 2012; Hafla et al. 2013; Kelly et al. 2010) and mature cows (Fitzsimons et al. 2014). In contrast, Manafiazar et al. (2014) reported that subcutaneous fat depths were negatively correlated with RFI in heifers. The lack of differences in subcutaneous fat depths in the present study confirms the lack of a difference seen in BCS throughout the study.

Cow Reproductive Performance and Pre-weaning Calf Performance

The effects of RFI_{2015} on cow reproductive performance and pre-weaning calf performance are presented in Table 19. There were no differences ($P > 0.22$) in length of gestation, conception rates, weaning rates, calf birth weights and calf weaning weights amongst RFI_{2015} classification groups. There was a trend ($P < 0.06$) for a difference in calf ADG as affected by RFI_{2015} classification, with calves from medium RFI cows having greater gains ($P = 0.02$) than gains for calves from low and high RFI cows. Since there were no differences in DMI amongst RFI_{2015} classification groups, it brings to question how valid the RFI_{2015} values used are at representing feed efficiency for the cows in the current study. Therefore these results may not show the true effect of RFI on calf pre-weaning performance. Past research by Arthur et al. (2005) and Basarab et al. 2007 found that RFI did not affect conception rates; however, Basarab et al. (2011) contradicts this concluding that high RFI cattle had greater conception rates at the beginning of the breeding season when compared to low RFI cattle. Past studies (Lawrence et al. 2011; Basarab et al. 2007; Black et al. 2013; Fitzsimmons et al. 2014; Meyer et al. 2008) reported that RFI did not affect birth weights, calf ADG and calf weaning weights. In contrast, Hafla et al.

(2013) found contradicting results in heifers, where low RFI heifers produced calves with heavier weaning weights than high RFI cows.

Table 16. Effects of Residual Feed Intake Classification on Dry Matter Intake (DMI) and Metabolizable Energy Intake (MEI)					
	RFI_{2015} Classification[1]				
Trait	Low	Medium	High	S.E.[3]	P-value
No. of Cows	27	52	28	-	-
Mean RFI	-2.44	-0.01	2.73	-	-
DMI throughout gestation (kg/d)	11.0	10.9	10.9	0.275	0.929
2nd trimester DMI (kg/d)	11.6	11.7	11.7	0.276	0.962
3rd trimester DMI (kg/d)	10.6	10.5	10.3	0.284	0.849
MEI throughout gestation (Mcal/d)	23.8	23.2	23.3	0.557	0.775
2nd trimester MEI (Mcal/d)	26.0	25.9	26.4	0.650	0.850
3rd trimester MEI (Mcal/d)	22.1	21.9	21.4	0.610	0.703

[1] RFI_{2015} classification includes: Low RFI less than 0.5 SD from the mean RFI of zero; Medium RFI within 0.5 SD above and below the mean RFI of zero; High RFI greater than 0.5 SD of the mean RFI of zero.
[2] The pooled standard error of treatment means.

Table 17. RFI_{2015} Classification Effects on Cow Body Weights and Average Daily Gain[1]					
	RFI_{2015} Classification[2]				
Trait	Low	Medium	High	S.E.[3]	P-value
No. of Cows	27	52	28	-	-
ADG throughout gestation (kg/d)	0.03	-0.01	-0.05	0.063	0.705
2nd trimester ADG (kg/d)	0.51	0.58	0.56	0.065	0.704
3rd trimester ADG (kg/d)	-0.31	-0.29	-0.27	0.065	0.924
ADG post-calving (kg/d)	0.05	-0.002	0.08	0.093	0.470
Average MBWT (kg)	132.7	129.6	131.0	2.201	0.581
G:F	0.004	0.002	0.007	0.0043	0.732

[1] The average daily gain measurements and metabolic body weight measurements are calculated based on conceptus adjusted body weights.
[2]RFI_{2015} classification includes: Low RFI less than 0.5 SD from the mean RFI of zero; Medium RFI within 0.5 SD above and below the mean RFI of zero; High RFI greater than 0.5 SD of the mean RFI of zero
[3] The pooled standard error of treatment means.

Table 18. Residual Feed Intake Classification Effects on Cow Body Condition.					
	RFI_{2015} Classification[1]				
Trait	Low	Medium	High	S.E.[2]	P-value
No. of Cows	27	52	28	-	-
BCS throughout gestation[3]	2.83	2.63	2.75	0.094	0.291
BCS 2nd trimester[4]	2.79	2.57	2.72	0.093	0.191
BCS 3rd trimester[5]	2.84	2.69	2.78	0.096	0.482
Rib fat depth (mm)[6]	7.45	7.29	7.51	0.700	0.968
Change in rib fat depth (mm)[7]	-0.96	-0.38	-0.66	0.241	0.204
Rump fat depth (mm)[8]	9.72	9.85	8.61	0.969	0.623
Change in rump fat depth (mm)[9]	-2.01	-0.07	0.86	0.918	0.125

[1]RFI_{2015} classification includes: Low RFI less than 0.5 SD from the mean RFI of zero; Medium RFI within 0.5 SD above and below the mean RFI of zero; High RFI greater than 0.5 SD of the mean RFI of zero.

