SUPPLEMENTING METABOLIZABLE PROTEIN TO EWES DURING LATE GESTATION: EFFECTS ON EWE AND OFFSPRING PERFORMANCE

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Supplementing metabolizable protein to ewes during late gestation:

Effects on ewe and offspring performance

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ABSTRACT

We hypothesized that MP intake at or above requirements during late gestation would improve dam and offspring performance. In year 1, ewes received one of three isocaloric dietary treatments during late gestation: **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation for a ewe bearing twins. Similarly, in year 2, ewes received one of three isocaloric dietary treatments during late gestation: **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements. Dam performance was positively impacted by supplementing MP at or above requirements by maintaining dam BW and BCS. However, milk production was not significantly altered by maternal MP intake during late gestation. In both years, maternal MP intake did not affect offspring performance from birth to weaning. Metabolizable protein intake in isocaloric diets during late gestation had little influence male offspring feedlot performance or carcass characteristics. A reduction in maternal MP intake during late gestation reduced wether lamb N retention, but maternal MP supplementation above requirements did not enhance N retention of wether offspring. The data from the current study suggests that feeding 100% of MP requirements during late gestation may have greatest positive impacts on female reproductive performance. This analysis was strictly to determine the profitability of wether offspring alone during the feedlot phase based on their BW entering the feedlot and their performance. The wethers born to ewes fed 60% of MP requirements were the most profitable in both years, due to reduced BW entering the feedlot and increased HCW at slaughter. Overall, increasing maternal MP intake above requirements during late gestation did not improve offspring performance compared with offspring from ewes consuming reduced MP during late gestation. Therefore, feeding ewes 100% of MP requirements during late gestation may be the most beneficial to ensure positive dam and offspring performance.

Key words: ewe lambs, late gestation, metabolizable protein, sheep, wethers

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DEDICATION

To my parents,

Thank you for providing
encouragement and support in my life
to dream big and achieve my goals.

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AA	amino acids
ADG	average daily gain
BCS	body condition score
BUN	blood urea nitrogen
BW	body weight
°C	degrees Celcius
CIDR	controlled intravaginal drug release
CP	crude protein
d	day
DIP	degradable intake protein
DM	dry matter
DMI	dry matter intake
DNA	deoxyribonucleic acid
EAA	essential amino acids
F1	ewe lambs
F2	lambs of F1
G:F	kg of gain:kg of feed; feed efficiency
GIT	gastrointestinal tract
HCW	hot carcass weight
h	hour
IDP	intestinally degradable protein
IGF1	insulin like growth factor 1

Ig	immunoglobulin(s)
IUP	intestinally undegradable protein
IVDMD	in vitro dry matter digestibility
kg/d	kilograms per day
LM	longissimus muscle
MCP	microbial crude protein
mm	millimeters
mo	month
MP	metabolizable protein
N	nitrogen
NDF	neutral detergent fiber
NE	net energy
NE_m	net energy of maintenance
NEFA	non-esterified fatty acids
NH_3	ammonia
NRC	National Research Council
OM	organic matter
RDP	rumen degradable protein
Ribeye	*longissimus dorsi*
RUP	rumen undegradable protein
SD	standard deviation
SEM	standard error of the mean
SQ	subcutaneous

UIP	undegradable intake protein
wk	week

CHAPTER 1. LITERATURE REVIEW

Introduction

Maternal nutrition during gestation can impact livestock production and were thought to occur by altering fetal development *in utero* (Wu et al., 2006; Funston et al., 2010b; Reynolds and Caton, 2012). In general, developmental programming has been defined as a stimulus or insult applied to the dam; therefore, the offspring may be affected *in utero*, or during early neonatal life, and carry those effects throughout life, thus having permanent effects on metabolism, physiology, and structure (Barker, 1995; Godfrey and Barker, 2000).

One method of altering fetal development is that of maternal nutrition. Because much of the research focuses on total nutrient intake and not specific nutrients, results can be difficult to interpret, as the ultimate cause of the effects is unknown. Recently, to elucidate the causes of alterations to fetal development, specific nutrients, such as energy and crude protein (**CP**), have been studied. However, much of the research in CP supplementation has occurred strictly during late gestation, disregarding early and mid-gestation nutrition of the dam. Although late gestation is important, the limited CP supplementation research available only provides a brief look into a narrow window of gestation. Therefore, maternal nutrition during gestation may have differing impacts on fetal growth and development depending on when it is applied.

Altering protein intake is one mode of maternal nutrition modification that has been recently studied for its effects on both dam and offspring growth and performance. Crude protein supplementation has been utilized during late gestation to improve both dam and offspring performance (Martin et al., 2007; Larson et al., 2009; Funston et al., 2010a). However, CP includes all portions of protein nitrogen (**N**), including both degradable and undegradable, and does not provide evidence of the N absorbed and utilized by the dam. Therefore, partitioning CP into the degradable and undegradable fractions may provide a more accurate estimate of the N absorbed and utilized by the dam during gestation. Metabolizable protein (**MP**) is defined as the protein derived from both feed and microbial crude protein (**MCP**) that is digested postruminally and the amino acids (**AA**) that are absorbed in the intestines (NRC, 2007; Figure 1.1). Therefore, altering MP intake may be used during gestation to impact dam and offspring growth and performance. However, minimal research has been conducted utilizing MP during late gestation as a means to alter dam and offspring performance (Patteron et al., 2003; Amanlou et al., 2011).

The objective of this review is to provide a discussion on the current literature available regarding the effects of maternal protein intake during gestation on dam and offspring growth and performance. Therefore, dam effects, fetal development, postpartum offspring performance from birth to weaning, male offspring performance, and female offspring performance will be discussed. With the current information available, we hypothesize that protein is crucial during gestation and that the proportion of protein in the diet may also impact dam and offspring performance; more specifically, in isocaloric diets, when the diet is composed of increased protein, there will be greater impacts on offspring, with little to no differences in dam performance.

Dam Effects

Crude protein supplementation is a common method used to improve dam performance during late gestation when ruminants are grazing low-quality forage. Therefore, CP supplementation is crucial during late gestation to the maintenance of maternal body weight (**BW**), body condition score (**BCS**), and reproductive efficiency in grazing sheep and beef cattle (Bohnert et al. 2002; Schauer et al., 2005; Schauer et al., 2010). Crude protein supplementation

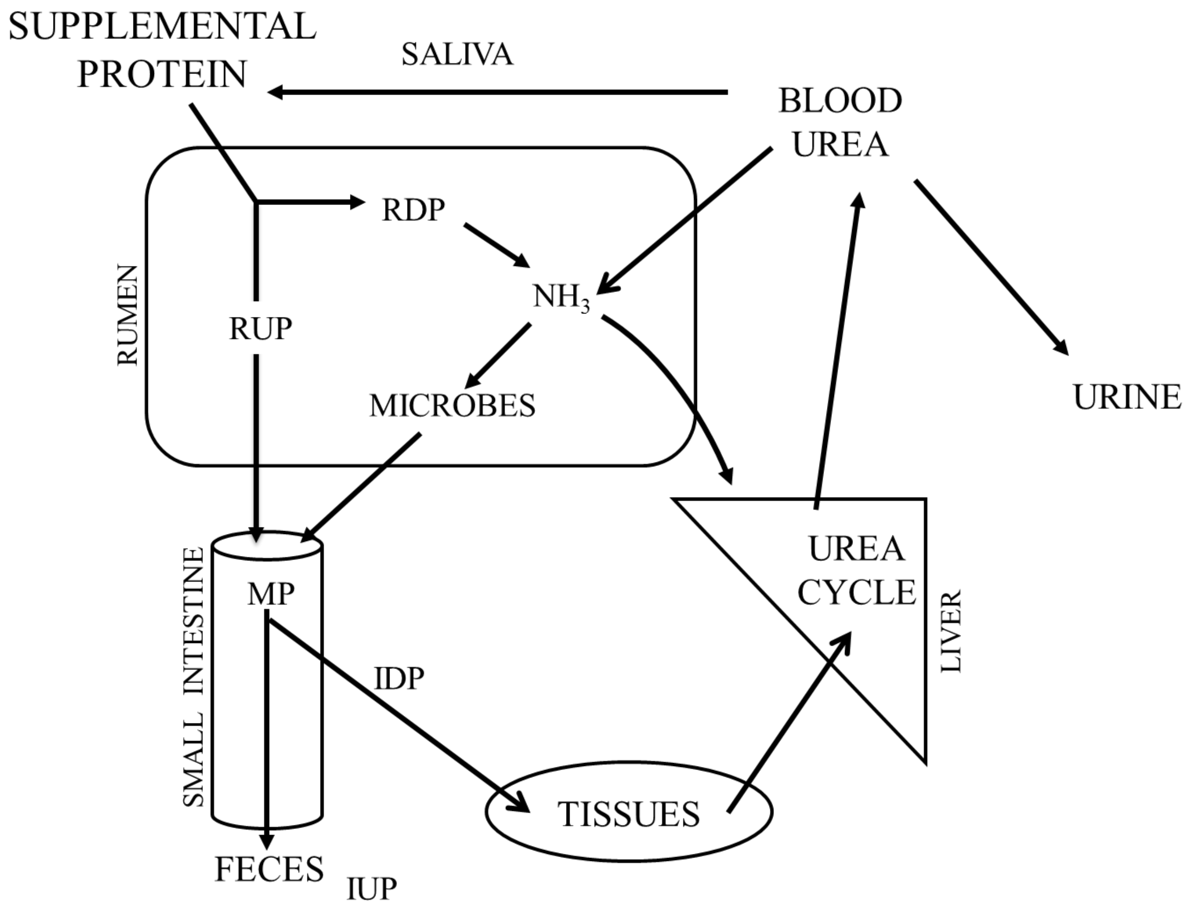

Figure 1.1. Schematic of protein degradation and absorption in the ruminant. Abbreviations include: RUP: rumen undegradable protein; RDP: rumen degradable protein; NH_3: ammonia; MP: metabolizable protein; IDP: intestinally degradable protein; and IUP: intestinally undegradable protein.

during late gestation may aid in the maintenance of rapid fetal growth and development as well as the growth of the dam. Effects of protein supplementation during gestation and lactation have been summarized in Table 1.1.

Late gestation nutrition is crucial in maintaining dam BW and BCS because of the high nutrient demand from the fetus. Cows grazing low-quality forage supplemented with CP during late gestation were heavier and had greater BCS precalving than those not supplemented with CP during late gestation (Bohnert et al., 2002; Larson et al., 2009). Similarly, Stalker et al. (2006)

observed that cows supplemented with CP during late gestation maintained BW while those that were consuming native upland range and not supplemented with CP lost BW during late gestation. Providing CP during late gestation minimized the mobilization of dam body reserves, suggesting that the increased available N was used to maintain both fetal growth and dam performance during the supplementation period. Moreover, in a study conducted by Anthony et al. (1986), heifers restricted to 81% of CP requirements during late gestation gained slower and weighed less at 14 d prior to calving compared with heifers fed at 141% of CP requirements. These studies suggest that increased CP intake during late gestation is utilized for both maternal and fetal growth. Increased CP intake during late gestation is possibly being used for both the increased energy and protein requirements of both the dam and fetus.

Providing adequate nutrition during the last third of gestation not only improves maternal BW and BCS prior to parturition, but may also minimize BW and BCS loss immediately post-parturition. In cows, postcalving BW and BCS were increased when supplemented with CP during late gestation compared with cows consuming only low-quality forage (Bohnert et al., 2002). Additionally, cows supplemented with CP during late gestation had greater BCS immediately pre- and postpartum compared with cows not supplemented with crude protein (Stalker et al., 2006). In addition to providing increased CP, the CP supplement may have been utilized as an energy source to minimize mobilization of body reserves and to maintain rapid fetal growth and development and milk production. During the 14 days (**d**) prior to parturition and first 21 d of lactation, ewes supplemented with a mulberry pellet to increase CP and net energy (**NE**) lost less weight prior to lambing compared with ewes grazing only guinea grass pasture (Godfrey and Dodson, 2003). However, due to CP and NE being increased, a general indication is that both increased CP and energy provided during late gestation maintained rapid

Table 1.1. Effects of protein supplementation during gestation and lactation on dam performance

Reference	Species	Treatment	Time of treatment	Response[1]	Additional Response[1]
Bohnert et al., 2002	Cattle	0.08% of BW/d CP supplement	late gestation	↑ precalving BW and BCS gain	↔ gestation length
				↓ postcalving BW and BCS loss	
Stalker et al., 2006	Cattle	0.45 kg/d CP supplement	late gestation	↑ precalving BW and BCS	calved later
Larson et al., 2009	Cattle	0.45 kg/d CP supplement	late gestation	↑ precalving BW and BCS	calved earlier
				↑ prebreeding BW and BCS	↑ % calved in first 21 d
				↔ BW and BCS at weaning	↔ milk production
Bohnert et al., 2011	Cattle	0.46 kg/d CP supplement	late gestation	↑ precalving BW and BCS gain	
				↓ postcalving BW and BCS loss	
Guzmán et al., 2006	Rats	10 or 20% casein	throughout gestation	↔ BW pre- and postpartum	
				↑ BW gain in 20%	
Ocak et al., 2005	Sheep	100 or 140% of CP requirements	late gestation	↑ BW at lambing	↓ colostrum yield
				↑ BW gain	
Godfrey and Dodson, 2003	Sheep	Mulberry pellet to ↑ NE and CP	late gestation to early lactation	↓ prelambing BW loss	↑ milk production
					↓ postpartum interval
Amanlou et al., 2011	Sheep	100, 114, or 124% of MP requirements	late gestation	↔ BW or BCS prelambing	↑ placenta weight, 114%
				↔ gestation length	↑ colostrum yield, 124%

[1] ↔: no change; ↑: increased; ↓: decreased

fetal growth as well as growth of the dam. Similarly, BW and BCS within 24 h post-calving were reduced in heifers fed 81% of CP requirements during late gestation compared with those fed 141% of CP requirements (Anthony et al., 1986). Dams fed reduced CP may not have lost more BW at calving, but may have lost a similar amount of weight as the dams fed increased CP, and due to the already reduced BW during late gestation, BW change may have been similar. However, during the wet season, ewes supplemented with mulberry pellet to increase CP and NE from 14 d prior to lambing and the first 21 d of lactation maintained a greater proportion of their pre-lambing weight after the supplementation period ended (Godfrey and Dodson, 2003). Upon realimentation to similar diets, postpartum average daily gain (**ADG**) was increased in heifers fed 81% of CP requirements during late gestation compared with heifers fed 141% of CP requirements (Anthony et al., 1986). Dams restricted in CP during late gestation experienced a period of compensatory gain upon realimentation which could be used to provide the nutrients for maternal growth and lactation. Realimentation at parturition may be a key factor in overcoming the reduced BCS during late gestation and early lactation and have improved body condition at rebreeding.

Many of the previous studies strictly account for CP, but do not evaluate how much N is available for absorption in the small intestine after rumen degradation. Metabolizable protein is defined as the protein derived from both feed and MCP that is digested postruminally and the AA that are absorbed in the intestines (NRC, 2007; Figure A.1). Since MP is the protein fraction absorbed in the small intestine for animal use, MP intake may produce a greater response in dam performance than accounting for the whole protein fraction as CP. However, BW change of ewes during the last 3 weeks (**wk**) of gestation and BCS change from d 130 of gestation to post-lambing were not altered due to maternal MP intake at 114 or 124% of requirements during late gestation (Amanlou et al., 2011). Similarly, Patterson et al. (2003) observed no difference in heifer BW and BCS due to feeding to meet MP or CP requirements during mid- to late gestation. Heifers fed to meet MP requirements from mid- to late gestation and not fed subirrigated meadow hay had reduced BW and BCS compared with heifers fed to meeting MP requirements and fed subirrigated meadow hay (8.5% CP; Patterson et al., 2003). Although MP is the N available for absorption in the small intestine, according to Patterson et al. (2003), it did not differ from the effects of CP on dam performance. Moreover, Kidane et al. (2010) observed no differences in ewe final BW when fed to 80 or 130% of MP requirements while grazing grass/clover or chicory during the last 3 weeks of gestation through the first 3 weeks of lactation. Suggesting MP may not play a major role in maternal BW and BCS in some cases due to the ruminant's ability to provide MCP as a protein source. Therefore, sufficient MCP may have been produced within the rumen to overcome the reduced MP intake during late gestation. Bunting et al. (1989) observed similar N flowing to the abomasum and the levels of bacterial CP synthesis were similar in heifer calves fed either high (126 g N/d) or low (66.5 g N/d) protein. Heifer calves fed low protein diets had a greater percentage of rumen bacterial N derived from blood urea N than heifer calves fed high protein (Bunting et al., 1989). Although Bunting et al. (1989) studied CP; the results suggests that ruminants have the ability to compensate for low N intake by recycling N to the rumen.

The improvement on dam BW and BCS immediately post-partum may be maintained later in lactation through prebreeding. Prebreeding BW and BCS were greater in cows supplemented with CP during late gestation compared with those that were not supplemented (Larson et al., 2009). However, at weaning, cow BW and BCS were no longer increased by CP supplementation during late gestation (Larson et al., 2009). Upon realimentation at parturition, cows may experience a period of compensatory gain, which may have led to the similarities between CP supplemented and non-CP supplemented dams. However, Stalker et al. (2006) observed an increase at prebreeding in BCS of cows supplemented with CP during late gestation. In a study conducted by Stalker et al. (2006), cows grazing subirrigated meadow pasture during the 30 d prior to breeding gained more BW and BCS compared with cows being fed grass hay. By providing CP immediately prior to breeding cows would be in optimal condition to breed during the first 21 d cycle and maintain pregnancy compared with cows that were not supplemented prior to breeding. When feeding to meet either MP or rumen degradable protein (**RDP**) requirements of cows from d 4 through 64 of lactation, cow ADG was increased in cows fed to meeting MP requirements compared with cows fed to meet RDP requirements (Patterson et al., 2003). However, cow initial and final BW and BCS were not altered by meeting MP or RDP requirements during lactation (Patterson et al., 2003). Feeding to meet MP requirements during pregnancy may not be as crucial to dam performance during gestation as feeding to meet MP requirements during lactation.