[2] The pooled standard error of treatment means.

[3] Body condition score as an average of all measurements collected throughout gestation.

[4] Body condition score as an average of all measurements collected throughout second trimester.

[5] Body condition score as an average of all measurements collected throughout third trimester.

[6] Average of all measurements of subcutaneous fat (mm) between the 12th and 13th ribs, during gestation.

[7] Change in subcutaneous rib fat (mm) between initial measurement and final pre-calving measurement.

[8] Average of all measurements of the subcutaneous rump fat (mm) during gestation.

[9] Change in subcutaneous rump fat (mm) between initial and final pre-calving measurements during gestation.

Table 19. Residual Feed Intake Classification Effect on Cow Reproductive Performance and Pre-Weaning Calf Performance.

	RFI_{2015} Classification[1]				
Trait	Low	Medium	High	S.E.[2]	P-value
No. of Cows	27	52	28	-	-
Length of gestation (d)	285.0	285.2	283.2	0.918	0.249
Conception rate[3] (%)	71.0	75.1	78.5	0.079	0.832
Weaning rate[4] (%)	96.0	96.4	93.3	0.037	0.828
Birth Weight (kg)	40.5	41.0	39.1	1.225	0.446
Calf ADG (kg/d)	1.08	1.16	1.09	0.028	0.063
Weaning Weight (kg)	258.3	272.4	264.0	6.167	0.221

[1]RFI_{2015} classification includes: Low RFI less than 0.5 SD from the mean RFI of zero; Medium RFI within 0.5 SD above and below the mean RFI of zero; High RFI greater than 0.5 SD of the mean RFI of zero.

[2] The pooled standard error of treatment means.

[3] Conception rate is the percentage of cows confirmed pregnant vs. not pregnant.

[4] Weaning rate is the percentage of cows weaning their own calf vs. cows not weaning a calf due to death of calf or orphaning calf.

4.4 Effects of Year and Trimester on RFI Classification

Identifying changes in RFI classification or re-ranking throughout a cow's productive life is important for cow-calf producers. There has been limited research on comparing feed efficiency and its repeatability in mature cows on various diets and at varying stages of production. However, it is useful to identify feed efficiency at an early age in replacement heifers so the most efficient (i.e. least costly) animals can be selected for the breeding herd. In the current study, cows were initially evaluated for feed efficiency using RFI classification in winter, 2015 during gestation with cows fed the HAYL diet (Year 1) described in Table 2. These cows were re-evaluated for RFI classification in 2016 when approximately 80% of the cows and first-calf heifers were placed on a different nutritional management regimen, in year 2 (Table 2). This was done to evaluate the impact that the nutritional regimen may have on cow feed efficiency and to test if RFI classification was a repeatable measure of feed efficiency. Data from both years were combined and 104 cows and first-calf heifers had complete data for both years. A regression analysis was performed using the following variables to determine the RFI_{year} model: ADG, MBWT, age, change in BCS, rib fat depth, the change in rib fat depth, rump fat depth and the change in rump fat depth. The best fitting RFI model was established as described in section 3.5 and cows were ranked for RFI classification based on 0.5 SD units from the mean of zero into low (efficient; RFI value < 0.5 SD of the mean), medium (intermediate; RFI value ± 0.5 SD of the mean) and high (inefficient; RFI value > 0.5 SD of the mean) RFI classification for each year. The mean RFI_{year} was 0.0016 with a standard deviation of 2.07. A cow was considered to have re-ranked if their RFI_{year} classification in the second year changed from the classification in year one.

There were no differences in RFI_{year} re-classification by year ($P = 0.69$; Table 20); however, RFI_{year} re-classification was affected by nutritional management regimen ($P = 0.012$)

and the nutritional management regimen by year interaction (P = 0.004). These results indicate that diet affects RFI classification as a measure of feed efficiency in a mature, gestating beef cow. When evaluating the changes in RFI classification by nutritional management regimen, each cow is evaluated individually for re-ranking. Of the cows that were maintained on the same nutritional regimen (the HAYL diet) in both years, 59.0% re-ranked (Table 21). In cows receiving one of the MSHAYL regimens, there were fewer incidences of re-ranking when compared to cows fed the HAYL diet. The cows fed MSHAYL with supplementation two times a week in year 2 had the lowest incidence of re-ranking at 10.0%. This data suggests there may be less re-ranking in cows fed the MSHAYL regimens.

Determination of changes in feed efficiency for a mature cow from year to year is important for assessing how age-related changes in body condition and metabolism impact nutrient requirements and costs for maintaining the cow. Knowledge of how stage of production in mature cows affects feed efficiency is also important for lowering overall feed costs. In an evaluation of heifers, Manafiazar et al. (2014) found that low-RFI heifers maintained their feed efficiency determined post-weaning at approximately 12 months of age as gestating first calf heifers. This indicated that it would be possible for producers to select replacement heifers based on a RFI classification determined at a young age.

In the current study, 118 cows were evaluated in both second and third trimesters to evaluate changes in feed efficiency and the impact nutritional management may have on RFI classification as gestation progresses. A regression analysis was performed on the following variables: days on feed, ADG, MBWT, BCS, rib fat depth, rump fat depth, conception rate, weaning rate, age, calf birth weight, calf weaning weight and calf ADG to determine $RFI_{trimester}$ classification as described in section 3.5. The mean $RFI_{trimester}$ was 0 and had a standard deviation of 4.316. $RFI_{trimester}$ ranking differed between trimesters and nutritional regimen ($P < 0.001$; Table 20). However, there was no nutritional management regimen by trimester interaction present ($P < 0.196$), indicating that re-ranking across trimesters was not affected by the specific nutritional management regimen for a given cow. Cows fed MSHAYL with supplementation three times a week had the largest number of cows that re-ranked, with 43.5% re-ranking (Table 22). However, it should be noted that the cows fed the MSHAYL diet with supplementation only received supplementation during the third trimester. The HAYL regimen had no cow which re-ranked. There was less re-ranking in cows fed the HAYL regimen which was the converse of RFI re-rankings by year. The HAYL diet exceeded energy requirements in both second and third trimesters; therefore, the feeding of this diet never challenged the cows to require extensive use of body reserves to meet nutrient demands, primarily to meet energy requirements. The number of HAYL cows in each $RFI_{trimester}$ classification is constant from trimester 2 to 3. There are limitations to using conceptus-adjusted ADG in third trimester for calculating RFI as the cow's nutritional requirements include the demands of the conceptus. Although it should be noted that conceptus-adjusted ADG was not selected for inclusion in the $RFI_{trimester}$ model for evaluating re-ranking by trimester.

The reduced re-ranking by trimester in cows that were maintained on the same diet in the current study contradicts Durunna et al. (2011c). These researchers evaluated steers over a 3-year study and found 51% of cattle re-ranked from the grower phase to the finisher phases of production while maintained on the same diet for both phases. Re-ranking was also observed in a later study (Durunna et al. 2012) with replacement heifers when fed the same diet in the first and second phases of the study. The re-ranking seen in the replacement heifers was concluded to be due to changes in growth rate, gut fill capacity and size of the heifers as the heifers would have been more physically mature, having greater gut fill capacity and higher maintenance requirements for a larger animal in the second phase of the experiment (Durunna et al. 2012). In the present study, re-ranking of RFI classification in cattle maintained on the same diet occurred with 59.0% of HAYL cows re-ranking in RFI_{year} from year 1 to year 2 (Table 21). When comparing years 1 and 2, there were more cows becoming less feed efficient when fed the HAYL diet in which RFI_{year} classification increased in year 2. In year 1, first-parity cows were evaluated as part of the breeding herd females on the HAYL diet. This may be due to pregnant heifers born in 2013 evaluated in 2015 (year 1) when they are less than two years of age at the start of the study. These breeding herd females will have a larger body frame and increased gut fill capacity as a three year old when evaluated in 2016 (year 2). This growth can be seen in year 2 (Table 14), where end of trial BW were greater then start of trial BW. In contrast, there was a limited change in $RFI_{trimester}$ classification for HAYL cows from second to third trimester (Table 22).

For cows fed MSHAYL diets, there was no distinct shift in RFI classification by year (Table 21); however, there were major changes in RFI classification by trimester (Table 22). First of all, there was a low number of high-RFI cows in second trimester for all MSHAYL regimens and this number did not change much in third trimester. Examination of the distribution for $RFI_{trimester}$ classification in second trimester as affected by the frequency of supplementation is misleading by itself as there is no supplementation occurring in second trimester. Frequency of supplementation in third trimester results in a dramatic drop in low-RFI cows versus the drop in low-RFI MSHAYL cows that were not supplemented; most of the cows that re-ranked were in the medium-RFI classification for third trimester. The question is whether this re-ranking is truly due to changes in efficiency or due to the dramatic increases in nutrient requirements in third trimester that require increases in DMI to meet nutrient requirements. It is difficult to establish how much of the nutrients are catabolised or go toward maternal tissues and fetus growth for each cow individually when fed the MSHAYL diets. In addition, gut fill is limiting the cow's ability to meet these requirements due to growth of the conceptus in late gestation and the limitations of slower rate of digestion for the millet straw versus the haylage (Eastridge et al. 2017; Wood et al. 2010b). In contrast to cows fed MSHAYL diets, most HAYL cows were ranked as high-RFI cows for both second and third trimesters. This was not due to the original allocation of cows to nutritional management regimen as cows were allocated to ensure similar days in gestation, age and breed composition across nutritional management regimens. The high palatability of the HAYL diet may be contributing to the high percentage of high-RFI cows relative to RFI classification for MSHAYL cows.