Length of gestation may be altered in cows with improved BW and BCS during late gestation due to CP supplementation. Cows grazing winter range and not supplemented with CP during late gestation calved almost 5 d later and had a reduced percentage of calves born in the first 21 d than those grazing corn residue or supplemented with CP (Larson et al., 2009). However, in a study conducted by Stalker et al. (2006), calves born to cows that were supplemented with CP during late gestation were born on average 3 d later than those from cows not supplemented with CP. Anthony et al. (1986) observed that heifers restricted to 81% of CP requirements during late gestation calved 6 d earlier than the heifers fed 141% of CP requirements. The varying results of gestation length suggest that more than just maternal nutrition can effect when parturition occurs. Male calves born to cows with increased CP intake due to either a supplement or improved winter range were born earlier than males born to cows with reduced CP intake from corn residue and not supplemented with CP (Larson et al., 2009). Cows grazing winter range had increased CP intake compared with cows grazing corn residue (Larson et al., 2009); therefore, supplementation of CP while grazing winter range may have provided CP above requirements and may have improved fetal development and signaled for an early onset of parturition. Dams that were not supplemented with CP during late gestation may have been under more physical stress due to the increased nutrient requirements of the fetus and gave birth earlier than dams that were supplemented with CP. Bispham et al. (2003) observed a reduction in plasma cortisol concentrations in ewes that were ME restricted from d 28 to 80 of gestation, and this coupled with reduced plasma leptin, IGF-1, and T_4 concentrations would promote lipolysis. An increase in lipolysis led to increased NEFA concentrations from d 28 to 80 of gestation, indicating a mobilization of maternal body reserves to maintain a supply of glucose to the fetus (Bispham et al., 2003). Although this research was not conducted on CP supplementation, this does indicate that the dam would be under stress during times of nutrient restriction and could cause earlier parturition. Similar to Larson et al. (2009), heifers born to cows supplemented with CP during the last third of gestation were born 4 d earlier than heifers born to cows that were not supplemented with CP (Funston et al., 2010a). The increased CP in the forage or CP supplement during late gestation may have affected fetal development, thereby influencing gestation length. The fetuses from CP supplemented dams may have been more fully developed earlier in late gestation compared with fetuses from non-CP supplemented dams. However, in similar research, gestation length was not altered due to maternal MP intake above requirements during late gestation (Amanlou et al., 2011). Similarly, in a study conducted by

Patterson et al. (2003), average calving date was not impacted by feeding heifers to meet MP or CP requirements from mid- to late gestation. Metabolizable protein did not alter dam BW or BCS and may not have supplied excess nutrients to enhance fetal development, and therefore, gestation length was not altered. The confounding results due to CP and MP suggest that factors other than maternal nutrition, such as maternal and fetal endocrine status, are crucial to initiating parturition.

Although BW and BCS were improved at prebreeding by maternal CP supplementation during late gestation, conception and pregnancy rates were not be altered. Pregnancy rate and conception during the first 21 d of breeding were not altered by CP supplementation during late gestation or forage quality during the 30 d prior to breeding (Stalker et al., 2006). Similarly, Larson et al. (2009) observed that cow pregnancy rate was not impacted by CP supplementation during late gestation. Both Stalker et al. (2006) and Larson et al. (2009) indicate that late gestation and prebreeding nutrition may not impact dam pregnancy and conception rates. The percentage of heifers detected in estrus by breeding was increased in heifers restricted to 81% of CP requirements compared with those fed at 141% of CP requirements (Anthony et al., 1986). Increased heifers in estrus may coincide with the increased ADG during lactation of the CP restricted dams and may be due to compensatory gain. However, Godfrey and Dodson (2003) also observed a shorter postpartum interval in ewes supplemented with mulberry pellet to increase CP and NE from 14 d prior to parturition through d 21 of lactation compared with ewes that were not supplemented. The results available are contradictory and this may be due to differences between cows and sheep, but also differences in supplement and/or timing of supplementation. Timing of supplementation or improved grazing pasture may also cause differences between dams during gestation.

Crude protein supplementation during late gestation allowed dams to maintain or increase BW and BCS compared with unsupplemented dams (Bohnert et al., 2002; Ocak et al., 2005; Stalker et al., 2006). However, when increasing MP in the diet, there were no improvements on dam BW or BCS. Results of gestation length varied upon the study, but cows supplemented with CP during late gestation calved later than unsupplemented cows, but this CP supplementation did not alter conception or pregnancy rates in the next breeding season. Results suggest that supplementing CP during late gestation can improve dam performance during late gestation and immediately post-partum compared with unsupplemented dams. Separating the MP fraction from the total CP may not be as beneficial to dam performance during late gestation. Therefore, supplementing MP above requirements may increase N above requirements and could be excreted prior to absorption and utilization.

Maternal Hormones and Metabolites

Nutrition during gestation may also alter maternal hormones and metabolites, which could ultimately lead to changes in dam and offspring performance. Crude protein supplementation may alter N recycling within the dam which could alter urea N concentrations as well as other hormones and metabolites, such as progesterone, estrogen, glucose, protein, and albumin (Anthony et al., 1986; Ramírez-Vera et al., 2012). Therefore, CP supplementation during late gestation may play a role in altering maternal hormones and metabolites, which could lead to changes in dam and offspring performance.

Increased requirements of the rapidly growing fetus, such as energy and CP, would be expected to alter metabolite concentrations of the dam due to late gestation CP intake. However, supplementing corn to increase CP and ME during the last 12 d of gestation does not alter blood glucose concentrations in does compared with only grazing subtropical semi-arid rangeland

(Ramírez-Vera et al., 2012). The length of supplementation may not have been a long enough time period to alter glucose concentrations, as it was only the final 12 d of gestation in the work of Ramírez-Vera et al. (2012). Glucose and urea N concentrations in ewes consuming 124% of MP requirements during late gestation were increased pre-lambing compared with ewes fed at 100 or 114% of MP requirements, but these concentrations were not altered post-lambing (Amanlou et al., 2011). These results suggest that the increase in MP intake provided increased N to the small intestine and increased N absorption. The increased MP may have provided increased glucogenic AA to the dam which increased circulating glucose to provide the fetus with increased energy needed for rapid growth. Similarly, heifers restricted to 81% of CP requirements had reduced serum glucose and urea nitrogen concentrations compared with heifers fed 141% of CP requirements (Anthony et al., 1986). Increased urea N concentrations in dams fed increased protein in the diet during late gestation would be expected as there was increased N available for absorption in the ewe intestine. Although there were increased urea N concentrations circulating in the dam, it is unknown whether this N source was available for fetal development or if it remained in the dam to be recycled to the rumen. However, Amanlou et al. (2011) observed no effect of the amount of rumen undegradable protein consumed by ewes during late gestation on circulating plasma albumin, total protein, calcium, or phosphorus pre- and post-lambing concentrations. Plasma protein concentrations may not be altered because of the MCP produced in the rumen to maintain CP flow to the small intestine in those fed a diet containing an increased proportion of RDP.

Maternal reproductive hormones, progesterone and estradiol, may also be influenced by maternal nutrition during late gestation (Anthony et al., 1986; Ramírez-Vera et al., 2012). Plasma progesterone concentrations in does grazing subtropical semi-arid rangeland were increased at 3, 4, and 6 d prepartum, at kidding, and 1 hour (**h**) postpartum compared with those supplemented with corn to increase CP and NE during the last 12 d of gestation (Ramírez-Vera et al., 2012). Heifers restricted to 81% of CP requirements had increased serum progesterone concentrations compared with heifers fed 141% of CP requirements (Anthony et al., 1986). Progesterone is produced throughout pregnancy to inhibit myometrial contractions in the uterus to maintain pregnancy (Senger, 2005). As pregnancy nears full term, progesterone concentrations are reduced to allow the myometrium to contract and corticosteroid concentrations are increased due to the increased stress upon the dam (Chamley et al., 1973; Senger, 2005). Although corticosteroid concentrations were not measured in Ramírez-Vera et al. (2012) or Anthony et al. (1986), the reduction in progesterone concentrations of nutritionally compromised pregnancies may due to an earlier onset of parturition. Crude protein intake during late gestation did not affect maternal serum estradiol concentrations during the final 10 d prior to calving (Anthony et al., 1986). Although not measured by Anthony et al. (1986), fetal cortisol is used to activate enzymes to convert progesterone to estradiol, with the increased estradiol concentrations being used to increase secretions from the cervix which promotes oxytocin secretion (Senger, 2005). In a study conducted by Camacho et al. (2012), fetal cortisol concentrations were increased at birth and decreased through 20 days of age; indicating that the fetus does produce cortisol during parturition and this cortisol could indicate increased stress at birth.

Similar to the lack of differences in dam performance, supplementing MP during late gestation had little effect on maternal hormones and metabolites (Amanlou et al., 2011). However, supplementing CP during late gestation did alter glucose and progesterone concentrations. The ultimate impacts on the fetus due to those changes were not readily apparent. Therefore, supplementing CP during late gestation positively impacted maternal performance, which may have had positive results on maternal hormone and metabolite concentrations.

Maternal Placental Development

Maternal placental development begins early in pregnancy and continues throughout gestation. However, supplementing CP during late gestation may positively impact maternal placental growth by increasing the number of cotyledons to caruncles (Sullivan et al., 2009a). Enhancing placental development may lead to increased nutrient available to the fetus and improve fetal growth and development. However, there has been little research on protein supplementation on placental development.

In sheep, placental growth, i.e. peak mass, has already occurred prior to late gestation. In sheep, the cotyledonary mass grows exponentially through d 70 to 80 of gestation and then slows until parturition (Stegeman, 1974). However, ewe placental weights were increased in ewes consuming 114% of MP requirements during late gestation compared with ewes fed 100 or 124% of MP requirements (Amanlou et al., 2011). These results could indicate that supplementing MP at 124% of requirements may have exceeded requirements and the MP could not be readily absorbed prior to excretion. The increased N from the MP supplement may have been used by the dam for other processes, such as fetal or mammary gland growth instead of being used for placental growth. Also, feeding 100% of MP requirements may have supplied sufficient protein to maintain normal placental growth and development. Therefore, this could indicate that feeding at 114% of MP requirements may actually be providing sufficient nutrition to enhance placental weight, but not in excess of requirements where the MP would be excreted before absorption or may have been utilized elsewhere in the animal. Sullivan et al. (2009a) observed an increase in placental weight in BeefX (½ Senepol × ¼ Brahman × ¼ Charolais) heifers restricted to 75% of CP requirements compared with BeefX heifers consuming 250% of CP requirements during early gestation. Suggesting the breed used may be more efficient in utilizing the available N to increase placental growth which could lead to an increase in the influx of nutrients to the fetus. However, in the same study, CBX (½ Senepol × ¼ Brahman × ⅛ Charolais × ⅛ Red Angus) heifers fed at 250% of CP requirements had increased placental weights compared with CBX heifers restricted 75% of CP requirements during early gestation (Sullivan et al., 2009a). This suggests that not only is placental weight affected by maternal nutrition, but also breed and species. Breed may have a large impact on placental development during early gestation and this may be due to an ability to compensate for the reduced nutrients available. Cotyledonary weight, cotyledonary surface area, placental efficiency, and the number of caruncles were not altered by heifer CP intake during early and mid-gestation (Sullivan et al., 2009a). The number of cotyledons was increased in heifers consuming increased CP during early (250% of requirements) and mid-gestation (228% of requirements) compared with heifers restricted to 75 and 63% of CP requirements during early and mid-gestation, respectively (Sullivan et al., 2009a). Although the number of cotyledons was increased in heifers fed increased CP during early and mid-gestation, this did not alter placental efficiency (Sullivan et al., 2009a). This also may be explained by the breed differences and the ability of some breeds to compensate for reduced CP during early to mid-gestation by increasing placental size to increase the absorption of available nutrients. The differences observed may also be due to species, where cattle and sheep placental development is different during pregnancy (reviewed in Vonnahme and Lemley, 2012). Placental weight in cattle increases throughout gestation (Reynolds et al., 1990); whereas sheep placental weight increases exponentially until approximately d 90 of gestation and then plateaus or decreases until parturition (Alexander, 1964). Therefore, nutrition may not be the only factor to consider when evaluating placental development, breed and species may also be key factors in placental growth.

Colostrum and Milk Yield

Mammary gland DNA content in sheep indicated that 98% of growth occurs during pregnancy in the dam with no more than 2% occurring during lactation (Anderson, 1975). Therefore, CP supplementation during late gestation may play a role in colostrum and milk production and composition (Table 1.1). The CP could be used to improve protein quality in the colostrum and milk which could improve offspring performance during lactation. Colostrum and milk yields may also be improved by CP supplementation which could also lead to increased offspring performance during lactation.

Increased nutrients provided to dams during late gestation can be utilized not only for rapid fetal growth, but also for enhanced colostrum production. Colostrum yield was increased in goats fed corn during the last 12 d of gestation compared with goats only grazing subtropical semi-arid rangeland (Ramírez-Vera et al., 2012). Corn was used to increase both the CP and NE provided to the does during this time of rapid fetal and mammary growth and development. This increase in CP and NE enhanced the amount of colostrum produced by the dam and could enhance neonatal growth. The percentage of fat within the colostrum was not affected by corn, fed to increased NE and CP, supplementation during the last 12 d of gestation (Ramírez-Vera et al., 2012). However, both protein and solids-not-fat (substances other than butterfat and water) were increased from 3 h postpartum to 10 h postpartum in does supplemented with corn in the last 12 d of gestation (Ramírez-Vera et al., 2012). The CP in the corn may have been used to increase the protein within the colostrum to be provided to the offspring. Moreover, an increase in lactose at 6 and 10 h after kidding and in the percentage of total solids at 10 h postpartum was observed in does that were supplemented with corn during the last 12 d of gestation (Ramirez-Vera et al., 2012). This could potentially increase the amount of protein and lactose provided to the offspring and could enhance offspring growth and development during lactation.

Since the MP fraction of CP is the protein available for absorption for animal use, the increased N available from absorption may improve milk and colostrum production or nutrient composition. Ewes consuming 100% of MP requirements during late gestation had the lowest colostrum yields, ewes consuming 114% of MP requirements were intermediate, and ewes consuming 124% of MP requirements were greatest (Amanlou et al., 2011). Increasing MP in the diet during late gestation may improve colostrum quantity, which could potentially lead to increased offspring growth. The increased N from the 124% MP may have been transferred to the mammary gland to improve colostrum production. Increased colostrum production and reduced placental weights observed by Amanlou et al. (2011) suggest that the mammary gland competes with the placenta for available nutrients during late gestation. This suggests that to compensate for the potential reduction in nutrient transfer via the fetus, the ewe improves colostrum production to provide increased nutrients immediately post-partum. Protein, fat, solids-not-fat, protein yield, fat yield, and solids-not-fat yield in colostrum were greater in ewes consuming 124% of MP requirements compared with ewes consuming 100 or 114% of MP requirements (Amanlou et al., 2011). Although increased MP intake during late gestation did not alter placental weights, the increased MP may have been utilized to improve mammary gland development and subsequently colostrum production.

Colostrum production and quality may not be the only portion altered by maternal nutrition, milk production and quality may also be impacted. However, in a study conducted by

Patterson et al. (2003), no differences in 24 h milk production in cows fed to meeting MP or RDP requirements during lactation were observed. Milk production of ewes fed mulberry pellet to increase CP and NE from 14 d prior to parturition through d 21 of lactation was increased during the dry season compared with those only grazing guineagrass, but this affect was not observed during the wet season (Godfrey and Dodson, 2003). The difference between the dry and wet seasons is not readily apparent, but could be due to differences in available nutrients. Therefore, the improvement in milk production may have been due to the increased CP and NE provided during a time of limiting nutrients in the dry season; whereas in the wet season, the guineagrass may have been better quality. Sullivan et al. (2009b) also observed that heifers fed 250% of CP requirements during the first third of pregnancy had increased milk production at 2 and 6 mo of lactation compared with heifers restricted to 75% of CP requirements. Milk production may be improved in dams consuming increased CP prior to parturition and this increased CP could be utilized as an energy source for the increased energy requirements of milk production. However, in work conducted by Larson et al. (2009), milk production during early and late lactation via weigh-suckle-weigh was not impacted by CP supplementation during late gestation. These conflicting results suggest that milk production may be influenced more by increased energy than increased CP. However, results of colostrum production and placental weight observed by Amanlou et al. (2011) suggest that the mammary gland may out compete the placenta for available nutrients during late gestation. Increased colostrum production by both CP and MP supplementation during late gestation (Sullivan et al., 2009b; Amanlou et al., 2011) suggests that the dam may compensate for the potential reduction in nutrients available to the fetus during late gestation by improving colostrum and milk production. This increase in colostrum yield may improve the passive immunity in the offspring during the first 24 h postpartum.

Fetal Development

In beef cattle, dam BW and BCS have been improved by late gestation CP supplementation (Anthony et al., 1986; Funston et al., 2010a; Stalker et al., 2006) and these improvements may also enhance fetal growth and development. Fetal growth is rapid during late gestation and increased CP during this time can aid in the maintenance of fetal development without having to draw on dam body reserves. Therefore, fetal development and growth may be positively impacted by maternal CP supplementation during late gestation.

Increasing CP intake during early gestation may lead to improved offspring performance due to improved fetal development. In a study conducted by Micke et al. (2010), a reduction in crown-rump length at d 39 of gestation was observed in fetuses from heifers consuming 75% of CP requirements during early gestation compared with heifers consuming 250% of CP requirements. As pregnancy progressed to d 68 of gestation, heifers consuming 75% of CP requirements during early pregnancy had fetuses that tended to have longer crown-nose lengths than fetuses from heifers consuming 250% of CP requirements (Micke et al., 2010). Suggesting that growth of the fetus in CP restricted dams may become disproportionate. The restricted nutrients available may have been used for organ development of the fetus, resulting in disproportional body growth. However, by d 95 of gestation, heifers consuming 250% of CP requirements had fetuses with smaller thoracic diameters and larger umbilical cord diameters than fetuses from heifers restricted to 75% of CP requirements. This suggests that as pregnancy progressed, the dam may have compensated for the restricted CP and increased the recycling of urea N to improve N flow to the fetus. Although the increased CP limited thoracic girth, the larger umbilical cord diameter may have allowed a greater influx of nutrients to the fetus.

Postpartum Offspring Effects from Birth to Weaning

Crude protein intake during gestation improved dam performance prior to and immediately post-parturition which may alter offspring growth post-partum. Increased CP intake during late gestation may program those offspring to have improved growth and performance compared with their counterparts from dams fed reduced CP during late gestation. The potential of having increased performance from birth to weaning can lead to increased performance during the feedlot phase for males and improved reproductive performance for females. The effects of protein supplementation during gestation and lactation have been studied in different species, as summarized in Table 1.2.