RMEI was also calculated by regressing performance traits on MEI instead of DMI using the same variables as when calculating $RFI_{trimester}$ as described in section 3.5. The mean RMEI was 0 with a standard deviation of 8.922. There were differences in RMEI classification between trimesters ($P = 0.001$; Table 20) and amongst nutritional management regimen ($P < 0.001$); however there was no trimester by nutritional management regimen interaction ($P > 0.79$). There is a trend for a lower percentage of MSHAYL supplemented cows to re-rank between trimesters using RMEI (Table 23). Increasing the frequency of supplementation resulted in a low number of low-RFI cows re-ranking between second and third trimesters. While supplementation only tended to increase DMI and MEI (Table 12), this increase in MEI appears to be effective for maintaining efficient nutrient utilization as nutrient requirements dramatically increase. The effect was more pronounced with more frequent supplementation which indicates that the cows supplemented once a week were not as effective at utilizing the supplement when compared to those that received the supplement at more frequent intervals. This shows that despite the increased labour required to supplement the cows more frequently, there would be reduced changes in RMEI classification if cows were supplemented more frequently.

In summary the results of the re-ranking by year and trimester show that the diet plays a significant role in the RFI and RMEI classifications for mature gestating beef cows. In this study the diet influenced RFI and RMEI; likely due to the reduced feed intake seen in cows on the MSHAYL diet as a result of the low palatability of the straw. It is important to note the palatability and gut fill factors for diets to ensure that the cattle are not over consuming feed resulting in feedstuffs not being full digested and utilized, as well as ensuring that the diet is concentrated enough to meet nutritional requirements when gut fill or palatability are limiting feed intake. For these reasons the diet and the intake of the diet should be considered when evaluating the feed efficiency of gestating beef cows to ensure the diets do not unintentionally restrict feed intake.

Table 20. The Effect of Nutritional Regimen, Year and Trimester on RFI and RMEI Classification			
RFI	Year	Nutritional Regimen	Year × Nutritional Regimen
P-value	0.688	0.012	0.004
RFI	Trimester	Nutritional Regimen	Trimester × Nutritional Regimen
P-value	0.001	<0.0001	0.196
RMEI	Trimester	Nutritional Regimen	Trimester × Nutritional Regimen
P-value	0.001	<0.0001	0.798

Table 21. Nutritional Management Regimen Effect on RFI Classification by Year.										
	Nutritional Management Regimen[1]									
			Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum							
	Haylage		None		1 d /WK		2 d /WK		3 d /WK	
Rank	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Low	5	1	7	10	7	4	5	5	8	7
Medium	13	4	7	8	7	15	9	11	6	12
High	4	17	8	4	8	3	6	4	6	1
Number re-ranked	13		4		8		2		6	
Total number of cows	22		22		22		20		20	
Percentage re-ranked	59.0		18.2		36.4		10.0		30.0	

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] The combined data for all 108 cows, with the average change in RFI classification among all cows.

Table 22. Nutritional Management Regimen Effect on RFI Classification by Trimester (Trim)

	Nutritional Management Regimen[1]									
			Frequency of Supplementation of Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum							
	HAYL		None		1 d /wk		2 d /wk		3 d/wk	
Rank	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM
Low	1	1	9	6	11	3	13	7	14	4
Medium	6	6	15	15	11	17	11	15	9	16
High	17	17	0	3	1	3	0	2	0	3
Number re-ranked	0		3		8		6		10	
Total number of cows	24		24		23		24		23	
Percentage re-ranked	0.0		12.5		34.8		25.0		43.5	

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] The combined data for all 118 cows, with the average change in RFI classification among all cows.

Table 23. Nutritional Management Regimen Effect on RMEI Classification by Trimester (Trim)

	Nutritional Management Regimen[1]									
			Frequency of Supplementation of Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum							
	HAYL		None		1 d /wk		2 d /wk		3 d /wk	
Rank	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM	2nd TRIM	3rd TRIM
Low	1	1	10	6	11	3	13	7	9	7
Medium	8	5	13	16	11	18	11	14	13	13
High	15	18	1	2	1	2	0	3	1	3
Number re-ranked	3		4		8		6		2	
Total number of cows	24		24		23		24		23	
Percentage re-ranked	12.5		16.7		34.8		25.0		8.7	

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

5.0 Conclusion and Implications

The objective of this study was to evaluate strategic supplementation of straw-based diets with energy and protein during late gestation, and its effects on cow performance and feed efficiency. The current study found that ADG increased in HAYL vs. MSHAYL fed cows during gestation and second trimester with ADG being negative across nutritional management regimens in third trimester. This indicated that as energy demands increased, none of the nutritional management regimens could provide enough nutrients to maintain body weight during late gestation. In contrast, BCS was not affected by nutritional management regimen. Frequency of supplementation affected changes in rib fat depth over gestation with cows supplemented three times a week losing the least amount of subcutaneous rib fat for supplemented cows. It should be noted that the biological significance of these results should be questioned, as the change in fat depth for all nutritional regimens was less than 2 mm. Due to the high palatability of the HAYL regimen, dry matter and metabolizable energy intakes for this diet exceeded respective intakes for MSHAYL diets. The reduced DMI of the straw based diets is likely due to lower palatability and reduced digestibility of the straw and subsequent slower rates of passage.

Despite nutritional management regimen differences in ADG, rib fat depths, DMI and MEI, there were no differences in pre-weaning calf performance or in the reproductive performance of the cows. Past studies have been inconclusive regarding the effects of supplementation during gestation on cow and calf performance. There were limited effects of the nutritional management regimens on blood parameters throughout gestation. The present study found that the MSHAYL regimen with supplementation once a week would be a suitable nutritional regimen on commercial operations to reduce cost of feed and labour associated with feeding of cattle, based on limited differences in cow performance during gestation across nutritional management regimens. In addition, none of those differences had an impact on the short term performance of the cow or calf post-calving. However, a major concern is that inadequate nutrition during gestation in cattle can produce offspring with impaired muscle growth and increased fatness (Du et al. 2015). Providing adequate nutrition during gestation increases body weights, reduces age to maturity, and increases fertility in replacement heifers (Funston and Summers 2013). It is possible that the nutritional management regimens could have effects on the long term performance of both cow and calf.

The present study found there were no differences in cow ADG, BCS, fat depth, DMI, MEI, length of gestation, calf birth and weaning weights amongst RFI classification groups. This was concluded to be due to RFI re-ranking between year 1 and year 2. While there were no significant changes in RFI classification by year, there was a RFI classification by nutritional management regimen interaction, along with a year by nutritional regimen interactions. Re-ranking was also evident between second and third trimesters, which marked the initiation of supplementation. There were differences in RFI classification by trimester and nutritional management regimen, along with a trimester by nutritional regimen interaction. This establishes there are changes in feed efficiency as gestation progresses along with a dramatic increase in nutritional requirements. More cows became inefficient in third trimester when fed one of the MSHAYL regimens with supplementation. This is likely the result of supplementation increasing the digestibility of the diet and increasing the rate of passage, as well as an increase in nutritional demand resulting in increased feed intake in third trimester. The present study was able to demonstrate there are changes in RFI classification between years and trimesters, especially with changes in nutritional management regimen.

It would be beneficial for this study to be repeated over multiple years to evaluate the long term effects these limiting nutritional management regimens may have on cow and calf performance, along with evaluating other low cost feedstuffs. Due to the segmentation of the Canadian beef industry, it may be beneficial to evaluate the performance of offspring in a feedlot setting and for replacement heifers in the breeding herd. This is needed to ensure there is no reduction in growth performance, meat quality characteristics and reproductive performance. Since the present study did not examine fetal programming, it is unknown regarding the effects that the MSHAYL regimens may have on performance of the offspring from the cows in the study. Evaluating the effects of offspring performance may aid in reducing segmentation of the industry if the replacement heifer selection does not negatively affect offspring performance. It would also be beneficial to cow-calf producers to know when their cows are most feed efficient and any changes in feed efficiency that may occur as stage of production changes, since the current study demonstrated that use of a specific diet does influence feed efficiency. The parameters of this study did not allow the long term effects of feeding millet straw based diets on cow and subsequent calf performance to be investigated and left these questions to be answered.

6.0 Appendix

6.1 Appendix Table 1. Botanical Composition of Grass Pasture during the 2016 Grazing Season.

Cycle One	% Grasses	% Legumes	% Weeds	% Dead	Cycle Three	% Grasses	% Legumes	% Weeds	% Dead
Field 4	75.6	7.7	16.7	0.0	Field 2	69.1	12.5	4.9	17.9
Field 5	66.5	11.5	22.0	0.0	Field 3	49.8	23.2	3.1	23.8
Field 6	51.3	10.1	38.6	0.0	Field 4	66.8	14.4	2.0	16.8
Field 7	54.9	19.9	25.1	0.0	Field 5	70.3	5.5	2.6	21.5
Field 8	55.1	12.9	32.0	0.0	Field 6	61.5	28.6	0.9	9.1
Field 11	68.7	11.1	20.2	0.0	Field 7	67.2	13.4	0.7	18.7
Field 12	78.9	9.3	11.8	0.0	Field 8	69.4	9.1	0.3	21.2
Field 13	64.1	4.5	31.4	0.0	Field 9	61.5	6.0	1.5	31.0
Field 14	36.4	23.7	36.9	0.0	Field 10	79.3	7.3	2.1	11.3
Field 15	58.4	11.3	30.2	0.0	Field 11	69.4	20.4	1.3	8.86
Field 16	56.8	12.2	31.1	0.0	Field 12	48.4	30.7	3.5	17.4
Cycle Two	**% Grasses**	**% Legumes**	**% Weeds**	**% Dead**	**Cycle Four**	**% Grasses**	**% Legumes**	**% Weeds**	**% Dead**
Field 2	70.9	17.3	3.5	8.3	Field 2	38.7	27.5	31.2	2.6
Field 3	76.3	12.7	2.4	8.6	Field 3	46.3	23.5	27.4	2.8
Field 4	87.8	5.1	4.0	3.2	Field 4	70.1	8.4	16.4	5.1
Field 5	87.4	5.6	2.8	4.3	Field 5	60.4	14.1	22.6	2.9
Field 6	84.9	6.4	5.4	3.4	Field 6	55.6	11.0	30.0	5.1
Field 7	85.4	6.5	2.4	5.6	Field 7	41.3	34.6	22.8	2.9
Field 8	77.2	7.0	8.5	7.3	Field 8	47.5	12.2	38.5	3.3