Providing adequate CP during late gestation is not only crucial the dam, but also fetal development which could lead to improvements in calf growth and performance from birth to weaning. However, calf birth weight was not affected by maternal CP supplementation during late gestation (Stalker et al., 2006; Larson et al., 2009). In a study conducted by Bohnert et al. (2002), protein supplementation during late gestation did not alter calf birth date or birth weight. Additionally, Anthony et al. (1986) reported that calf birth weight, body length, heart girth, thigh width, head width, and calf vigor were not affected by maternal CP intake during late gestation. Increased CP intake during late gestation may play a larger role in male offspring than in female offspring, as males are normally larger at birth than females. In a study conducted by Funston et al. (2010a), protein supplementation during the last third of gestation did not impact heifer calf birth weight. However, steer calf birth weight tended to be increased in those born to cows supplemented with CP during late gestation compared with those born to cows not supplemented

Table 1.2. Effects of protein supplementation during gestation and lactation on offspring response from birth to weaning

Reference	Species	Treatment	Time	Response[1]	Additional Response[1]
Bohnert et al., 2002	Cattle	0.08% of BW/d of CP supplement	late gestation	↔ calf birth weight	
Stalker et al., 2006	Cattle	0.45 kg/d CP supplement	late gestation	↔ calf birth weight ↑ calf weaning BW	↑ ADG birth to weaning ↑ percent calves weaned
Martin et al., 2007	Cattle	0.45 kg/d CP supplement	late gestation	↑ heifer adj. 205 d BW	
Larson et al., 2009	Cattle	0.45 kg/d CP supplement	late gestation	↔ steer calf birth weight ↔ steer calf weaning weight	↔ % steer calves treated for illness
Funston et al., 2010	Cattle	0.40 kg/d CP supplement	late gestation	↔ heifer calf birth weight ↑ heifer calf weaning BW	↔ % heifer calves treated for illness
Guzmán et al., 2006	Rats	10 or 20% casein	throughout gestation	↓ birth weight in 10% ↓ abdominal diameter in 10%	↔ body length ↔ head diameter
Godfrey and Dodson, 2003	Sheep	Mulberry pellet to ↑ NE and CP	late gestation to early lactation	↑ birth weight in dry season ↑ weaning BW in dry season	↑ ADG birth to weaning in dry season
Ocak et al., 2005	Sheep	100 or 140% of CP requirements	late gestation	↑ lamb birth weight ↔ lamb weaning weight	↔ lamb weight gain
Amanlou et al., 2011	Sheep	100, 114, or 124% of MP requirements	late gestation	↔ lamb birth weight ↔ lamb weaning weight	↔ lamb weight gain

[1] ↔: no change; ↑: increased; ↓: decreased

with CP (Larson et al., 2009). Therefore, CP supplementation may have been utilized for dam performance during late gestation rather than being used for fetal growth *in utero*. In sheep, lamb birth weight was not altered due to maternal MP consumption above requirements during late gestation (Amanlou et al., 2011). In a study conducted by Patterson et al. (2003), cows fed to meet MP or RDP requirements from d 15 through 64 of lactation had no effects on calf initial and final BW or ADG. These results suggest that maternal protein supplementation during gestation may not alter offspring birth weight, which may be due to the ruminant's ability to recycle N, and this may provide adequate N to maintain fetal growth during late gestation. During the dry season, ewes supplemented with mulberry pellet to increase CP and NE from d 14 prior to lambing through d 21 of lactation gave birth to heavier lambs than those ewes grazing guineagrass (Godfrey and Dodson, 2003). Due to the lack of differences observed with CP supplementation, the increase in birth weight may have been from the increased NE from the pellet.

According to Larson et al. (2009) and Stalker et al. (2006), there were no differences in birth weights, but some research has indicated offspring growth and performance may be altered through weaning. Pre-breeding calf BW was reduced in calves born to cows grazing winter range and not supplemented with CP during late gestation compared with those grazing corn residue or supplemented with CP (Larson et al., 2009). Larson et al. (2009) also observed a reduction in calf weaning weight in those born to cows not supplemented with CP and grazing winter range compared with calves born to cows supplemented with CP or grazing corn residue. Milk production was not altered by maternal CP supplementation; therefore, some other function must be impacting offspring performance through weaning, such as improving absorption of nutrients in the gut. The majority of gastrointestinal growth and cellular proliferation, more specifically small intestine growth, occurs *in utero* during early gestation and continues to grow at a slower rate until adulthood (Weaver et al., 1991). Therefore, offspring gut development and growth may be altered by maternal nutrition during gestation. Dam CP supplementation during late gestation increased calf weaning weight, ADG from birth to weaning, and percent calves weaned compared with their non-CP supplemented counterparts (Stalker et al., 2006). Birth weight was not altered by maternal CP supplementation, but the offspring may have been programmed to have increased performance at weaning compared with offspring from non-CP supplemented cows. Although birth weight was not affected, heifer weaning weight was increased in those born to cows supplemented with CP during late gestation (Funston et al., 2010a). Steer weaning BW was reduced in those born to cows that were grazing winter range and not supplemented with CP during late gestation compared with those supplemented with CP and/or grazing corn residue (Larson et al., 2009). Gender may also be a factor in weaning weights, as males are generally heavier and have more rapid growth rates than females. Calves born to cows that were supplemented with CP during late gestation may have been programmed to have improved performance postnatally. Improved performance may also have been due to improved milk production by the dam; however, only Larson et al. (2009) evaluated milk production, which was not altered. Therefore, the available pasture may have aided in improving the weaning weights of the offspring from CP supplemented dams or an improvement of gut function in those offspring. To my knowledge there has been no research conducted in the area of CP intake on offspring intestinal growth and function, but Trahair et al. (1997) did observe a reduction in small intestine weight, duodenal crypt depth, and duodenal mucosal area in offspring from nutritionally restricted ewes. This suggests that offspring small intestine development is altered by maternal nutrition, which could alter nutrient absorption and may have led to improved weaning weights. However, percent of calves weaned and adjusted 205 d BW were not affected by maternal CP supplementation during late gestation (Larson et al., 2009). In sheep, lamb BW at weaning and BW gain from birth to weaning were not altered due to maternal MP consumption above requirements during late gestation (Amanlou et al., 2011). Providing excess MP to dams during late gestation did not alter dam performance or lamb birth weights; therefore, MP may not have a large role in offspring performance. Similarly, in both dry and wet seasons, weaning weights and ADG were increased in lambs born to ewes supplemented with mulberry pellet to increase CP and NE from 14 d prior to parturition through d 21 of lactation compared with lambs born to ewes grazing only guineagrass (Godfrey and Dodson, 2003). Providing increased CP and NE during lactation may have improved weaning weights of lambs due to the improved colostrum quality of the dams. There were no differences in dam performance and lamb birth weight in offspring from dams with increased MP intake, which suggests that offspring may not have been programmed for improved performance post-natally.

Improved nutrition/grazing during lactation may have provided both the dam and offspring with increased nutrients which may have led to increased weaning weights. Cows grazing subirrigated meadow pasture during the 30 d prior to breeding had calves with increased weaning weights compared with those from cows fed grass hay (Stalker et al., 2006). The increased weaning weights observed may have been due to the calf consumption of the improved pastures, not from the dietary CP supplementation during late gestation.

In the majority of research, birth weights of offspring from CP supplemented dams were not altered, but as offspring aged, weaning weights were increased compared with offspring from non-CP supplemented dams. Therefore, CP supplementation during late gestation may program offspring to have improved growth by weaning and this could lead to improved growth and performance later in life. Improved growth from birth to weaning may have been due to improved milk quality and/or production or improved gastrointestinal function due to improved fetal development. Although Larson et al. (2009) did not observe any differences in milk production, but milk quality may have been altered. However, milk production was not measured in the majority of these studies and therefore, cannot be eliminated as a pertaining factor. Due to the observed increased weaning weights of offspring from cows that were supplemented with CP during late gestation (Stalker et al., 2006; Larson et al., 2009), male offspring could have improved feedlot performance and carcass characteristics and females could have enhanced reproductive performance due to improved gastrointestinal function and efficiency.

Male Offspring

Feedlot Performance

Male offspring of ruminants are often placed in the feedlot for backgrounding and finishing prior to harvest. Crude protein supplementation during late gestation improved weaning weights in offspring, which could lead to improved feedlot performance. This improved performance could lead to greater carcass quality and ultimately lead to an increase in profits for the producer. The effects of protein supplementation on male offspring performance in the feedlot have been summarized in Table 1.3.

Not only does feedlot nutrition affect the growth potential of steers, but also the nutrition they receive *in utero* during late gestation. Steer initial feedlot BW, BW at implantation of estradiol and trenbolone acetate (Revelor ®-S), and final feedlot BW were reduced in those born to cows that were grazing winter range and not supplemented with CP during late gestation (Larson et al., 2009). The CP provided by the winter range was not sufficient to improve male

Table 1.3. Effects of protein supplementation during gestation on offspring response after weaning

Reference	Species	Treatment	Time	Response[1]	Additional Response[1]
Stalker et al., 2006	Cattle	0.45 kg/d CP supplement	late gestation	↑ steer initial feedlot BW ↔ steer ADG, DMI, G:F	↔ steer carcass characteristics
Martin et al., 2007	Cattle	0.45 kg/d CP supplement	late gestation	↑ heifer prebreeding BW ↔ heifer initial and final BW and BCS ↔ heifer ADG, DMI, G:F	↔ age at puberty ↑ % heifers calving in first 21 d ↑ % heifer pregnancy rate
Larson et al., 2009	Cattle	0.45 kg/d CP supplement	late gestation	↔ steer initial feedlot BW ↑ steer reimplant BW ↔ steer final feedlot BW ↔ steer ADG, DMI, G:F ↓ % steers treated for illness	↔ steer HCW, 12th rib fat, LM area, Yield Grade ↑ steer marbling score, % Choice
Funston et al., 2010	Cattle	0.40 kg/d CP supplement	late gestation	↔ heifer ADG postweaning ↔ heifer BW at puberty ↔ heifer prebreeding BW	↓ age at puberty ↔ % heifers pubertal at breeding ↔ % pregnant heifers
Da Silva et al., 2001	Sheep	moderate or high growth rates	early to mid-gestation	↔ age of first ovulation in ewe lambs ↔ # of ovulatory cycles in ewe lambs	↔ length of first breeding season for ewe lambs
Neville et al., 2010	Sheep	60, 100, or 140% of requirements	mid- to late gestation	↔ wether N balance parameters	

[1] ↔: no change; ↑: increased; ↓: decreased

offspring performance. At the beginning of the finishing period, steers from cows supplemented with CP during late gestation and grazed subirrigated meadow pasture 30 days prior to breeding had increased BW compared with steers from cows that were not supplemented with CP and/or fed grass hay (Stalker et al., 2006). Crude protein supplementation may be required during late gestation to program those fetuses to have improved BW in the feedlot. However, the improved BW at the beginning of finishing may have been due to the improved grazing pasture prior to breeding. In a study conducted by Larson et al. (2009), dry matter intake (**DMI**) and ADG tended to be increased in steers born to cows supplemented with CP during late gestation compared with those born to cows not supplemented with CP. Suggesting that with increased ADG, those steers would grow more rapidly and have a reduced number of days on feed. However, Stalker et al. (2006) reported that there was no effect of maternal nutrition during late gestation on ADG, DMI, or feed efficiency (**G:F**) during the finishing period. The results of Stalker et al. (2006) indicate that although steers from non-CP supplemented dams had reduced weaning weights, they may be able to overcome this difference in BW before entering the feedlot by being more efficient in nutrient utilization and have similar performance during the feedlot phase.

Previous results suggest that CP supplementation during late gestation may positively improve feedlot performance of male offspring. Increased feedlot DMI and ADG may result in a reduced number of days on feed and increased profits. However, the results were limited to a small number of studies and these results were conflicting. Therefore, these results are not definitive and require further research. If steer offspring from CP supplemented dams are programmed to outperform those from dams that were no CP supplemented, this could also improve carcass quality of male offspring.

To our knowledge there has been no research conducted on dam protein supplementation during late gestation on offspring N balance. The one study that has been conducted utilized total nutrient intake in ewes during late gestation and evaluated N balance in wether offspring. In a study conducted by Neville et al. (2010), there were no differences in N balance parameters in wethers due to maternal dietary nutrition provided at 60, 100, or 140% of NRC (1985) requirements during gestation. Therefore, it is unknown how maternal CP supplementation during gestation may alter offspring N utilization. To our knowledge, MP supplementation during gestation has not been studied for its effects on offspring performance beyond weaning. Speculation on possible results is difficult due to the limited and conflicting results in the feedlot performance. However, if feedlot performance is enhanced by maternal CP supplementation during late gestation, N balance of steers may also be improved. An improvement in N balance would suggest that supplementation of CP during gestation may program steers to be more efficient in N utilization, leading to the improved feedlot performance.

Carcass Characteristics

Many factors are involved when determining meat quality, but they can be divided into two main categories, genetic and environmental factors (Okeudo and Moss, 2005). Fetal programming utilizes genetics to alter muscle development, but this is accomplished by altering the diet, or environmental factors, or the dam. Therefore, utilizing CP supplementation during late gestation to program male offspring to have increased carcass quality compared with males from non-CP supplemented dams is difficult. However, CP supplementation may be able to alter growth of the offspring, which could lead to improved carcass quality. The effects of protein supplementation on male offspring carcass characteristics have been summarized in Table 1.3.

Although the feedlot results were conflicting, carcass characteristics may be altered by maternal nutrition during late gestation. Similar to the feedlot results, steers born to cows grazing winter range and not supplemented with CP during late gestation had lower HCW compared with steers born to cows grazing winter range and supplemented with CP and those born to cows grazing corn residue and being supplemented or not supplemented with CP (Larson et al., 2009). The reduced HCW of steers from dams grazing winter range and not supplemented with CP were likely due to the reduced BW at the end of the feedlot phase (Larson et al., 2009). Steers with reduced BW at the end of the feedlot phase may have been programmed to have reduced performance in the feedlot due to the reduced CP available during the last third of gestation, which could lead to reduced carcass quality. In addition, Larson et al. (2009) reported that steers born to cows supplemented with CP during late gestation had increased marbling scores and proportion of steers grading USDA Choice or greater and tended to have increased empty body fat compared with steers from cows not supplemented with CP. The contradictory results in the feedlot studies also led to differing results in carcass characteristics. In a study by Stalker et al. (2006), carcass characteristics were not altered due to maternal CP supplementation during late gestation. However, due to the similarities in steer feedlot performance described by Stalker et al. (2006), the lack of differences in carcass characteristics is not surprising. Therefore, due to the conflicting results in both feedlot performance and carcass characteristics, a definitive conclusion cannot be reached. The differences of results between studies may be due to the variations between studies.

Female Offspring

Heifer weaning weights were improved by maternal CP supplementation during late gestation, which could lead to improved reproductive efficiency (Funston et al., 2010).

However, due to the relatively few studies available evaluating the effects of CP supplementation on female offspring development, the results may not be conclusive across all species and dietary alterations. Improving female offspring growth and reproductive efficiency could increase their lifetime offspring production and improve herd/flock development. Table 1.3 summarizes the effects of maternal protein supplementation during gestation on female offspring growth and development.

Maternal CP supplementation during late gestation improved male offspring growth in the feedlot; therefore, female offspring growth and reproductive development may also be improved. Heifers born to cows supplemented with CP during late gestation had greater adjusted 205 d BW, prebreeding BW, and BW at pregnancy diagnosis compared with heifers born to cows that were not supplemented (Martin et al., 2007). Previous results (Larson et al., 2009; Funston et al., 2010a) indicated that steers and heifers of CP supplemented dams had improved weaning weights, which may have led to improved BW through pregnancy diagnosis. However, Martin et al. (2007) also did not observe any effects on heifer progeny performance during at 84 d individual feeding trial due to maternal CP supplementation. In a similar study conducted by Funston et al. (2010a), G:F and ADG were increased in heifers from cows supplemented CP and grazing corn residue during late gestation compared with those grazing winter range or not supplemented , although there was no difference in BW at puberty. The improved feed efficiency and gains may increase the body condition of the heifer prior to breeding, which could lead to improved reproductive efficiency. During a feeding trial, heifers born to cows supplemented during late gestation tended to have increased BW upon entering the feeding trial (Funston et al., 2010a). Crude protein supplementation may have programmed those female offspring to have increased growth compared with females from non-CP supplemented dams; thereby improving the potential for increased conception and pregnancy rates.

Due to improved growth, female offspring may also have enhanced reproductive efficiency by reduced number of days to first estrus and the onset of puberty. Funston et al. (2010a) observed heifers from cows supplemented with CP during late gestation tended to reach puberty at a younger age than those born to unsupplemented cows. Suggesting an increased potential to breed and maintain pregnancy during the first 21 d breeding cycle. A study conducted by Martin et al. (2007) observed heifers born to cows supplemented with CP during late gestation having increased pregnancy rates and percentage of heifers calving in the first 21 d compared with heifers born to cows that were not supplemented during late gestation (Martin et al., 2007). Improvement of female offspring from CP supplemented cows to achieve puberty faster (Funston et al., 2010a) and increased pregnancy rates (Martin et al., 2007) may have been due to increased BW at prebreeding. Increased BW may have been due to increased fat deposition, which is a signal for the onset of puberty in the female. However, there were no differences associated with CP supplementation to dams during late gestation on heifer progeny percent pubertal by breeding or the percent pregnant (Funston et al., 2010a). Adipose deposition in the female is a major determinant of the onset of puberty; therefore, the lack of differences in BW at puberty would suggest there would be no alterations between the percentages of pubertal heifers at breeding.

The results between Martin et al. (2007) and Funston et al. (2010a) are conflicting. Improved heifer growth and reproductive efficiency would suggest that the offspring from the heifers may also be positively impacted. Heifer progeny calf production was not impacted by maternal CP supplementation during late gestation (Funston et al., 2010a). In addition, calf birth date, birth weight, or weaning weight in offspring born to heifer progeny were not altered by grand-dam nutrition during late gestation (Martin et al., 2007). Crude protein supplementation may have programmed female offspring to have improved pubertal status and breeding efficiency compared with female offspring from unsupplemented dams, but these effects may not alter offspring performance beyond the F1 generation.

Crude protein supplementation during late gestation may have programmed female offspring to have increased growth and reproductive performance compared with females from dams that were not supplemented with CP. However, CP supplementation during late gestation may not improve subsequent offspring performance beyond the F1 generation. The increased reproductive performance could lead to increased production throughout her lifetime. To our knowledge there has been no previous research conducted in the area of MP supplementation during gestation on female offspring performance beyond weaning.

Offspring Immunity

Late gestation CP supplementation may improve male and female growth and performance postpartum and this could partially be due to the increased immunity of those offspring. Increasing the immunity of the offspring allows more energy to be put into growth and performance than to fighting illness. Therefore, improving offspring immunity could lead to increased growth, carcass quality, or reproductive efficiency.

Not only is immunity affected immediately postpartum, but also into the growing phase of offspring. Percent of steers treated from birth to weaning was not affected by maternal CP supplementation during late gestation (Larson et al., 2009). Steers from cows that were supplemented with CP during late gestation were treated less for respiratory and gastrointestinal disease from weaning to slaughter than those born to cows that were not supplemented (Larson et al., 2009). Indicating that offspring of CP supplemented dams may have an improved immune system to ward off potential illnesses. Reduced incidences of illness in the feedlot could lead to reduced number of days on feed due to less energy expended on fighting the illness and more energy used for growth. However, why CP supplementation during late gestation may improve immune function of offspring is unclear. One possible explanation would be due to increased immunoglobulin (**Ig**) concentrations. Concentrations of Ig G were not altered in steers due to maternal dietary CP treatment pre- or postpartum in cows (Stalker et al., 2006). The body utilizes Ig to fight against infections; therefore, these unaltered IgG concentrations suggest that some other factor may be involved in offspring immunity other than IgG. However, IgG concentrations were not evaluated in Larson et al. (2009), so it cannot be ruled out as a factor in the reduction of illness treatments in steers from CP supplemented dams. There has been little research conducted on the effects of maternal CP supplementation on offspring immunity, and to our knowledge, no research has been conducted with MP supplementation.

Economics

There has been minimal research conducted into the economic feasibility of supplementing CP during pregnancy. There are added costs, but also added benefits to late gestation CP supplementation due to the increased offspring growth and performance. The little information that is available indicates that the CP supplement provided during gestation adds extra costs, such as labor, fuel, and the supplement, to the producer and has been summarized in Table 1.4.

Calves born to cows supplemented with CP during late gestation had reduced net return at weaning compared with calves from non-supplemented cows (Larson et al., 2009). Alternatively, Stalker et al. (2006) observed an increase in weaned calf and carcass values in

Table 1.4. Effects of protein supplementation during late gestation on the profitability of the offspring

Reference	Species	Treatment	Time	Response[1]	Additional Response[1]
Stalker et al., 2006	Cattle	0.45 kg/d CP supplement	late gestation	↑ weaned calf value ↑ weaned calf net return ↑ net return if steers are from retained ownership	↑ carcass value ↔ feedlot net return
Larson et al., 2009	Cattle	0.45 kg/d CP supplement	late gestation	↑ weaned calf value ↓ weaned calf net return	↑ carcass value ↑ feedlot net return
Funston et al., 2010	Cattle	0.40 kg/d CP supplement	late gestation	↑ weaned calf value ↑ weaned calf net return	↑ net cost of 1 pregnant heifer

[1] ↔: no change; ↑: increased; ↓: decreased

those calves from cows that were supplemented with CP during late gestation and those from cows grazing subirrigated meadow pasture prior to breeding. The increased value of weaned calves and carcasses may offset the added costs associated with supplementation. Similarly, carcasses of steers born to cows CP supplemented during late gestation were of greater value than those from cows that were non-supplemented (Larson et al., 2009). Similar results were observed by Bohnert et al. (2009), where carcasses of steers from cows supplemented with CP during late gestation were increased in value compared with carcasses of steers from cows that were not supplemented. Suggesting that CP supplementation during late gestation not only improved carcass quality, but led to increased carcass values. Bohnert et al. (2009) observed that during the cow-calf phase, cows that were supplemented with CP during late gestation had increased net returns compared with their unsupplemented counterparts, despite the increased supplement costs. However, net returns were reduced following the growing and feedlot phases in calves from cows that were supplemented during late gestation (Bohnert et al., 2009). Adding to the potential of increased net returns, health costs in the feedlot phase were drastically reduced in those steers from cows supplemented with CP during late gestation compared with those from cows that were not supplemented (Bohnert et al., 2009). Reducing the number of treated illnesses within the feedlot can lead to increased net returns during the feedlot phase.

All production systems are different and each individual should evaluate all costs associated with their farm prior to beginning a CP supplementation system. However, in the previously researched production systems, results indicate that supplementing CP during late gestation is more economical due to the increased growth of the offspring and reduced medical treatments of those offspring compared with offspring from unsupplemented dams. In general, CP supplementation adds to the total cost of any production system, but the improved revenue of the offspring may offset the costs associated with supplementation.

Conclusion

Providing a CP supplement during gestation provides increased N for both the dam and offspring. This increased N provided during gestation positively impacts dam performance prior to and immediately post-parturition. However, this improved growth performance of the dam did not lead to increased offspring birth weights; although, offspring performance may have been positively altered later in life due to maternal CP supplementation. Results of offspring performance were conflicting between studies and further research is needed to elucidate the causes of these effects. Although maternal MP intake did not alter dam or offspring performance to weaning, effects beyond weaning are unknown. Therefore, more research needs to be conducted on the effects of MP intake during gestation on offspring performance post-weaning.

Statement of the Problem

Fetal programming and its effects on both livestock production and humans has been extensively reviewed (Wu et al., 2006; Funston et al., 2010; Reynolds and Caton, 2012). However, much of the previous research has focused on global nutrient restriction during pregnancy, and not on specific nutrient intake. Global nutrient intake produces confounding results because the ultimate cause of the results cannot be elucidated. However, very few of the global nutrient supply studies evaluate offspring performance post-weaning (Neville et al., 2010). Therefore, the potential for evaluating specific nutrient supply (i.e. energy or protein) during pregnancy has increased in recent years (Larson et al., 2009; Funston et al., 2010; Amanlou et al., 2011).

Recently, CP supplementation during late gestation has been evaluated. However, similar to the total nutrient studies, few studies have evaluated dam performance and offspring performance post-weaning (Larson et al., 2009; Martin et al., 2007; Funston et al., 2010a). However, these previous studies focus on strictly supplementation of CP during late gestation and they do not discuss how the CP supplementation relates to beef cow requirements during late gestation. According to Stalker et al. (2006), feeding of the CP supplement provided adequate CP during late gestation for spring-calving cows to maintain BCS while grazing dormant upland range. Although the results of Stalker et al. (2006) indicate that the BCS of cows was maintained with CP supplementation, this does not explain if the supplement provided sufficient CP to meet requirements.

Results of previous research indicates that there needs to be more focus on specific nutrients, such as protein, to accurately determine how each nutrient in the diet alters both dam and offspring performance. Therefore, MP intake during late gestation may provide more insight into the effects protein intake on fetal development and dam performance during a time of rapid growth as it only accounts for the N available for absorption and utilization in the small intestine. However, there has been minimal research conducted in the area of MP intake during gestation (Patterson et al., 2003; Amanlou et al., 2011). Therefore, additional research needs to be conducted utilizing MP intake during late gestation to determine the effects on both dam and offspring performance. Our hypothesis was that restricting MP intake during the last trimester of pregnancy would negatively impact maternal and offspring performance, while increasing MP intake above requirements would improve maternal and offspring performance. Therefore, our objectives were to determine the effects of MP intake during late gestation both below and above requirements on dam and offspring performance.

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CHAPTER 2. SUPPLEMENTING METABOLIZABLE PROTEIN TO EWES DURING LATE GESTATION: I. EFFECTS ON EWE PERFORMANCE AND OFFSPRING PERFORMANCE FROM BIRTH TO WEANING

Abstract

Our objective was to determine how MP intake during late gestation affected ewe and offspring performance from birth to weaning in ewes fed isocaloric diets. Maternal dietary treatments were applied at d 100 of gestation and in year 1 were isocaloric and contained: **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation for a ewe bearing twins. In year 2, maternal dietary treatments were isocaloric and contained: **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements on a DM basis of a ewe bearing twins during the last 4 weeks gestation. In year 1, there was no effect ($P \geq 0.22$) of maternal MP restriction on ewe weight change at lambing, change in BCS during gestation, gestation length, or lamb birth weight per unit initial or final ewe BW. There was a treatment × day effect ($P < 0.001$) for ewe BW. At d 114 and 142 of gestation the 60MP1 ewes weighed less ($P = 0.02$ and $P = 0.01$, respectively) than the 100MP1 ewes. Ewe BCS increased ($P = 0.01$) linearly as MP increased in the diet. As MP increased in the diet, there was a linear ($P = 0.01$) increase in change in BW. At lambing, ewe BW ($P = 0.02$) and BCS ($P = 0.01$) increased linearly as MP in the diet increased. Percent BW loss from d 100 of gestation to immediately postpartum was linearly ($P < 0.001$) reduced as MP increased in the diet. There was a linear increase in BCS loss as MP was reduced in the diet from d 100 ($P = 0.01$) and 142 ($P = 0.05$) of gestation to immediately postpartum. In year 2, there were no significant effects ($P \geq 0.35$) of maternal dietary treatment on weight change from d 142 to lambing, change in BCS during gestation, change in BCS from d 100 and 142 to lambing, BCS at lambing, or lamb birth weight per unit initial or final ewe BW. There was a linear ($P \leq 0.02$) increase in BW at lambing and BW gain during gestation as MP intake increased during late gestation. Percent BW loss from d 100 of gestation to immediately postpartum was linearly ($P < 0.001$) reduced as MP increased in the diet in year 2. These results suggest that ewes maintain and gain BW and BCS when consuming increased MP during late gestation.

Key words: ewes, late gestation, metabolizable protein

Introduction

When a stimulus is applied to the dam during pregnancy, the offspring may be affected while still *in utero* and carry those effects throughout life (Barker, 1995). The most common methods of nutritional manipulation of fetal development are to alter either N or total nutrient intake during gestation. However, many of the CP supplementation studies do not address how the CP intake relates to requirements of the dam, but focuses solely on CP supplementation. Increasing N intake during late gestation is a common technique used to maintain dam BW, body condition, and offspring performance (Martin et al., 2007) during a time of rapid fetal development. Dams that are not supplemented with N during late gestation weigh less immediately prior to calving compared with cows supplemented with N (Larson et al., 2009). These negative impacts on dam performance can also have negative effects on offspring performance, such as reduced birth weights or weaning weights (Larson et al., 2009). However, the nutrients retained by the dam may not mimic what is fed when utilizing energy or CP as a method of nutritional manipulation.

Therefore, for the purposes of the current study, MP was evaluated. Metabolizable protein is defined by the NRC (2007) as the true protein, which is derived from dietary and microbial protein that is digested post-ruminally and from which the constituent AA are absorbed from the intestine. Amanlou et al. (2011) observed that colostrum yield tended to increase as MP increased in the diet from 100 to 124% of requirements during late gestation. Therefore, providing adequate MP during gestation may serve as a more appropriate indicator of how protein intake affects dams during late gestation.

We hypothesized that isocaloric diets provided to dams with differing maternal MP levels would impact fetal growth and development. More specifically, we hypothesized that the greater proportion of the diet that is composed of MP would yield improved offspring growth by potentially increasing nutrient transfer by the placenta or by increased nutrients within the milk. Therefore, the objectives were to evaluate isocaloric diets with increasing levels of MP during late gestation on ewe performance and offspring growth from birth to weaning.

Materials and Methods

All procedures were approved by the North Dakota State University Animal Care and Use Committee (#A0921).

Ewes

Year 1. Multiparous western-whiteface ewes (n = 509) were synchronized utilizing controlled intravaginal drug release (CIDR; Eazi-Breed^{TM} CIDR$^{®}$, Pharmacia & Upjohn Pty Limited, Rydalmere, Australia) devices. Ewes were randomly assigned into 1 of 5 breeding groups (4 groups of 102 ewes/breeding group; 1 group of 101 ewes/breeding group). Controlled intravaginal drug release devices were inserted on d -14. All breeding groups were maintained in a single flock during the CIDR insertion and breeding periods. Breeding was staggered to ensure that the ram to ewe ratio did not exceed 1:10 per day of breeding. Day 0 is denoted by the day CIDRs were removed and a 5 mL injection of P. G. 600 ® (Intervet Inc., Millsboro, DE) was administered and when Rambouillet rams (n = 12) were fitted with marking harnesses and introduced to the flock. Breeding marks were observed three times per week to determine day of breeding. Time of breeding was confirmed when pregnancy was determined via ultrasonography (B – Mode; Aloka SSD-500V, Aloka America, Wallingford, CT) 30 and 60 days after ram introduction. All ewes selected for the project were bred within the first 34 days of the breeding season.

On ~ d 50 of gestation, pregnant ewes (n = 295) were moved to and maintained in a common group pasture at the Hettinger Research Extension Center (Hettinger, ND). On ~ d 90 of gestation, ewes were moved to a total confinement barn and placed into 21 pens (20 pens of 14 ewes/pen; 1 pen of 15 ewes/pen) and acclimated to low-quality straw (Table 2.1) and the 100MP1 supplement (100% of the MP requirements (as determined by NRC, 2007; Table 2.2)) for 7 d prior to starting dietary treatments. Ewes were weighed on two consecutive days (d 99 and 100 of gestation) prior to the initiation of treatments. On d 99 of gestation, ewes were body condition scored on a scale of 1 to 5 (1 = emaciated, 5 = obese; Russell, 1984). Expected lambing date was determined by breeding marks. On d 100 ± 8 (SD) of gestation, using the average of the initial weights (d 99 and 100 of gestation), ewes were stratified by BW, BCS, age, and expected lambing date to one of three isocaloric dietary treatments (Table 2.2; n = 7): **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation for a ewe bearing twins. On d 100 ± 8 (SD), treatments were initiated. Metabolizable protein intake was determined by the average body weight of the pen and offered once daily at 0800 h. Ewes were given one hour to consume the supplement then low-quality forage was offered. Body weights and BCS were collected every 14 d throughout the dietary treatment period, and the amount of supplement offered was adjusted due to changes in average body weight per pen. Trace mineral was supplemented once per week to allow for 8.5 g·ewe^{-1}·day^{-1} consumption. Trace mineral composition was 16% Ca, 8% P, 21% Salt, 2.75% Mg, 3 ppm Co, 5 ppm Cu, 100 ppm I, 1400 ppm Mn, 20 ppm Se, 3000 ppm Zn, 113,500 IU/kg vitamin A, 11,350 IU/kg vitamin D, and 227 IU/kg vitamin E. At lambing, BCS and a two day weight were obtained on all ewes. Once ewes had lambed, the ewes and lambs were moved to grouping pens and were intermingled between dietary treatments where they were maintained on a lactation ration (Table 2.1) which was formulated to meet or exceed nutritional requirements until weaning.

Year 2. Multiparous western-whiteface ewes (n = 229) were managed in a single flock prior to and during breeding. Twelve Rambouillet rams were fitted with marking harnesses and were introduced to the flock (d 0; 1:20 ram:ewe ratio). On d 17 and 34, breeding marks were recorded, and ewes selected for the experiment were those marked within the first 34 d of breeding.

Table 2.1. Nutrient composition of fescue straw and lactation ration in years 1 and 2

	Fescue Straw[1]		
Item	Year 1	Year 2	Lactation Ration[2]
Diet, % DM	64.51	56.51	100.00
DM, %	83.05	77.61	64.37
NEm, Mcal/kg	2.22	2.12	—
CP, % of DM	3.04	3.07	11.52
MP, % of DM	1.95	1.97	—
NDF, % of DM	79.85	81.13	48.05
ADF, % of DM	48.97	51.10	27.16
Ash, % of DM	9.49	7.78	8.59

[1] Ewes were fed fescue straw in each year to limit metabolizable protein intake.

[2] Ewes were fed a common ration during lactation across all dietary treatments; 28.5% oats, 28.5% haylage, 42.9% chopped hay.

On d 34, ewes were moved to and maintained in a common group pasture at the Hettinger Research Extension Center. Upon pregnancy confirmation via ultrasonography at d 75, pregnant ewes (n = 169) were selected and on d 90 of gestation ewes were weighed, stratified by BW, and placed in a total confinement barn (14 ewes/pen) and acclimated to a low quality straw (Table 2.1) and the 100MP2 supplement (100% of the MP requirements) for 7 d prior to starting dietary treatments. On d 99 of gestation, ewes were body condition scored on a scale of 1 to 5 (1 = emaciated, 5 = obese; Russell, 1984). On d 100 ± 8 (SD) of gestation, using the average of the initial weights (d 99 and 100 of gestation), ewes were stratified by BW, BCS, age, and expected lambing date to one of three isocaloric dietary treatments (Table 2.2; n = 4): **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements on a DM basis of a ewe carrying twins during the last 4 weeks gestation (NRC, 2007). Dietary treatment application and lambing procedures were similar to year 1.

Lambs

In both years, lambs were weighed and tagged within 24 h of birth; sex, lambing assistance, and lamb vigor (0 = extremely active and vigorous; 4 = very weak and little movement; Matheson et al., 2011) were also recorded. Lambs were then moved with the ewes to grouping pens and had full-access to creep pellet (crude fat: 2%, crude fiber: 15%; Ca: 1.5%; P: 0.35%; salt: 1%; Se: 0.2 ppm; Vitamin A: 1134 IU/kg; Vitamin D: 114 IU/kg; and Vitamin E: 2.3 IU/kg) and water prior to weaning. At 14 days of age all lambs were vaccinated for tetanus and *Clostridium Perfringens* types C and D (CD-T; Bar Vac CD-T, Boehringer Ingelhein, Ridgefield, CT), tails were docked, and ram lambs were castrated. Lambs were weaned at 69 ± 5 d (SD) of age in year 1 and at 61 ± 12 (SD) d of age in year 2, and vaccinated again for tetanus and *Clostridium Perfringens* types C and D (CD-T; Bar Vac CD-T, Boehringer Ingelhein,

Table 2.2. Ingredient and nutrient composition of dietary supplements fed to ewes in year 1 and 2

	Year 1[1]			Year 2[2]		
Item	60MP1	80MP1	100MP1	60MP2	100MP2	140MP2
Ingredient, % DM						
Corn	18.50	15.00	5.00	30.00	19.00	—
DDGS[3]	7.00	20.00	30.00	4.00	24.00	43.00
Soyhulls	9.50	—	—	9.00	—	—
Trace mineral[4]	0.49	0.49	0.49	0.49	0.49	0.49
Nutrient composition						
DM, %	88.75	89.34	89.68	88.64	90.19	92.16
NEm, Mcal/kg	2.00	2.22	2.14	2.05	2.19	2.06
CP, % of DM	13.16	20.21	25.13	10.21	18.67	28.68
MP, % of DM	8.41	13.01	16.31	6.54	11.96	18.37
NDF, % of DM	31.03	30.73	39.79	29.64	31.40	45.34
ADF, % of DM	15.69	7.45	10.49	13.87	8.68	13.34
Ash, % of DM	3.22	3.48	4.55	3.53	3.80	5.13

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements.

[2] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirement; and 140MP2: 140% of the metabolizable protein of 100MP2.

[3] Dried distillers grains with solubles

[4] Trace mineral content: 16.0-17.0% Ca; 8.0% P; 21.0-23.0% Salt; 2.75% Mg; 3 ppm Co; 5 ppm Cu; 100 ppm I; 1,400 ppm Mn; 20 ppm Se; 3,000 ppm Zn; 113,500 IU/kg Vitamin A; 11,350 IU/kg Vitamin D; and 227 IU/kg Vitamin E.

Ridgefield, CT), and weighed. Once removed from ewes, lambs were moved to feedlot pens and were comingled across maternal dietary treatments.

Weigh-Suckle-Weigh

In year 1, three hour milk production was evaluated (Benson et al., 1999) in ewes that gave birth to singletons [60MP1 (n = 15); 80MP1 (n = 16); 100MP1 (n = 16)] at an average 23 ± 4 (SD) d of age. After lambs were removed from their ewes for three hours, lambs were allowed to suckle until satisfied. Once done suckling, lambs were removed from ewes for another three hours. Thereafter, lambs were weighed, allowed to suckle until lambs were satisfied, and then reweighed.

Laboratory Analysis

In years 1 and 2, samples of each MP dietary supplement and fescue straw were collected every 7 d throughout the duration of the trial. These samples were dried at 55°C for 48 h using a forced-air oven. Dried samples were ground through a Wiley Mill (Arthur H. Thomas Co., Philadelphia, PA) to pass through a 2 mm screen. Feed samples were composited by month and were analyzed for DM, ash, and N (methods 934.01, 942.05, and 2001.11, respectively; AOAC, 2010). Concentrations of NDF and ADF were determined using Ankom 200 Fiber Analyzer (Ankom Technology, Fairport, NY).

The undegradable intake protein (**UIP**) content of each MP dietary supplement and fescue straw was determined each year using in vitro dry matter digestibility (**IVDMD**). Approximately 5 g of each supplement and straw was weighed into 6 cm x 10 cm Dacron bag in duplicate at each time point. Prior to suspension in the rumen, the samples were soaked in 39 degrees Celcius (**°C**) water for 5 min to remove soluble protein. The bags were then placed in a large nylon netted bag within the rumen of one fistulated Holstein steer. The nylon netted bag was connected to the cannula plug via a nylon cord. Samples were incubated in the rumen for 0, 2, 4, 8, 12, 24, 36, 72, and 96 h. The bags were removed and rinsed with tap water until runoff was clear and dried in a 55°C drying oven for 48 h. Residual material was weighed to determine rumen DM digestibility. Nitrogen analysis (method 2001.11; AOAC, 2010) was then completed on each remaining sample to determine the UIP portion of each feed. The UIP was then incorporated into the MP calculation: $CP = MP/((64 + (0.16 \times \% UIP))/100)$; based on the NRC (2007).