Field 9	67.0	13.1	4.3	15.7	Field 9	66.2	16.3	15.5	1.3
Field 11	72.5	13.7	8.0	5.9	Field 10	34.0	28.6	34.7	1.8
Field 12	84.2	9.2	3.0	3.6	Field 11	43.4	26.6	27.4	2.0
Field 13	67.9	10.9	11.1	10.2	Field 12	58.5	9.6	29.0	2.7
Field 14	86.4	3.3	4.1	6.3	Field 13	46.5	25.9	22.6	5.0
Field 15	79.6	8.4	2.9	9.1	Field 14	35.2	12.8	48.6	3.4
Field 16	72.6	15.9	4.7	6.8	Field 15	53.8	18.3	28.0	0

6.2 Appendix Table 1: ANOVA to Examine Effect of RFI Classification, Nutritional Management Regimen and RFI Classification by Nutritional Management Regimen Interaction on Performance Traits

Trait	RFI Classification	Nutritional Management Regimen	RFI Classification × Nutritional Management Regimen
ADG throughout gestation (kg/d)	0.705	<0.0001	0.850
2nd trimester ADG (kg/d)	0.704	<0.0001	0.974
3rd trimester ADG (kg/d)	0.924	0.748	0.701
MBWT (kg)	0.581	0.829	0.054
BCS throughout gestation	0.291	0.795	0.673
2nd trimester BCS	0.191	0.799	0.380
3rd trimester BCS	0.482	0.419	0.526
Subcutaneous rib fat depth (mm)	0.968	0.942	0.904
Change in subcutaneous rib fat depth (mm)	0.204	<0.0001	0.981
Subcutaneous rump fat depth (mm)	0.623	0.484	0.365
Change in Subcutaneous rump fat depth (mm)	0.125	0.901	0.879
DMI throughout gestation (kg/d)	0.929	<0.0001	0.868
2nd trimester DMI (kg/d)	0.962	<0.0001	0.756
3rd trimester DMI (kg/d)	0.850	<0.0001	0.827
MEI throughout gestation (Mcal/d)	0.775	<0.0001	0.829
2nd trimester MEI (Mcal/d)	0.850	<0.0001	0.692
3rd trimester MEI (Mcal/d)	0.700	<0.0001	0.746
G:F	0.732	0.001	0.904
Length of gestation (d)	0.249	0.131	0.292
Conception rate (%)	0.832	0.317	0.962
Weaning rate (%)	0.828	0.352	0.338
Calf birth weight (kg)	0.446	0.707	0.727
Calf weaning weight (kg)	0.221	0.811	0.123
Calf ADG (kg/d)	0.063	0.883	0.625
Cow ADG (kg/d)	0.736	0.470	0.149