Statistical Analyses

Year 1. Ewe BW change during gestation, ewe BW change at lambing, ewe BCS change during gestation, ewe BCS change at lambing, ewe gestation length, lamb birth weight per ewe BW at d 100 of gestation, lamb birth weight per ewe BW at d 142 of gestation (final pre-partum BW), three hour milk production, lamb birth BW, lamb ADG from birth to weaning, and lamb weaning BW were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model included the main effects of maternal dietary treatment, ewe pen, breeding cycle (d 0 through 17 or d 18 through 34) and all interactions. Ewe pen served as the experimental unit (n = 7). Repeated measures analysis was performed for ewe BW (compound symmetry) and BCS (ante-dependence) to determine differences within each 14 d weight period. The GLIMMIX procedure of SAS was used to analyze the percentage of males born within each treatment, percentage of twin born within each treatment, percentage of assisted births within each treatment, and the percentage of lambs requiring treatment for illness at birth. If the interaction was found to be clearly not significant ($P > 0.30$), it was removed from the model. When a significant *F*-test was observed ($P \leq 0.15$), pre-planned comparisons of linear and quadratic contrasts were utilized to partition treatment effects. Significance was set at $P \leq 0.05$ and tendencies at $P \leq 0.10$.

Year 2. Analysis of ewe performance and offspring performance from birth to weaning were previously discussed in year 1. All parameters analyzed were similar except gestation length and 3 h milk production, which were not evaluated in year 2. Pen served as the experimental unit (n = 4). Repeated measures analysis was performed for ewe BW (ante-dependence) and BCS (autoregressive) to determine differences within each 14 d weight period. Interactions, means separation, and significance were similar to year 1.

Results

Ewes

Year 1. Ewe weight change at lambing, change in BCS during gestation, gestation length, and lamb birth weight per unit initial or final ewe BW were not affected ($P \geq 0.22$; Table 2.3) by maternal dietary treatment. There was a treatment × day effect ($P < 0.001$; Figure 2.1) for ewe BW. At d 114 and 142 of gestation the 60MP1 ewes weighed less ($P = 0.02$ and $P = 0.01$, respectively) than the 100MP1 ewes. There was also a day effect ($P < 0.001$) for ewe BW during gestation. However, the same results were not observed for BCS throughout the trial. There was no treatment × day effect ($P = 0.66$; Figure 2.2) for BCS during gestation. Although, BCS on d 128 of gestation tended ($P = 0.08$) to be greater than on d 142. An overall treatment effect of ewe BCS was observed, which increased ($P = 0.01$; Figure 2.2) linearly as MP increased in the diet. Additionally, as MP increased in the diet, there was a linear ($P = 0.01$; Table 2.3) increase in change in BW during gestation. At lambing, ewe BW ($P = 0.02$) and BCS ($P = 0.01$) increased linearly as MP in the diet increased. There was a linear ($P < 0.001$) reduction in the percentage of BW loss from d 100 of gestation to immediately postpartum as MP increased in the diet. There was a linear increase in BCS loss as MP was reduced in the diet from d 100 ($P = 0.01$; Table 2.3) and 142 ($P = 0.05$) of gestation to immediately postpartum. There tended ($P = 0.06$) to be a greater reduction in BCS from d 142 of gestation to lambing in the 80MP1 ewes compared with the 100MP1 ewes. There was no treatment × birth type effect for lamb birth weight per unit initial ($P = 0.89$) or final ($P = 0.44$) ewe BW. However, there was a birth type effect for both lamb birth weight per unit initial ($P < 0.001$; data not shown) and final ($P < 0.001$; data not shown) ewe BW, with twin lambs having greater birth weight per unit ewe BW compared with singletons.

Year 2. There were no significant effects ($P \geq 0.35$; Table 2.4) of maternal dietary treatment on weight change from d 142 to lambing, change in BCS during gestation, change in BCS from d 100 and 142 to lambing, BCS at lambing, or lamb birth weight per unit initial or final ewe BW. Although there were treatment × day differences detected ($P < 0.001$) for ewe BW during gestation, upon separation of the mean, no significant ($P > 0.05$; Figure 2.3) differences were observed. As MP increased in the diet, there was a linear ($P = 0.01$) increase in change in BW. There was a linear ($P < 0.001$) reduction in percent BW loss from d 100 of gestation to immediately postpartum as MP increased in the diet. There was no treatment × day ($P = 0.39$; Figure 2.4) effect on BCS of ewes throughout late gestation. At lambing, ewe BW increased ($P = 0.02$) linearly as MP in the diet increased. There was no treatment × birth type interaction ($P \geq 0.44$) observed for lamb birth weight per unit initial and final ewe BW. As expected, twins had increased birth weight per unit initial ($P < 0.001$; data not shown) and final ($P < 0.001$; data not shown) ewe BW compared with singletons.

Lambs

Year 1. There was no effect ($P \geq 0.19$; Table 2.5) of maternal dietary treatment on lamb birth weight, 3 h milk production, age at weaning, percent BW growth from birth to weaning, percentage of assisted births within each treatment, and the percentage of lambs requiring treatment for illness at birth. The only differences observed in birth weight were with gender and birth type. The male offspring weighed more ($P = 0.004$) at birth than the female offspring. Singletons weighed more ($P < 0.001$) at birth than twins, regardless of maternal dietary treatment. There was a tendency for linearly increased weaning BW ($P = 0.08$) and ADG from birth to weaning ($P = 0.10$) as MP increased in the ewe diet. Similar to birth weight, singletons weighed more ($P = 0.03$) at weaning than twins.

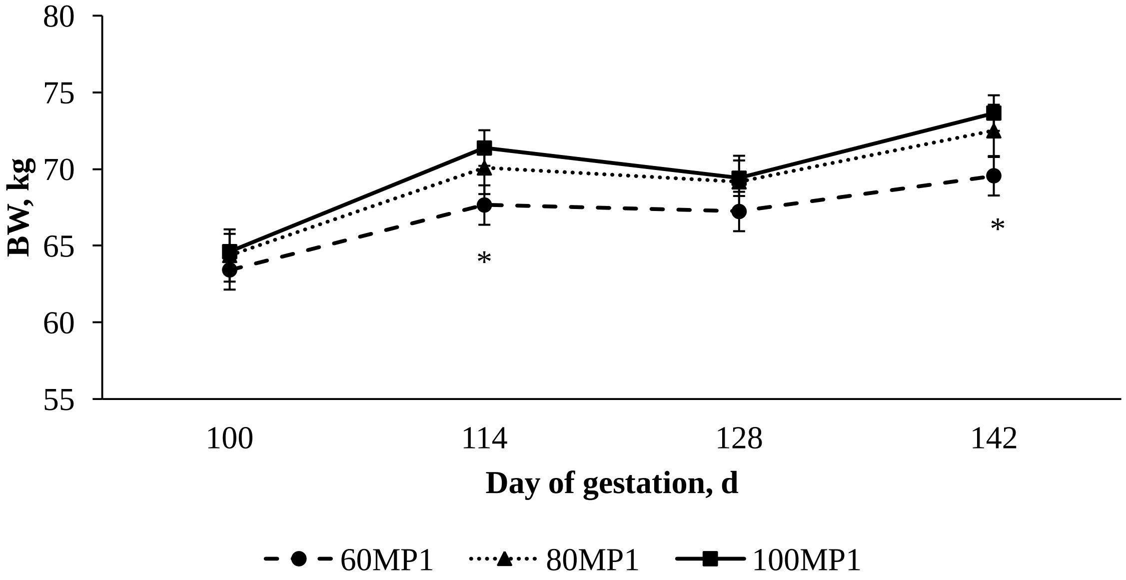

Figure 2.1. Effect of maternal metabolizable protein supplementation on ewe BW during late gestation in year 1. Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements. Asterisk (*) indicates significant difference between 60MP1 and 100MP1 at d 114 and 142 of gestation. Least squares means ± SEM are presented for gestation and at lambing (n = 7). Dietary treatment: $P = 0.20$; day: $P < 0.001$; treatment × day: $P < 0.001$; linear: $P = 0.08$; and quadratic: $P = 0.64$.

Year 2. There were no effects ($P \geq 0.25$; Table 2.6) of maternal dietary treatment on lamb birth BW, weaning BW, age at weaning, percent BW growth from birth to weaning, ADG from birth to weaning, percentage of assisted births within each treatment, and the percentage of lambs requiring treatment for illness at birth. Similar to Year 1, males ($P = 0.02$) and singletons ($P < 0.001$) were heavier at birth compared with females and twins, respectively. Singletons were also heavier ($P = 0.03$) at weaning compared with twins. There was a treatment × gender interaction ($P = 0.04$) for ADG from birth to weaning. Ewe lambs from the 100MP2 ewes had increased ($P = 0.02$) ADG from birth to weaning compared with the lambs from 140MP2 ewes. Regardless of maternal dietary treatment, singletons ($P = 0.03$) and males ($P = 0.05$) had increased ADG from birth to weaning compared with twins and females, respectively.

Discussion

Our results suggest that increased maternal MP intake may positively impact the ewe, without altering offspring performance from birth to weaning. Therefore, offspring of ewes from the 100 and 140% MP treatments were not programmed to have improved growth compared with their restricted counterparts through weaning.

Crude protein supplementation has been utilized to increase dam BW and BCS during late gestation when nutrient demands are greater (Bohnert et al., 2002; Stalker et al., 2006). By d 142 of gestation in both years of the study, the ewes supplemented with MP at and above

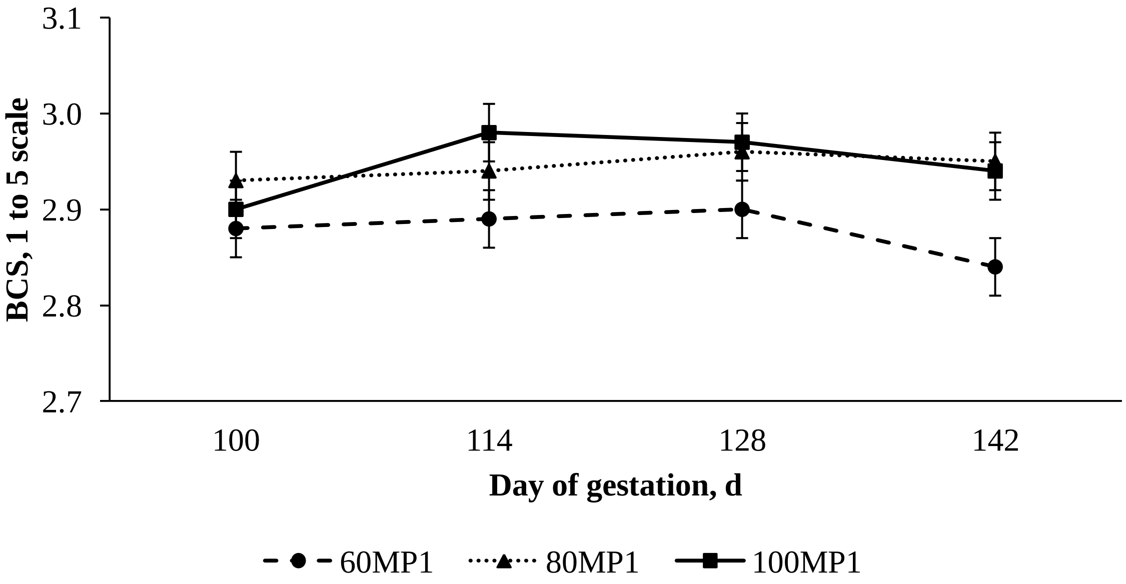

Figure 2.2. Effect of maternal metabolizable protein supplementation on ewe BCS during late gestation in year 1. Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements. Least squares means ± SEM are presented for gestation and at lambing (n = 7). Dietary treatment: *P* = 0.01; day: *P* = 0.08; treatment × day: *P* = 0.66; linear: *P* = 0.01; and quadratic: *P* = 0.17.

Table 2.3. Effects of maternal metabolizable protein supplementation during the last 50 d of gestation on ewe performance for year 1

	Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP1	80MP1	100MP1	SEM[2]	*P* – value[3]	Linear	Quadratic
Initial BW, kg	63.4	64.4	64.6	1.07	0.71	0.43	0.79
BW at lambing,[5] kg	59.2	62.3	62.9	1.14	0.04	0.02	0.36
Weight change, kg							
Gestation	6.47	8.90	9.12	0.59	0.01	0.01	0.15
Lambing	-12.55	-11.24	-11.97	0.59	0.33	0.50	0.16
Percent BW change,[6] %	-10.65	-4.98	-4.98	1.02	<0.001	<0.001	0.02
Initial BCS	2.9	2.9	2.9	0.03	0.51	0.53	0.33
BCS at lambing[5]	2.7	2.7	2.9	0.06	0.02	0.01	0.45
BCS change							
Gestation	-0.02	0.02	0.02	0.04	0.68	0.44	0.65
Lambing							
d 100 to lambing[7]	-0.20	-0.17	0.02	0.05	0.02	0.01	0.24
d 142 to lambing[8]	-0.18	-0.20	-0.02	0.05	0.06	0.05	0.14
Gestation length, d	148	149	149	0.60	0.93	0.71	0.99
Lamb birth BW/initial ewe BW,[9] g/kg	101.87	106.03	105.96	1.97	0.22	0.14	0.36
Lamb birth BW/final ewe BW,[9] g/kg	92.10	93.48	91.69	1.62	0.70	0.86	0.41

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of the metabolizable protein requirements; and 100MP1: 100% of metabolizable protein requirements.

[2] Greatest SEM presented (n = 7).

[3] *P* -value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Ewe BW and BCS measured within 24 h after parturition.

[6] Percent BW change from initial BW (d 100 of gestation) to BW immediately postpartum.

[7] Change in ewe BCS from the initial BCS (d 100 of gestation) to the BCS immediately postpartum.

[8] Change in ewe BCS from the final BCS (d 142 of gestation) to the BCS immediately postpartum.

[9] Lamb birth BW per unit of initial and final pre-partum ewe BW.

Table 2.4. Effects of maternal metabolizable protein supplementation during the last 50 d of gestation on ewe performance for year 2

	Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP2	100MP2	140MP2	SEM[2]	*P* – value[3]	Linear	Quadratic
Initial BW, kg	67.4	67.4	67.3	1.61	1.00	0.95	0.97
BW at lambing,[5] kg	60.8	64.4	65.4	1.44	0.06	0.02	0.48
Weight change, kg							
Gestation	5.16	8.00	8.69	0.78	0.02	0.01	0.28
Lambing	-12.59	-11.36	-11.24	0.86	0.35	0.26	0.60
Percent BW change,[6] %	-11.62	-5.09	-4.04	1.44	<0.001	<0.001	0.12
Initial BCS	3.0	3.0	3.0	0.01	0.40	0.22	0.40
BCS at lambing[5]	2.9	3.0	3.0	0.04	0.93	0.74	0.88
BCS change							
Gestation	0.00	0.00	-0.02	0.01	0.40	0.22	0.49
Lambing							
d 100 to lambing[7]	-0.06	-0.04	-0.04	0.04	0.94	0.74	0.88
d 142 to lambing[8]	-0.06	-0.04	-0.02	0.04	0.81	0.51	0.96
Lamb birth BW/initial ewe BW,[9] g/kg	100.47	103.96	101.24	2.78	0.66	0.84	0.38
Lamb birth BW/final ewe BW,[9] g/kg	93.35	92.33	89.71	2.81	0.63	0.37	0.82

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of metabolizable protein requirements; and 140MP1: 140% of metabolizable protein requirements.

[2] Greatest SEM presented (n = 4).

[3] *P* -value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Ewe BW and BCS measured within 24 h after parturition.

[6] Percent BW change from initial BW (d 100 of gestation) to BW immediately postpartum.

[7] Change in ewe BCS from the initial BCS (d 100 of gestation) to the BCS immediately postpartum.

[8] Change in ewe BCS from the final BCS (d 142 of gestation) to the BCS immediately postpartum.

[9] Lamb birth BW per unit of initial and final pre-partum ewe BW.

requirements were heavier than those restricted to 60% of MP requirements. All ewes gained BW during the last third of gestation, but by d 114 of gestation, increased MP intake above at or above requirements increased the weight gain of those ewes. Similar to the current study, previous research has indicated that supplementation of protein during late gestation improves dam BW gain and BCS and restriction of protein results in reductions of dam BW and BCS. Similarly, Larson et al. (2009) observed an increase in precalving BW and BCS in cows that were supplemented with CP during late gestation compared with their unsupplemented counterparts. Cows supplemented with CP during the last 78 d of gestation had increased BW at both pre- and post-calving compared with those cows that were not supplemented (Bohnert et al., 2002). These studies suggest that increasing CP intake during late gestation enhances dam performance and minimizes the mobilization of dam body reserves to maintain fetal growth. Moreover, Anthony et al. (1986) demonstrated that cows limited to 81% of CP requirements during late gestation had reduced weight gains and reduced prepartum BW compared with cows supplemented at 141% of CP requirements. When ewes were fed ad-libitum throughout gestation, they were heavier and had greater body condition than the maintenance fed ewes (Kenyon et al., 2009). Ewes supplemented with pelleted feed, with increased CP and NE relative to the control, during the final 14 d of gestation lost less weight than their unsupplemented counterparts (Godfrey and Dodson, 2003). Additionally, Meyer et al. (2010) described ewe BW gain during late gestation that maintenance of BW in the 60% restricted (NRC, 1985) ewes were due to the rapid fetal growth during late gestation offsetting the BW loss of the ewe. The increase in BW of ewes fed 100% of requirements was due the rapid fetal growth during late gestation and the ewes maintaining BW and the increase in BW of ewes fed 140% of requirements was due to the ewes gaining BW by maternal tissue growth and rapid fetal growth

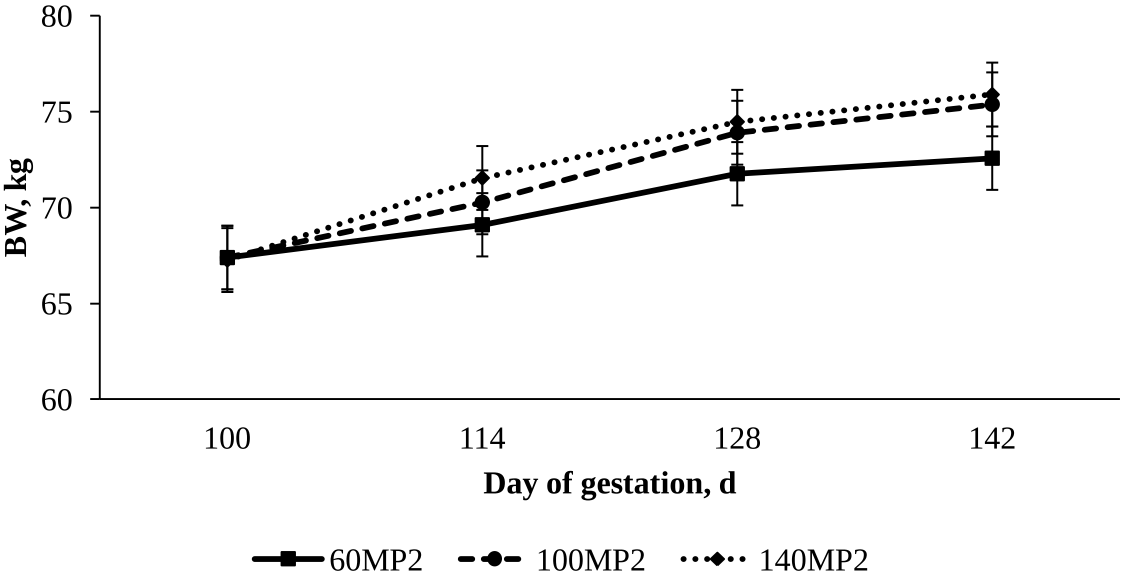

Figure 2.3. Effect of maternal metabolizable protein supplementation on ewe BW during late gestation in year 2. Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of metabolizable protein requirements; and 140MP2: 140% of metabolizable protein requirements. Least squares means ± SEM are presented for gestation and at lambing (n = 4). Dietary treatment: $P = 0.65$; day: $P < 0.001$; treatment × day: $P < 0.001$; linear: $P = 0.38$; and quadratic: $P = 0.81$.