6.3 Appendix Table 2: Nutritional Management Regimen Effects on Cow Blood Parameters During Gestation

		Nutritional Management Regimen[1]										
	Time × Treatment interaction		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum						P-value for contrasts[2]			
Trait		HAYL	None	1 d /wk	2 d /wk	3 d /wk	S.E.[3]	P-value	1	2	3	4
Calcium	0.961	2.19	2.24	2.22	2.19	2.17	0.022	0.155	0.441	0.073	0.103	0.700
Phosphorous	0.762	1.89	2.08	2.08	2.19	2.10	0.040	<0.001	<0.001	0.354	0.169	0.119
Ca:P	0.509	1.19	1.10	1.11	1.02	1.09	0.088	<0.001	<0.001	0.256	0.031	0.017
Mg	0.881	0.88	0.90	0.87	0.88	0.89	0.011	0.197	0.356	0.084	0.163	0.693
Na	0.824	134.3	138.8	137.7	138.4	136.5	1.096	0.032	0.005	0.312	0.842	0.197
K	0.731	4.43	4.54	4.50	4.52	4.42	0.049	0.287	0.237	0.267	0.634	0.155
Cl	0.918	94.03	97.10	96.03	96.34	94.91	0.842	0.082	0.031	0.159	0.685	0.230
NaK	0.560	30.47	30.68	30.77	30.80	31.11	0.250	0.449	0.182	0.436	0.539	0.379
Protein	0.950	70.40	70.78	71.43	71.29	71.78	0.790	0.733	0.300	0.413	0.912	0.661
Albumin	0.978	36.03	37.79	37.04	36.64	37.45	0.402	0.023	0.009	0.102	0.997	0.155
Globulin	0.838	34.36	32.99	34.39	34.65	34.33	0.526	0.168	0.647	0.014	0.866	0.665
AG	0.642	1.07	1.17	1.09	1.07	1.11	0.016	0.001	0.036	<0.001	0.969	0.124
Urea	0.285	4.32	4.43	4.37	4.67	4.44	0.083	0.052	0.098	0.481	0.064	0.058
Glucose	0.737	3.23	3.18	3.22	3.18	3.15	0.041	0.627	0.334	0.985	0.250	0.621
GGT	0.999	18.33	17.63	17.22	18.69	17.56	0.435	0.297	0.363	0.748	0.164	0.138
AST	0.239	69.09	63.81	66.33	65.27	62.59	1.320	0.007	0.002	0.534	0.131	0.150
GLDH	0.996	8.12	8.41	8.84	7.76	8.49	0.887	0.933	0.796	0.964	0.502	0.558
BHB	0.459	345.2	348.3	347.3	358.6	344.6	11.184	0.910	0.720	0.881	0.748	0.374
NEFA	0.820	0.16	0.17	0.16	0.14	0.17	0.009	0.208	0.650	0.209	0.794	0.038
Haptoglobin	0.814	0.12	0.13	0.12	0.18	0.14	0.023	0.316	0.339	0.438	0.140	0.236
CaOs	0.819	265.6	247.2	272.1	273.8	269.6	2.165	0.034	0.006	0.326	0.884	0.173
Cholesterol	0.859	3.17	3.07	2.92	2.92	3.06	0.064	0.025	0.013	0.170	0.334	0.121

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] Contrasts: 1 = cows fed HAYL (70% haylage/30% straw diet) vs. all ad lib straw based diets (MSHAYL); 2 = cows fed MSHAYL without supplementation vs. cows fed MSHAYL with supplementation; 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two and three times a week; 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.
[3] The pooled standard error of treatment means.

6.4 Appendix Table 3: Nutritional Management Regimen Effects on Cow Blood Parameters in Second Trimester

		Nutritional Management Regimen[1]										
	Time × Treatment Interaction		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum						P-value for contrasts[2]			
Trait		HAYL	None	1 d /wk	2 d /wk	3 d /wk	S.E.[3]	P-value	1	2	3	4
Calcium	0.847	2.22	2.21	2.16	2.17	2.15	0.075	0.713	0.430	0.292	0.958	0.757
Phosphorous	0.431	1.89	1.98	2.00	2.31	2.11	0.115	0.022	0.047	0.059	0.015	0.108
Ca:P	0.348	1.20	1.14	1.13	0.97	1.06	0.047	0.038	0.044	0.110	0.022	0.165
Mg	0.596	0.87	0.90	0.85	0.90	0.87	0.021	0.224	0.753	0.255	0.084	0.301
Na	0.013	138.2	138.5	132.0	142.1	136.8	0.972	0.003	0.736	0.472	0.0004	0.067
K	0.273	4.56	4.54	4.33	4.67	4.46	0.099	0.127	0.636	0.655	0.023	0.170
Cl	0.013	96.67	96.77	91.23	98.93	94.90	1.476	0.001	0.531	0.275	<0.001	0.066
NaK	0.803	30.41	30.41	30.41	30.51	30.82	0.573	0.968	0.796	0.867	0.661	0.712
Protein	0.594	72.07	71.92	70.62	69.33	72.14	1.669	0.749	0.628	0.496	0.945	0.255
Albumin	0.781	36.52	37.97	36.63	37.00	37.50	0.857	0.527	0.542	0.275	0.320	0.694
Globulin	0.468	35.54	33.96	34.25	32.33	34.64	1.144	0.562	0.246	0.863	0.518	0.172
AG	0.520	1.05	0.14	1.07	1.16	1.10	0.039	0.314	0.170	0.546	0.153	0.299
Urea	0.537	3.92	3.95	3.44	3.80	3.77	0.147	0.029	0.348	0.087	0.024	0.893
Glucose	0.563	3.25	3.12	3.06	3.12	3.13	0.094	0.702	0.250	0.828	0.479	0.896
GGT	0.989	17.84	17.83	17.01	19.67	19.36	1.281	0.426	0.708	0.541	0.061	0.872
AST	0.423	70.79	62.66	63.58	63.81	60.15	3.086	0.238	0.044	0.964	0.618	0.421
GLDH	0.995	8.40	9.07	9.43	8.93	9.89	2.608	0.996	0.785	0.92	0.995	0.804
BHBA	0.670	357.8	329.3	307.1	333.9	326.5	31.178	0.838	0.412	0.840	0.477	0.873
NEFA	0.844	0.10	0.14	0.13	0.11	0.14	0.012	0.107	0.070	0.636	0.631	0.060
Haptoglobin	0.998	0.12	0.14	0.13	0.20	0.13	0.262	0.929	0.767	0.806	0.531	0.421
CaOs	0.014	272.6	273.1	260.0	280.1	269.6	3.873	0.003	0.705	0.449	<0.001	0.067
Cholesterol	0.829	3.34	2.98	2.89	2.92	3.07	0.152	0.303	0.060	0.907	0.490	0.524

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] Contrasts: 1 = cows fed HAYL (70% haylage/30% straw diet) vs. all ad lib straw based diets (MSHAYL); 2 = cows fed MSHAYL without supplementation vs. cows fed MSHAYL with supplementation; 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two and three times a week; 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.
[3] The pooled standard error of treatment means.