(Meyer et al., 2010). Although there were no differences in year 2 of the current study, all ewes gained weight during late gestation; suggesting that restriction of MP to 60% of requirements provided sufficient N to the dam to maintain BW, but also fetal growth.

In both years of the current trial, a greater change in BCS was expected during gestation due to the MP restriction to 60% of requirements. In year 1, the restricted ewes had a numerical reduction in BCS during gestation which may indicate a mobilization of ewe body reserves to maintain fetal growth. The reduction in year 1 from initial BCS to lambing BCS also suggests that body reserves were mobilized for the increased energy required for parturition. Similar results were also observed in the change from final prepartum BCS to lambing BCS. These changes suggest the 60MP1 and 80MP1 ewes were utilizing body reserves to maintain

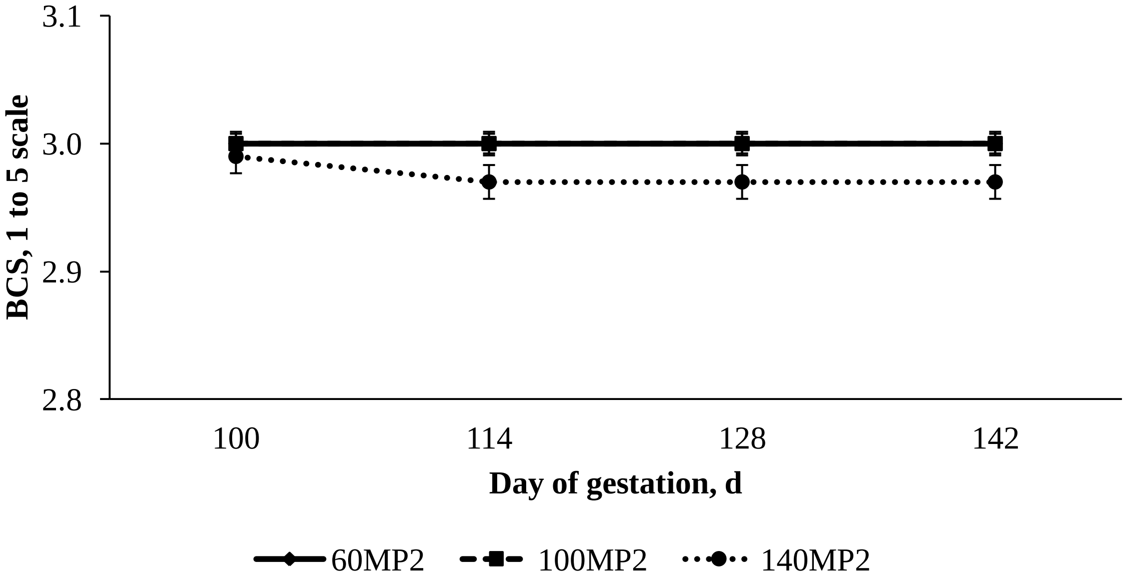

Figure 2.4. Effect of maternal metabolizable protein supplementation on ewe BCS during late gestation in year 2. Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of metabolizable protein requirements; and 140MP2: 140% of metabolizable protein requirements. Least squares means ± SEM are presented for gestation and at lambing (n = 4). Dietary treatment: *P* = 0.40; day: *P* = 0.37; treatment × day: *P* = 0.39; linear: *P* = 0.22; and quadratic: *P* = 0.40.

pregnancy and fetal growth during the supplementation period, even though ewe BW continued to increase. However, in year 2, these results were not replicated. The differences in BCS results between years 1 and 2 could be due to ewes in year 2 being in improved condition prior to the start of treatments compared with year 1. The loss in BCS observed during pregnancy is best explained by Naismith and Morgan (1976) and Robinson (1986) who stated that during early pregnancy dams are in an anabolic phase, followed by a catabolic phase during late pregnancy. Naismith and Morgan (1976) concluded that protein is stored during early pregnancy to sustain fetal growth and development during late pregnancy. Therefore, ewes consuming restricted MP may have begun to mobilize protein stores to provide sufficient nutrients to the fetus. Additionally, Robinson (1986) also discussed the loss of lipid throughout the whole of pregnancy to provide energy for the growing fetal demands. These results suggest that although MP is provided at or above requirements, the ewe may be in a catabolic state and have a net loss in BCS due to the increased energy and protein demands during late gestation.

When dams are supplemented with CP during late gestation, gestation length may be decreased. Funston et al. (2010) observed a 4 d reduction in gestation length in cows that were supplemented with CP during the last third of gestation. Moreover, Stalker et al. (2006) noted that CP supplemented cows had calves that were born 3 d earlier than their unsupplemented counterparts. Non-supplemented and grazing winter range cows calved 5 d later than those cows that were supplemented with CP and grazing corn residue during late gestation (Larson et al., 2009). Each of these studies suggests that increasing maternal CP intake during late gestation may reduce gestation length, and this could be due to an increase in fetal development during the supplementation period. Similarly, Swanson et al. (2008) observed a reduction in gestation length in ewe lambs supplemented at 140% of NRC (1985) total nutrient requirements during late gestation compared with those fed 100 and 60% of requirements. This is contrary to the results observed in year 1 of the current study, in which there was no difference in gestation length due to the MP intake of the dam during late gestation. Similar to our results, Amanlou et al. (2011) reported that gestation length was not altered by maternal MP supplementation in ewes during late gestation. Gestation length could not be measured accurately in year 2 due to the lack of breeding mark observations on a daily basis. These results suggest that supplementing MP at or above requirements increases maternal BW and BCS, without effecting gestation length.

Similar to our results, Anthony et al. (1986) did not observe any effects on calf birth weight when dams were either fed low (81%) or high (141%) protein diets during late gestation (89 days prior to parturition). Similarly, calf birth weight was not affected when cows were supplemented with CP during the last 78 d of gestation compared with calves born to cows

Table 2.5. Effects of maternal metabolizable protein supplementation during the last 50 d of gestation on lamb performance and 3-h milk production for year 1

	Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP1	80MP1	100MP1	SEM[2]	*P* – value[3]	Linear	Quadratic
Birth weight, kg	4.54	4.50	4.74	0.11	0.30	0.22	0.33
3-h milk production,[5] kg	0.13	0.13	0.16	0.04	0.86	0.67	0.78
Weaning BW, kg	17.55	19.51	19.12	0.66	0.07	0.08	0.14
Age at weaning, d	69	68	69	0.63	0.19	0.70	0.07
Percent BW change,[6] %	273.4	284.7	287.4	13.64	0.72	0.44	0.79
ADG,[7] kg/d	0.18	0.21	0.20	0.01	0.07	0.10	0.10
Ease at birth,[8] %	3.7	5.0	6.4	3.0	0.78	0.49	0.91
Morbidity at birth,[9] %	16.1	12.7	8.5	3.9	0.30	0.13	0.91

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of metabolizable protein requirements; and 100MP1: 100% of metabolizable protein requirements.

[2] Greatest SEM presented (n = 7).

[3] *P* -value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Three hour milk production was evaluated (Benson et al., 1999) using ewes that gave birth to singletons (60MP1: n = 15; 80MP1 and 100MP1: n = 16) at an average 23 ± 4 (SD) d of age. Lambs were removed from their ewes for three hours and allowed to suckle until satisfied. Once done suckling, lambs were removed from ewes for another three hours. Thereafter, lambs were weighed, allowed to suckle until satisfied, and then reweighed.

[6] Percent BW change from birth to weaning.

[7] ADG calculated: (weight at birth, kg – weight at weaning)/age at weaning.

[8] Ease of birth = percentage of assisted births within each treatment.

[9] Condition at birth = percentage of lambs requiring treatment for illness at birth.

or low levels of protein, there were no effects on calf birth weight (Bond and Wiltbank, 1970) suggesting that protein intake during late gestation does not alter birth weights. Minimizing the effects of nutrition on birth weight may reduce the chances of birthing problems, such as dystocia. Similarly, Blair et al. (2010) observed no differences in fetal BW at d 103 and 137 of pregnancy between ewes managed at maintenance or 1.5× maintenance of total nutrient intake under New Zealand pastoral grazing conditions from d 19 to 137 of pregnancy. Amanlou et al. (2011) also observed no effects of maternal MP supplementation on lamb birth weight. Contrary to the results in both years of the current study, Larson et al. (2009) observed a tendency for increased birth weights in calves from cows supplemented with CP during late gestation. Ocak et al. (2005) also observed an increase in lamb birth weight in ewes fed 140% of the CP requirement during late gestation. During the dry season in the U.S. Virgin Islands, ewes supplemented with commercial sheep pellet, containing increased CP and energy, while grazing low-quality forage during the last 14 d of gestation had increased lamb birth weight compared with those that were not supplemented with the sheep pellet (Godfrey and Dodson, 2003). Due to the lack of CP effects on birth weights from previous results (Bohnert et al., 2002; Larson et al., 2009; Amanlou et al., 2011), the improvement of birth weights in Godfrey and Dodson (2003) may have been due to the increased NE in the diet. Additionally, Meyer et al. (2010) observed a reduction in birth weight expressed per unit of initial ewe BW (d 38 of gestation) in lambs born to ewes restricted to 60% of NRC (1985) total nutrient requirements. When birth weight was expressed per unit final ewe BW (d 137 of gestation), the restricted lambs had increased BW compared with both 100% and 140% lambs (Meyer et al., 2010). Therefore, to maintain fetal growth, dam body reserves were mobilized, and the weight of the fetus was a greater proportion of ewe BW (Meyer et al., 2010). In the current study, both singleton and twin

Table 2.6. Effects of maternal metabolizable protein supplementation during the last 50 d of gestation on lamb performance from birth to weaning in year 2

	Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP2	100MP2	140MP2	SEM[2]	*P* – value[3]	Linear	Quadratic
Birth weight, kg	4.63	4.79	4.61	0.11	0.45	0.92	0.22
Weaning BW, kg	15.25	16.69	16.04	0.85	0.49	0.51	0.33
Age at weaning, d	61	62	64	3.78	0.81	0.53	0.91
Percent BW change,[5] %	247.5	293.2	253.7	28.52	0.49	0.88	0.25
ADG,[6] kg/d	0.18	0.20	0.18	0.01	0.25	0.78	0.11
Ease at birth,[7] %	1.2	2.9	4.1	2.3	0.53	0.26	0.92
Morbidity at birth,[8] %	6.8	13.3	12.3	5.5	0.55	0.43	0.47

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirements; and 140MP1: 140% of the metabolizable protein requirements.

[2] Greatest SEM presented (n = 4).

[3] *P* -value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Percent BW change from birth to weaning.

[6] ADG calculated: (weight at birth, kg – weight at weaning)/age at weaning.

[7] Ease of birth = percentage of assisted births within each treatment.

[8] Morbidity at birth = percentage of lambs requiring treatment for illness at birth.

bearing ewes were utilized and a birth type effect was observed. The birth type effect was expected as twins would encompass more of the ewe BW than a single lamb. Overall, our results suggest that birth weight may not be negatively impacted by maternal MP restriction.

The mammary system develops during gestation, with very little growth occurring during lactation (Anderson, 1975). Therefore, late gestation nutrition has the potential to impact mammary development and production. However, Larson et al. (2009) observed no effects of CP supplementation during late gestation on milk production, which was similar to our trial in year 1. Contrary to the results observed in the current study, Swanson et al. (2008) and Meyer et al. (2011) observed an increase in colostrum weight and volume in ewes fed at 100% of NRC (1985) total nutrient requirements compared with those ewes fed at 60 and 140% of requirements. During the first 20 d of lactation, ewes fed at 100% and 140% of NRC (1985) total nutrient requirements had increased milk weight and volume compared with ewes restricted at 60% of NRC (1985) requirements (Meyer et al., 2011). However, the differences noted in Meyer et al. (2011) compared with the current study may be attributed to the mechanical milking conducted by Meyer et al. (2011) compared with the current study of utilizing the lambs in a weigh-suckle-weigh and measuring the difference in weights, as well as the difference in diets. Similarly, Wang et al. (2007) observed a linear increase in milk production of dairy cows as MP in the diet was increased linearly from 8.2% to 10.3% MP (% of DM). Additionally, Amanlou et al. (2011) observed a tendency for increased colostrum yield with increased MP supplementation at 114 and 124% of requirements. The MP absorbed by the dam may have been shuttled to the mammary gland to enhance colostrum production. Ewes consuming increased MP during late gestation had increased protein, fat, and solids-not-fat (substances other than butterfat and water) in colostrum (Amanlou et al., 2011), which may have improved colostrum quality. Moreover, ewes supplemented with pelleted feed, which contained increased CP and energy, during the last 14 d of gestation and the first 21 d of lactation had increased milk production compared with ewes that were not supplemented and only grazed low-quality forage (Godfrey and Dodson, 2003) suggesting that providing increased CP and energy during lactation may play a large role in increasing the energy to the dam for increased milk production. In a study conducted by Bond and Wiltbank (1970), the milk production in the first lactation of heifers fed low energy or protein diets was reduced compared with those heifers fed medium and high energy or protein diets. When cows were supplemented immediately post-partum with either 100 or 150% of CP requirements and either high or low escape CP, there was no effect on milk yield (Rusche et al., 1993). Anderson (1975) determined that the greatest mammary gland growth and development occurs during pregnancy, with protein and dried fat-free tissue being reduced during the first 5 d of lactation compared with late pregnancy. This suggests that milk production may be influenced by maternal nutrition during gestation when the mammary system is developing than at the end of gestation. However, in these studies milk production was not evaluated based on the number of offspring produced per dam.

Average daily gain of lambs from birth to weaning has also been positively affected by maternal nutrition during late gestation. Improvement in ADG may be partly explained by an alteration in the milk components of dams fed increased MP during late gestation. Godfrey and Dodson (2003) observed an increase in birth to weaning ADG in lambs born to ewes supplemented with sheep pellet, to increase CP and NE, during the last 14 d of gestation and first 21 d of lactation in the dry season compared with their unsupplemented counterparts. As reported previously, these dams also had an increase in milk production. Similarly, calves born to cows supplemented with CP during late gestation had increased ADG from birth to weaning compared with those calves born to unsupplemented cows (Stalker et al., 2006). Average daily gain may have been improved by increased milk production in the dams, but milk production was not measured by Stalker et al. (2006). Increased milk production may not be the only factor influencing calf ADG; cows grazed improved meadow pasture or hay prior to breeding (Stalker et al., 2006), which may have altered calf ADG. However, Larson et al. (2009) did evaluate milk production, which was not altered by CP supplementation. Therefore, the increased ADG observed by Stalker et al. (2006) may have been due to improved grazing pastures or colostrum quality. However, similar to our results in year 2, ewe dietary treatment (60, 100, or 140 % of total nutrient requirements; NRC, 1985)) during late gestation did not affect lamb ADG from birth to weaning (Neville et al., 2010). The results of our trial suggest that ADG from birth to weaning may not be influenced by maternal MP intake during late gestation, especially when milk production is not affected. However, while our trials cannot be compared across years, the lower BCS of the ewes in year 1 may have resulted in decreased milk production compared with year 2; thereby causing a marginal increase in ADG for year 1 as MP increased in the ewe diets.

In year 1, weaning BW tended to increase as MP increased in the diet, but weaning BW was not altered by maternal MP intake in year 2. Similar to the results observed in year 2, calf weaning weights were not influenced by maternal total nutrient restriction during early gestation (Long et al., 2010). Additionally, Martin et al. (2007) observed similar weaning weights between calves from both CP supplemented and unsupplemented cows. Similar to the tendency observed in year 1, cows that were maintained on winter range and were not supplemented with CP had heifers with reduced adjusted weaning weights compared with those that were supplemented with CP or grazed corn residue (Funston et al., 2010). At d 100 of lactation, lambs born to ewes fed ad-libitum throughout gestation were heavier than the lambs born to ewes fed to maintenance throughout gestation (Kenyon et al., 2009). Godfrey and Dodson (2003) also observed an increase in weaning weight of lambs born to ewes during the dry season that were supplemented with sheep pellet that contained increased CP and energy for the last 14 d of gestation and first 21 d of lactation compared with those born to unsupplemented ewes. Calves born to cows that were supplemented with CP during late gestation were heavier at weaning than calves born to cows that were not supplemented (Stalker et al., 2006). However, Amanlou et al. (2011) observed no effects of maternal MP supplementation (114 and 124% of MP requirements) on lamb weaning BW. Although there was a tendency for weaning weights to be linearly increased as MP in the diet increased, this tendency was not observed in year 2. However, there was a numerical linear increase in the weaning weights as MP in the diet increased. The current results suggest that weaning weights may be reduced in lambs born to dams fed less than required MP, but feeding above MP requirements during late gestation may not improve weaning weights of lambs. This response likely is affected by initial ewe BCS, with ewes having a lower BCS likely being more positively impacted by increasing MP concentration in the diet.

Although, economic analysis was calculated for the current study, there have been a few studies that evaluated the economic profitability of supplementing CP during late gestation. Stalker et al. (2006) and Funston et al. (2010) observed that even with the added cost of the CP supplement during late gestation, the increased weaned calves of the CP supplemented dams were able to overcome the added costs of the supplement. However, in our study, we did not observe any differences in average weaning BW in either year. Therefore, we may have similar weaned lamb values across treatments, which may suggest that the difference in net returns would be due to the supplement cost.

Implications

These results suggest that dam performance can be positively impacted by supplementing MP at or above requirements by maintaining dam BW and BCS. However, milk production was not significantly altered by maternal MP intake during late gestation. Restricting MP during late gestation may not negatively impact lamb birth weights, but may reduce weaning weights especially when ewes are below a BCS of 3. However, supplementing above MP requirements during late gestation will likely improve weaning weights. The results of the current study suggest that supplementing MP during late gestation may be a key asset to be utilized to improve dam performance from late gestation to weaning, but may have marginal effects on lamb growth from lambing to weaning.

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CHAPTER 3. SUPPLEMENTING METABOLIZABLE PROTEIN TO EWES DURING LATE GESTATION: II. EFFECTS ON WETHER LAMB FEEDLOT PERFORMANCE, CARCASS CHARACTERISTICS, AND NITROGEN BALANCE

Abstract

The objective of the current study was to determine the effects of maternal MP restriction or supplementation during late gestation on male offspring feedlot performance, carcass characteristics, and nitrogen retention. Maternal dietary treatments were applied at d 100 of gestation and in year 1 were isocaloric and contained: **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation for a ewe bearing twins. In year 2, maternal dietary treatments were isocaloric and contained: **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements on a DM basis of a ewe bearing twins during the last 4 weeks gestation. In year 1, there was no effect ($P \geq 0.33$) of maternal dietary treatment on initial BW, final BW, ADG, G:F, or morbidity. There was a quadratic effect ($P = 0.04$) for days on feed, with the 80MP1 lambs being on feed longer than the 60MP1 and 100MP1 lambs. A quadratic effect ($P = 0.05$) was also observed for DMI, with the 80MP1 wethers consuming less feed than the 60MP1 and 100MP1 wethers. There was no effect ($P \geq 0.18$) of maternal MP intake during late gestation on the majority of carcass characteristics in year 1 or on the N balance parameters of on initial BW; DM, NDF, ADF, or N digestibility; daily fecal N excretion; or daily N balance. However, daily urinary N excretion per unit of initial BW was linearly reduced ($P = 0.02$) as MP intake increased and daily digested N retained increased linearly ($P = 0.04$) as maternal MP increased. There was a treatment × day interaction ($P = 0.004$) for serum urea N concentrations. The 60MP1 wethers had greater serum urea N concentrations on d 16, 18, 19, and 20 ($P \leq 0.04$) than 80MP1 and 100MP1 wethers; and on d 17 ($P \leq 0.05$) compared with 80MP1 wethers. In year 2, there was no effect ($P \geq 0.22$) of maternal dietary treatment on initial BW, final BW, ADG, G:F, or morbidity. There was a linear increase ($P = 0.04$) in DMI as maternal MP increased from 60 to 140% of MP requirements. Carcass characteristics ($P \geq 0.40$) and N balance parameters ($P \geq 0.46$) in year 2 were not affected by ewe MP intake during late gestation. These results suggest that maternal MP intake above or below requirements during late gestation may not affect wether feedlot performance or carcass characteristics.

Key words: carcass characteristics, feedlot, metabolizable protein, wethers

Introduction

During times of feeding low-quality forage, protein supplements are often fed to maintain livestock BW and BCS (Bohnert et al., 2002a, 2002b; Schauer et al., 2005). Crude protein supplementation not only allows dams to maintain BW and BCS, but appears to improve offspring performance as well (Stalker et al., 2006; Larson et al., 2009). Crude protein supplementation to the dam is just one method of improving livestock performance during gestation. The effect on offspring from a gestational stimulus is known as developmental programming, which has been known to effect fetal development and postnatal growth and health (Barker et al., 1995; Godfrey and Barker, 2000; Drake and Walker, 2004).

Commonly, CP supplementation (Larson et al., 2009) or total nutrient under- or overnutrition (Neville et al., 2010) has been the most common of the nutritional impacts applied during gestation. Metabolizable protein has been defined as the protein and amino acids that are digested and absorbed post-ruminally (Burroughs et al., 1975). Since MP is the protein directly available to the dam, it may be an indicator of how protein intake during gestation will ultimately affect male offspring performance in the feedlot. However, there has been minimal research conducted on the effects of MP intake during late gestation in sheep on offspring performance.

We hypothesized that offspring from ewes with reduced MP intake during the last third of gestation would have male offspring with reduced feedlot growth performance, carcass characteristics, and nitrogen retention. Moreover, wethers from ewes with increased MP intake would have improved feedlot performance, carcass characteristics, and nitrogen retention. Therefore, our objective was to evaluate the male offspring feedlot performance, carcass characteristics, and nitrogen balance from ewes fed varying levels of maternal MP intake in isocaloric diets during the last third of gestation.

Materials and Methods

All procedures were approved by the North Dakota State University Animal Care and Use Committee (#A0921).

Ewes

Year 1. Maternal nutrition study and design has been previously reported in Chapter 2. Briefly, on ~ d 50 of gestation, pregnant western whiteface ewes (n = 295) were moved to and maintained in a common group pasture at the Hettinger Research Extension Center. On ~ d 90 of gestation, ewes were moved to a total confinement barn and placed into 21 pens (20 pens of 14 ewes/pen; 1 pen of 15 ewes/pen) and acclimated to low-quality straw (Table 3.1) and the 100MP1 supplement (100% of the MP requirements (as determined by NRC, 2007; Table 3.2) for 7 d prior to starting dietary treatments. Ewes were reweighed on two consecutive days (d 99 and 100 of gestation) prior to the initiation of treatments. On d 99 of gestation, ewes were body condition scored on a scale of 1 to 5 (1 = emaciated, 5 = obese; Russell, 1984). Expected lambing date was determined by breeding marks obtained 3× weekly during the 34 d breeding season. On d 100 ± 8 (SD) of gestation, using the average of the start weights (d 99 and 100 of gestation), ewes were stratified by BW, BCS, age, and expected lambing date to one of three isocaloric dietary treatments (Table 3.2; n = 7): **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation for a ewe bearing twins. On d 100 ± 8 (SD) d, treatments were initiated. Supplementation was determined by the average body weight of the pen and offered once daily at 0800 h. Ewes were given one hour to consume the supplement before the fescue straw was offered. Body weights and BCS were collected every 14 days throughout the dietary treatment period, and a two day weight and BCS was obtained at and after lambing. Supplement intake was adjusted for changes in average pen body weight every 14 days. Trace mineral was supplemented once weekly to allow for 8.5 $g \cdot ewe^{-1} \cdot day^{-1}$ consumption. Trace mineral composition was 16% Ca, 8% P, 21% Salt, 2.75% Mg, 3 ppm Co, 5 ppm Cu, 100 ppm I, 1400 ppm Mn, 20 ppm Se, 3000 ppm Zn, 113,500 IU/kg vitamin A, 11,350 IU/kg vitamin D, and 227 IU/kg vitamin E. Upon lambing, ewe-lamb pairs were moved to grouping pens and were intermingled between dietary treatments where they were maintained on a lactation ration (Table 3.2) which was formulated to meet or exceed dam nutritional requirements until weaning.

Year 2. Thirty three days after ram introduction, 229 ewes were moved to and maintained in a common group pasture at the Hettinger Research Extension Center (Hettinger, ND). Pregnancy diagnosis was performed via ultrasonography (Aloka SSD-500V, B-Mode; Aloka America, Wallingford, CT) 75 days after ram introduction and ewes that were determined to be bred during the first 34 day of the breeding season were moved and maintained in a common group pasture (n = 169). On d 90 of gestation, pregnant ewes were moved to a total confinement barn, placed into 12 pens (14 ewes/pen), and acclimated to a low-quality straw

Table 3.1. Nutrient composition of fescue straw and lactation ration in years 1 and 2

	Fescue Straw[1]		
Item	Year 1	Year 2	Lactation Ration[2]
% in diet, % DM	64.51	56.51	100.00
DM, %	83.05	77.61	64.37
NEm, Mcal/kg	2.22	2.12	—
CP, % of DM	3.04	3.07	11.52
MP, % of DM	1.95	1.97	—
NDF, % of DM	79.85	81.13	48.05
ADF, % of DM	48.97	51.10	27.16
Ash, % of DM	9.49	7.78	8.59

[1] Ewes were fed fescue straw, in each year to limit metabolizable protein intake to the supplement.

[2] Ewes were fed a common ration during lactation across all dietary treatments; 28.5% oats, 28.5% haylage, 42.9% chopped hay.

(Table 3.1) and a supplement that met 100% of the MP requirements for a ewe carrying twins during the last third of gestation (Table 3.2). Ewes were reweighed on two consecutive days (d 99 and 100 of gestation) just prior to the initiation of treatments. On d 100 of gestation, using the average of the start weights, ewes were stratified by weight, age, body condition score, and expected lambing date to one of three isocaloric dietary treatments (Table 3.2; n = 4): **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements on a DM basis of a ewe bearing twins during the last 4 weeks gestation (NRC, 2007). Dietary treatment application and lambing was similar to year 1.

Lambs

In both years, lambs were weighed and tagged within 24 h of birth; sex, lambing assistance, and lamb vigor (0 = extremely active and vigorous; 4 = very weak and little movement; Matheson et al., 2011) were also recorded. Lambs were then moved with the ewes to

Table 3.2. Ingredient and nutrient composition of dietary supplements fed to ewes in year 1 and 2

	Year 1[1]			Year 2[2]		
Item	60MP1	80MP1	100MP1	60MP2	100MP2	140MP2
Ingredient, % DM						
Corn	18.50	15.00	5.00	30.00	19.00	—
DDGS[3]	7.00	20.00	30.00	4.00	24.00	43.00
Soyhulls	9.50	—	—	9.00	—	—
Trace mineral[4]	0.49	0.49	0.49	0.49	0.49	0.49
Nutrient composition						
DM, %	88.75	89.34	89.68	88.64	90.19	92.16
NEm, Mcal/kg	2.00	2.22	2.14	2.05	2.19	2.06
CP, % of DM	13.16	20.21	25.13	10.21	18.67	28.68
MP, % of DM	8.41	13.01	16.31	6.54	11.96	18.37
NDF, % of DM	31.03	30.73	39.79	29.64	31.40	45.34
ADF, % of DM	15.69	7.45	10.49	13.87	8.68	13.34
Ash, % of DM	3.22	3.48	4.55	3.53	3.80	5.13

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of the metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements.

[2] Maternal diets (DM basis) were balanced for mature ewes bearing twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirement; and 140MP2: 140% of the metabolizable protein requirements.

[3] Dried distillers grains with solubles.

[4] Trace mineral content: 16.0-17.0% Ca; 8.0% P; 21.0-23.0% Salt; 2.75% Mg; 3 ppm Co; 5 ppm Cu; 100 ppm I; 1,400 ppm Mn; 20 ppm Se; 3,000 ppm Zn; 113,500 IU/kg Vitamin A; 11,350 IU/kg Vitamin D; and 227 IU/kg Vitamin E.

grouping pens and had full-access to creep pellet (crude fat: 2%, crude fiber: 15%; Ca: 1.5%; P: 0.35%; salt: 1%; Se: 0.2 ppm; Vitamin A: 1134 IU/kg; Vitamin D: 114 IU/kg; and Vitamin E: 2.3 IU/kg) and water prior to weaning. At 14 days of age all lambs were vaccinated for tetanus and *Clostridium Perfringens* types C and D (CD-T; Bar Vac CD-T, Boehringer Ingelhein, Ridgefield, CT), tails were docked, and ram lambs were castrated. Lambs were weaned at 69 ± 5 (SD) days of age in year 1 and at 61 ± 12 (SD) days of age in year 2, and vaccinated again for tetanus and *Clostridium Perfringens* types C and D (CD-T; Bar Vac CD-T, Boehringer Ingelhein, Ridgefield, CT), and weighed. Once removed from ewes, lambs were moved to feedlot pens and were comingled across maternal dietary treatments. Lambs were fed a commercial market lamb pellet and corn post-weaning in a step-up ration: 100:0, 75:25, 50:50, 25:75, and 15:85.

Feedlot

In year 1, at 89 ± 5 (SD) days of age (n = 31 for 60MP1, n = 33 for 80MP1, and n = 24 for 100MP1), and in year 2, at 102 ± 11 (SD) days of age (n = 20 for 60MP2, n = 22 for 100MP2, and n = 20 for 140MP2), wether lambs were revaccinated for tetanus and *Clostridium Perfringens* types C and D and placed in the feedlot. In both years, wethers were allotted by maternal dietary treatment and blocked by weight (heavy and light) into one of two pens per maternal dietary treatment. One additional pen was allocated to the sub-sample of wethers utilized in the N balance trial. Wethers were fed approximately 85% whole, shelled corn and 15% commercial market lamb pellet diet (Table 3.3). The feedlot ration was balanced to meet or exceed CP and NE requirements of growing lambs (NRC, 2007). Wethers were fed a mixed diet ad libitum via bulk feeders. Samples of feed were collected every 14 days throughout the study in each year. Feed samples were dried in a forced-air oven at 55°C for 48 h. Samples were then composited across the trial in each year. Lambs had continuous access to fresh water and shade. Water troughs were cleaned at least once weekly and animal health was monitored daily. Lambs treated for respiratory and gastrointestinal issues were noted. Bulk feeders were cleaned and the feed refusals were weighed every 28 days to calculate DMI. In year 1, wethers were weighed on two consecutive days at the beginning (d 0, 1) and end (d 109, 110 and d 143, 144) of the feedlot phase, and on d 28, 56, 84, 110, and 144. In year 2, wethers were weighed on two consecutive

Table 3.3. Ingredient and nutrient composition of diets fed to feedlot wether lambs in years 1 and 2

Item	Year 1	Year 2
Ingredient		
Whole corn, %	84.4	84.7
Market lamb pellet, %[1]	15.6	15.3
Nutrient composition		
DM, %	89.06	89.54
CP, % of DM	13.12	13.50
NDF, % of DM	13.48	22.93
ADF, % of DM	3.42	4.23
Ash, % of DM	4.59	5.52

[1] Commercial Market Lamb Pellet contained: 0.22 g/kg Chlortetracycline; 38.0% CP; 3.75-4.75% Ca; 0.6% P; 3.0-4.0% salt; 1.2 ppm Se; 52,863 IU/kg Vitamin A; 5,286 IU/kg Vitamin D; and 209 IU/kg Vitamin E.

days at the beginning (d 0, 1) and end (d 137, 138) of the feedlot phase, and on d 28, 56, 84, 112, and 138. Therefore, in year 2, days on feed were similar for all wethers.

Carcass Characteristics

In year 1, all wethers weighing at least 69 kg were shipped for harvest to a commercial abattoir (Iowa Lamb Corporation, Hawarden, IA) on d 110 after entering the feedlot and all remaining wethers were shipped to the same commercial abattoir on d 144 of the trial. Additionally, a sub-set of 30 lambs (15 lambs/harvest date; 5 lambs/maternal dietary treatment/harvest date) were shipped to the NDSU Meat Lab for harvest, carcass data, and rib section collection. Hot carcass weight was collected immediately post-exsanguination. In year 2, wethers (n = 14 for 60MP2, n = 18 for 100MP2, and n = 17 for 140MP2) were shipped for harvest to a commercial abattoir (Superior Farms, Denver, CO) on d 138 of the trial. Wethers not shipped for harvest in year 2 were removed from the trial due to non-treatment related issues. In both years, carcass data was collected by trained university personnel at the commercial abattoir and NDSU Meat Lab following a 24 h chill. Carcass data collected included HCW, LM area, back fat thickness, body wall thickness, leg score, conformation score, flank streaking, and quality grade. Conformation score, leg score, and quality grade were scored on a 1 to 15 scale (1 = cull; 15 = high prime). Dressing percentage was calculated by (HCW/final feedlot BW) × 100. Yield grade was calculated by (back fat thickness × 10) + 0.4. Quality grade was calculated using wether lamb maturity, flank streaking, and conformation. Flank streaking was scored as: 100-199 = practically devoid; 200-299 = traces; 300-399 = slight; 400-499 = small; 500-599 = modest. Percentage of boneless, closely trimmed retail cuts (BCRTC) was calculated using the equation from Savell and Smith (2000).

Warner-Bratzler Shear Force

In year 1, Warner-Bratzler shear force (**WBSF**) was evaluated using three 1 inch thick *longissimus dorsi* (**ribeye**) from the 10th through 12th ribs on the left side of each wether harvested at NDSU Meat Lab. Each ribeye was trimmed of excess fat and vacuum packed and aged for 10 d at 4°C and were then frozen (-20°C) until WBSF analysis. Prior to analysis, frozen ribeyes were thawed at 4°C for 24 h. Ribeyes were then removed from the vacuum packages, placed on metal trays, and covered with plastic wrap to allow ribeyes to warm to room temperature. Grills (George Foreman Grill, GRP99) were placed in a fume hood and preheated to 176.7°C. Each ribeye was weighed and the temperature recorded prior to grilling. Ribeyes were then cooked to an internal temperature of 71°C and removed from the grill. The final temperature and the amount of time needed to reach the proper internal temperature were recorded. Ribeyes were placed on a metal tray to cool for 5 min and reweighed. Ribeyes were covered with plastic wrap and allowed to cool to room temperature. Once the ribeyes had cooled to room temperature, a total of 6 core samples (1.27 cm diameter) that ran parallel to the longitudinal orientation of the muscle fibers were taken from three rib sections. Each core was then analyzed by the Mecmesin Warner Bratzler Meat Shear: Basic Shear Gauge (BFG500N, G-R Manufacturing Co., Manhattan, KS). The Warner-Bratzler head moved at a crosshead speed of 200 mm/min. Each shear force was measured in kilograms, recorded, and averaged for each wether for statistical analysis.

Nitrogen Balance

A sub-sample of wethers was utilized in a N balance trial in both years. Fifteen wethers each year (year 1: 31.6 ± 1.4 kg; year 2: 29.0 ± 2.8 kg), 5 wethers/maternal dietary treatment, were placed into N balance crates within an enclosed building with a 13 h light and 11 h dark cycle. The trial was 21 d in length and consisted of an adaptation period on d 1 through 14 and a collection period on d 15 through 21. Nitrogen balance wethers were fed a similar whole ration to wethers remaining in the feedlot (85% whole, shelled corn, 15% commercial market lamb pellet; % DM basis; Table 3.4). The diet was provided daily at 0730 at 105% of the average intake for the previous 5 days. Feed refusals were collected and weighed from the previous day and determined before the 0730 feeding. An intramuscular injection of vitamins A, D, and E (100,000; 10,000; and 300 IU of vitamins A, D, and E, respectively; Vitamin E-AD; VetOne, Neogen Corp., Lexington, KY) was administered to each lamb on d 1. Wethers had continuous access to fresh water. On d 15 through 21, feed, orts, urine, and feces were collected and composited daily by lamb. Orts were weighed and collected on a 20% of total weight basis and composited daily by lamb. Total urine was collected into urinals containing 100 mL of 6 *N* HCl to maintain urine pH < 3 and weighed with 25% of the total being collected and stored at 4°C. Total feces was collected and weighed with 7.5% on a weight basis was collected and dried in a forced-air oven at 55°C for 96 h. Feed samples were collected daily from d 15 through 21 and composited. Feed and ort samples were dried in a forced-air oven at 55°C for 48 h. On d 15 to 21, 10 mL of blood was collected via jugular venipuncture 4 h after the 0730 feeding using Vacutainer tubes (VT6430; Franklin Lakes, NJ). Blood samples were cooled at 4°C for 4 h, centrifuged (3,640 × *g*; 20 min), and serum was harvested and stored (-20°C) for blood urea-N analysis. Upon completion of the N balance trials, wethers were placed back into their feedlot pen until harvest.