6.5 Appendix Table 4: Nutritional Management Regimen Effect on Cow Blood Parameters During Third Trimester

		Nutritional Management Regimens[1]							P-value for contrasts[2]			
	Time × Treatment Interaction		Frequency of Supplementation for Limit-fed Haylage (MSHAYL) Diets Fed with Straw Ad libitum									
Trait		HAYL	None	1 d /wk	2 d /wk	3 d / wk	S.E.[3]	P-value	1	2	3	4
Calcium	0.335	2.21	2.22	2.24	2.17	2.18	0.032	0.526	0.853	0.423	0.125	0.770
Phosphorous	0.589	1.89	2.12	2.01	2.17	2.09	0.052	0.003	<0.001	0.559	0.072	0.236
Ca:P	0.445	1.20	1.07	1.15	1.02	1.09	0.027	<0.001	<0.001	0.666	0.004	0.052
Mg	0.203	0.86	0.92	0.87	0.88	0.89	0.016	0.125	0.153	0.043	0.357	0.625
Na	0.443	133.3	137.7	138.3	137.1	136.1	1.697	0.284	0.041	0.771	0.440	0.689
K	0.678	4.41	4.57	4.53	4.44	4.40	0.069	0.298	0.335	0.148	0.206	0.708
Cl	0.492	93.23	96.57	96.88	95.54	94.75	1.314	0.301	0.071	0.567	0.296	0.667
NaK	0.464	30.39	30.34	30.76	31.04	31.21	0.322	0.205	0.217	0.069	0.362	0.706
Protein	0.720	70.16	71.28	70.15	73.35	73.39	2.335	0.745	0.471	0.706	0.261	0.990
Albumin	0.745	36.21	37.39	36.64	36.57	37.11	0.558	0.578	0.255	0.327	0.772	0.485
Globulin	0.763	35.31	32.55	34.12	34.50	34.22	0.728	0.103	0.079	0.037	0.789	0.778
AG	0.991	1.04	1.17	1.10	1.08	1.10	0.021	0.002	0.006	0.002	0.865	0.417
Urea	0.904	5.08	4.64	4.98	5.34	5.20	0.273	0.437	0.884	0.091	0.390	0.720
Glucose	0.198	3.18	3.27	3.28	3.15	3.25	0.114	0.904	0.633	0.742	0.562	0.552
GGT	0.979	17.73	16.35	16.89	17.70	16.18	1.287	0.860	0.508	0.697	0.975	0.401
AST	0.241	72.57	62.21	69.58	67.42	64.32	3.501	0.238	0.089	0.224	0.387	0.528
GLDH	0.998	7.57	6.68	6.76	5.99	7.61	1.176	0.851	0.539	0.934	0.977	0.327
BHBA	0.325	327.1	330.0	381.2	372.3	333.56	23.130	0.292	0.293	0.223	0.320	0.235
NEFA	0.762	0.20	0.21	0.16	0.14	0.18	0.029	0.424	0.330	0.144	0.887	0.382
Haptoglobin	0.631	0.11	0.12	0.12	0.13	0.15	0.021	0.586	0.504	0.468	0.416	0.303
CaOs	0.438	264.3	272.8	273.9	271.7	269.6	3.359	0.293	0.044	0.776	0.441	0.663
Cholesterol	0.953	3.10	3.02	2.80	2.77	3.01	0.081	0.019	0.035	0.090	0.390	0.037

[1] Nutritional Management Regimen includes: HAYL (70% haylage/30% straw diet fed ad libitum); MSHAYL (cows fed haylage at 0.8% of BW along with ad libitum straw with cows not supplemented (None for no supplementation) or supplemented once per week (1 d/wk), twice per week (2 d/wk), or three times per week (3 d/wk) for the last 75 days of gestation.

[2] Contrasts: 1 = cows fed HAYL (70% haylage/30% straw diet) vs. all ad lib straw based diets (MSHAYL); 2 = cows fed MSHAYL without supplementation vs. cows fed MSHAYL with supplementation; 3 = cows fed MSHAYL supplemented once a week vs. the average of cows fed MSHAYL supplemented two and three times a week; 4 = cows fed MSHAYL supplemented two times a week vs. cows fed MSHAYL supplemented three times a week.
[3] The pooled standard error of treatment means.

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