Table 3.4. Ingredients and nutrient composition of diets fed to nitrogen balance wether lambs in years 1 and 2

Item	Year 1	Year 2
Ingredient		
Whole corn, %	85	85
Market lamb pellet, %[1]	15	15
Nutrient composition		
DM, %	87.49	89.86
CP, % of DM	15.19	13.02
NDF, % of DM	15.54	19.63
ADF, % of DM	3.76	4.09
Ash, % of DM	4.86	4.92

[1] Commercial Market Lamb Pellet contained: 0.22 g/kg Chlortetracycline; 38.0% CP; 3.75-4.75% Ca; 0.6% P; 3.0-4.0% salt; 1.2 ppm Se; 52,863 IU/lb Vitamin A; 5,286 IU/kg Vitamin D; and 209 IU/kg Vitamin E.

Laboratory Analysis

Feces, orts, and diets were ground through a Wiley Mill (Arthur H. Thomas Co., Philadelphia, PA) to pass through a 1 mm screen. Feedlot diet, N balance diet, and feces samples were analyzed for DM, ash, and N (methods 934.01, 942.05, and 2001.11, respectively; AOAC, 2010). Concentrations of NDF (Ankom Technology, Fairport, NY.), and ADF (Ankom Technology, Fairport, NY) were determined using Ankom 200 Fiber Analyzer (Ankom Technology, Fairport, NY). Urine samples were analyzed for Kjeldahl N via method 2001.11

(AOAC, 2010). Serum urea N was analyzed using Sigma Diagnostic Urea Nitrogen procedure no. 640.

Statistical Analyses

Wether feedlot performance, carcass characteristics, and Warner-Bratzler shear force (year 1 only) parameters were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model included the main effects of maternal dietary treatment, birth type, and the interaction. Random effects included maternal pen nested within maternal dietary treatment. Individual wether was utilized as the experimental unit. The GLIMMIX procedure of SAS was used to test if maternal dietary treatment had an effect of the percentage of lambs treated for illness during the feedlot phase. If the interaction was found to be clearly not significant ($P > 0.30$), it was removed from the model. When a significant *F*-test was observed ($P \leq 0.15$), pre-planned comparisons of linear and quadratic contrasts were utilized to partition treatment effects. Significance was set at $P \leq 0.05$ and tendencies at $P \leq 0.10$.

Nitrogen balance data was analyzed using the MIXED procedure of SAS. The model included maternal dietary treatment and rep. When a significant *F*-test was observed ($P \leq 0.15$), pre-planned comparisons of linear and quadratic contrasts were utilized to partition treatment effects. Serum concentration of urea N was analyzed using the REPEATED statement with the MIXED procedure of SAS. The model included treatment, day, and treatment × day. The RANDOM statement included rep × treatment. In year 1, the ante-dependence (1) and in year 2, the variance components were used as the covariance structures.

Results and Discussion

Feedlot Performance

In year 1, there was no effect ($P \geq 0.33$; Table 3.5) of maternal dietary treatment on initial BW, final BW, ADG, G:F, or morbidity. There was a quadratic effect ($P = 0.04$) for days on feed, with the 80MP1 lambs being on feed longer than the 60MP1 and 100MP1 lambs. A quadratic effect ($P = 0.05$) was also observed for DMI, with the 80MP1 wethers consuming less feed than the 60MP1 and 100MP1 wethers. In year 2, there was no effect ($P \geq 0.22$; Table 3.6) of maternal dietary treatment on initial BW, final BW, ADG, G:F, or morbidity. There was a linear increase ($P = 0.04$) in DMI as maternal MP increased from 60 to 140% of MP requirements.

During the feedlot phase, there was no effect of maternal dietary treatment on wether BW entering and exiting the feedlot. Similar to our results, Neville et al. (2010) did not observe differences in offspring feedlot initial and final BW due to total maternal nutrient supply (60, 100, 140% of total nutrient requirements; NRC, 1985). However, in research by Larson et al. (2009), steers born to dams that were not supplemented with CP during late gestation and grazing winter range were lighter upon entering and exiting the feedlot than steers born to cows that grazed winter range and were supplemented with CP during late gestation. Similarly, Stalker et al. (2006) also observed an increase in calf BW when entering the finishing period for those born to cows supplemented with CP during late gestation and grazing sub-irrigated meadow. In cattle, protein supplementation and grazing improved pastures during late gestation enhanced offspring growth prior to entering the feedlot (Stalker et al., 2006; Larson et al., 2009). However, Stalker et al. (2006) and Larson et al. (2009) observed increases in weaning BW of calves born to CP supplemented cows, but in the current study, there were was only a tendency

Table 3.5. Effects of maternal metabolizable protein supplementation on feedlot performance of wethers in year 1

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP1	80MP1	100MP1	SEM[2]	*P* – value[3]	Linear	Quadratic
Initial BW, kg	29.2	28.2	29.8	2.08	0.85	0.82	0.60
Final BW, kg	69.8	68.4	66.5	1.59	0.33	0.14	0.89
Days on feed, d	127	133	123	3.8	0.10	0.38	0.04
ADG, kg/d	0.32	0.31	0.30	0.01	0.40	0.18	0.93
DMI, kg/lamb/d	1.50	1.44	1.49	0.02	0.13	0.84	0.05
G:F, kg gain:kg DMI	0.23	0.22	0.21	0.01	0.64	0.36	0.79
Morbidity,[5] %	6.4	20.5	20.2	9.1	0.33	0.22	0.43

[1] Maternal dietary treatment: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of the metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements.

[2] Greatest SEM presented (n = 31 for 60MP1, n = 33 for 80MP1, and n = 24 for 100MP1).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Percentage treated for illness during the feedlot phase.

Table 3.6. Effects of maternal metabolizable protein supplementation on feedlot performance of wethers in year 2

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[3]	
Item	60MP2	100MP2	140MP2	SEM[2]	*P* – value[3]	Linear	Quadratic
Initial BW, kg	25.3	28.3	29.5	2.08	0.36	0.18	0.71
Final BW, kg	59.7	62.7	63.2	2.21	0.48	0.27	0.65
ADG, kg/d	0.24	0.25	0.24	0.01	0.82	0.79	0.59
DMI, kg/lamb/d	1.02	1.05	1.12	0.03	0.09	0.04	0.66
G:F, kg gain:kg DMI	0.24	0.24	0.22	0.02	0.60	0.35	0.73
Morbidity,[4] %	13.6	31.8	9.1	10.0	0.12	0.69	0.04

[1] Maternal dietary treatment: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirements; and 140MP2: 140% of the metabolizable protein requirements.

[2] Greatest SEM presented (n = 20 for 60MP2, n = 22 for 100MP2, and n = 20 for 140MP2).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Percentage treated for illness during the feedlot phase.

in year 1 for increased weaning BW and there were no differences in weaning BW in year 2 (Chapter 2). Therefore, the differences between the current study and previous research may be due to the increased CP provided (Larson et al., 2009; Stalker et al., 2006) or simply species variation.

Although increasing MP intake during late gestation did not alter wether lamb BW entering and exiting the feedlot, performance during the feedlot phase may have been impacted by maternal MP intake. However, performance during the feedlot phase in the current study was not affected by maternal MP intake. Previously, Larson et al. (2009) observed no differences in steer ADG, DMI, or G:F due to maternal dietary CP supplementation. Additionally, Stalker et al. (2006) reported no differences in calf ADG, DMI, or G:F during the finishing phase due to maternal CP supplementation, suggesting that CP supplementation during late gestation may not positively enhance offspring performance during the feedlot phase. Similarly, when ewes were fed at 50% of AFRC (1993) total nutrient requirements during mid-gestation, there was no effect on lamb G:F, intake, or ADG (Daniel et al., 2007). Additionally, Neville et al. (2010) observed no effects of maternal under- or overnutrition during gestation on wether lamb DMI, ADG, G:F, initial BW, or final BW. These previous studies have indicated that DMI was not altered by maternal nutrition, but this was not the case in our trials. Dry matter intake was altered in both years, with a quadratic response in year 1 and a linear response in year 2. However, the cause of the effects on DMI is not readily apparent, as there were no differences in feed efficiency or final BW. These results would suggest that global nutrient intake and/or protein intake during late gestation may not alter offspring performance in the feedlot. Our results suggest that maternal MP intake during late gestation does not alter wether offspring growth and performance within the feedlot.

Contrary to the current results, Underwood et al. (2010) observed that steers born to cows grazing improved pasture (11.1% CP) from d 120 to 180 of gestation had increased gain, ADG, and live weight at slaughter during the finishing period compared with steers from cows grazing native range (6.5% CP). As the maternal nutritional treatments occurred during mid-gestation, the gastrointestinal tract may have been altered, which resulted in the improved efficiency of those steers, which led to increased ADG and live weights. However, as feed efficiency or intestinal integrity were not measured, it is unknown if these factors led to the improved ADG or live weights. Offspring from growth restricted pregnancies may also have a negatively impacted immune system. In a study conducted by Larson et al. (2009), there was an increase in the percentage of steers treated from weaning to slaughter for respiratory and gastrointestinal disease in those born to cows that were not supplemented with CP during late gestation. These data suggest that offspring from nutritionally restricted pregnancies may have a compromised immune system. However, our results suggest that restricted MP intake during late gestation may not negatively impact wether offspring immune system evidenced by our lack of response in feedlot morbidity. Overall, the current results suggest that feedlot performance in sheep may not be altered by maternal MP intake during late gestation.

Carcass Characteristics

There was no effect ($P \geq 0.27$; Table 3.7) of maternal MP intake during late gestation on HCW, dressing percentage, LM area, back fat thickness, body wall thickness, leg score, conformation score, quality grade, yield grade, BCTRC, or WBSF in year 1. In year 1, there was a linear tendency ($P = 0.06$) for flank streaking to increase in wethers as MP increased in the late gestation ewe diet. Similarly, carcass characteristics in year 2 were not affected ($P \geq 0.40$; Table 3.8) by ewe MP intake during late gestation.

Table 3.7. Effects of maternal metabolizable protein supplementation on carcass characteristics of wethers in year 1

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP1	80MP1	100MP1	SEM[2]	*P*-value[3]	Linear	Quadratic
HCW, kg	36.1	35.0	34.3	0.91	0.33	0.14	0.88
Dressing Percentage, %	51.8	51.2	51.4	0.44	0.53	0.53	0.38
LM area, cm^2	17.7	17.7	17.6	0.49	0.95	0.76	0.94
Back fat thickness, cm	0.7	0.8	0.7	0.06	0.27	0.43	0.14
Body wall thickness, cm	2.8	2.7	2.7	0.10	0.72	0.42	0.92
Leg score[5]	12	12	12	0.2	0.84	0.61	0.74
Conformation score[5]	12	12	12	0.2	0.64	0.98	0.35
Flank streaking[6]	362	365	395	13.5	0.13	0.06	0.36
Quality grade[5]	12	12	12	0.1	0.38	0.17	0.98
Yield grade[7]	3.3	3.5	3.2	0.3	0.54	0.85	0.27
BCTRC,[8] %	44.79	44.94	48.56	2.01	0.34	0.19	0.48
WBSF,[9] kg	3.28	2.72	2.81	0.31	0.40	0.30	0.40

[1] Maternal dietary treatment: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of the metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements.

[2] Greatest SEM presented (n = 31 for 60MP1, n = 33 for 80MP1, and n = 24 for 100MP1).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Leg score, conformation score, and quality grade: 1 = cull to 15 = high prime.

[6] Flank streaking: 100-199 = practically devoid; 200-299 = traces; 300-399 = slight; 400-499 = small; 500-599 = modest.

[7] Yield grade = (back fat thickness × 10) + 0.4.

[8] Percent boneless, closely trimmed, retail cuts (% BCTRC) = [49.936 – (0.0848 × 2.204 × Hot Carcass Weight, kg) – (4.376 × 0.393 × 12th rib fat thickness, cm) – (3.53 × 0.393 × body wall thickness, cm) + (2.456 × 0.155 × LM area, cm^2)].

[9] Warner Bratzler shear force.

Similar to the current results, Larson et al. (2009) did not observe any differences in 12th rib fat depth, LM area, or yield grade in steer offspring due to maternal CP supplementation during late gestation. Similarly, Stalker et al. (2006) also did not observe any differences in HCW, marbling score, dressing percent, 12th rib fat thickness, LM area, percentage of calves grading choice, or yield grade due to maternal CP supplementation during late gestation on steer offspring. Protein supplementation during late gestation may not be utilized by the dam to program fetuses to have improved carcass characteristics and quality. When there was a global restriction of nutrients, dams restricted to 55% of NRC (1996) total nutrient requirements or fed at 100% of requirements, there was no effect on steer carcass characteristics (Long et al., 2010). Additionally, Daniel et al. (2007) observed no effects of maternal dietary restriction from d 30 to 85 of gestation on slaughter weight of lambs. However, similar to year 1, Larson et al. (2009) observed increased marbling scores steers born to cows that were supplemented with CP during late gestation. Also, a greater proportion of steers born to cows that were supplemented with CP achieved quality grades of choice or greater (Larson et al., 2009), suggesting that CP supplementation during late gestation may program fetuses to have greater intramuscular adipose deposition, which could lead to increased carcass quality. However, Muñoz et al. (2009) did not observe any effects of maternal ME restricted to 60% of requirements and supplemented at 200% of requirements during early and mid-pregnancy on dressing percentage or LM area, but reported fat depth measured at 50 mm over the LM was increased in wether offspring from ewes restricted to 60% of ME requirements during early gestation compared with wethers from ewes fed 100 or 200% of ME requirements. Additionally, wether lambs born to ewes restricted to 50% of NRC (1985) total nutrient requirements from d 28 to 78 of gestation had increased kidney-pelvic fat and tended to have increased HCW compared with wethers born to ewes fed at

Table 3.8. Effects of maternal metabolizable protein supplementation on carcass characteristics of wethers in year 2

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP2	100MP2	140MP2	SEM[2]	*P* – value[3]	Linear	Quadratic
HCW, kg	32.6	32.3	32.3	1.29	0.99	0.89	0.92
Dressing percentage, %	49.9	49.4	49.3	0.46	0.62	0.38	0.65
LM area, cm^2	16.5	16.4	16.7	0.60	0.94	0.83	0.81
Back fat thickness, cm	0.7	0.7	0.6	0.06	0.56	0.30	0.96
Body wall thickness, cm	2.7	2.3	2.5	0.16	0.40	0.41	0.29
Leg score[5]	12	12	12	0.3	0.55	0.54	0.39
Conformation score[5]	12	12	12	0.3	0.86	0.59	0.93
Flank streaking[6]	396	409	398	18.2	0.83	0.96	0.54
Quality grade[5]	12	12	12	0.3	0.78	0.97	0.48
Yield grade[7]	3.2	3.0	2.9	0.25	0.56	0.30	0.96
BCTRC,[8] %	45.16	45.69	45.69	0.38	0.50	0.30	0.53

[1] Maternal dietary treatment: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirements; and 140MP2: 140% of the metabolizable protein requirements.

[2] Greatest SEM presented (n = 14 for 60MP2, n = 18 for 100MP2, and n = 17 for 140MP2).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Leg score, conformation score, and quality grade: 1 = cull to 15 = high prime.

[6] Flank streaking: 100-199 = practically devoid; 200-299 = traces; 300-399 = slight; 400-499 = small; 500-599 = modest.

[7] Yield grade = (back fat thickness × 10) + 0.4.

[8] Percent boneless, closely trimmed, retail cuts (% BCTRC) = [49.936 – (0.0848 × 2.204 × Hot Carcass Weight, kg) – (4.376 × 0.393 × 12th rib fat thickness, cm) – (3.53 × 0.393 × body wall thickness, cm) + (2.456 × 0.155 × LM area, cm^2)].

100% of requirements (Ford et al., 2007). Therefore, total nutrient supply and energy intake during gestation may alter fat deposition in male offspring. Cows grazing improved pasture gave birth to steers that had increased 12th rib fat thickness and HCW after the finishing phase compared with steers from cows grazing native range (Underwood et al., 2010). Moreover, Underwood et al. (2010) also observed an increase shear force and a reduction in ether extract of LM in steers from cows that grazed native range compared with those from cows that grazed improved pasture. Cows grazing native range had steers that had increased number of adipocytes compared with steers from cows grazing improved pastures (Underwood et al., 2010). The current results suggest that maternal MP intake in isocaloric diets may have little impact on carcass characteristics of wether offspring. Total caloric intake during gestation may have a greater impact on offspring adipose deposition.

The lack of differences observed in male offspring from dams provided under- or overnutrition during pregnancy may be due to the lack of muscle fiber development during late gestation. This would suggest there may be differences between species in muscle hyperplasia and result in differences in the effects of maternal nutrition on carcass measurements. Fetal skeletal muscle development occurs during early and mid-gestation in sheep and cattle (Yan et al., 2012). Similarly, Du et al. (2010) determined that by late gestation there were no alterations to the number of muscle fibers in cattle and sheep due to maternal nutrient restriction because the skeletal muscle had matured. When cows were restricted to 55% of NRC (1996) total nutrient requirements during early gestation, steer offspring muscle fiber area was increased compared with steers born to cows fed at 100% of requirements (Long et al., 2010). Fahey et al. (2005a) determined that in sheep, muscle cell proliferation occurs prior to d 85 of gestation and muscle cell differentiation occurs around d 85. Fahey et al. (2005b) also determined that restricting the ewe to 50% of AFRC (1993) total nutrient requirements from d 30 to d 70 of gestation negatively impacted muscle fiber formation of the offspring, but restriction after the onset of fiber formation (d 55 to 95 of gestation) and after fiber formation is completed (d 85 to 115 of gestation) had little effect on muscle fiber formation. These results suggest that to cause negative impacts on muscle fiber formation, ultimately affecting lean carcass measurements, such as LM area, maternal undernutrition must be present earlier in pregnancy. These studies indicate differences in lean carcass measurements, not fat accumulation, which is used to calculate yield grade or in the measurement of body wall thickness. Therefore, the results of Fahey et al. (2005a, b) suggest that maternal nutrition needs to be administered prior to late gestation to alter offspring muscle development and subsequent lean carcass measurements.

Over the past decades, many amendments have been made by the USDA to lamb and mutton carcass grading in efforts to aid sheep producers in meeting consumer preferences (Jones, 2005). Therefore, with the continued efforts to meet consumer demand, the consistency of carcass grading in lambs can vary widely between plants. Assessing quality grade in lamb carcasses is determined by maturity, flank streaking, and conformation score. Therefore, due to the lack of differences in maturity, flank streaking, and conformation score, it would be expected that quality grade was unaffected by maternal MP intake during late gestation. Yield grade is solely calculated from back fat thickness (back fat thickness × 10 + 0.4), and due to similar back fat thicknesses between maternal dietary treatment, yield grade would not be affected. Leg score, conformation score, and flank streaking are all subjective scores that assess fat or muscling. The conformation score is affected by leg score and due to the lack of differences in the leg score, conformation score was also not altered by maternal MP intake during late gestation. Carcass measurements were taken by trained university personnel and were the same personnel across years; therefore, this minimized variation and increased consistency between years and carcass measurements.

Nitrogen Balance

In year 1, there was no effect ($P \geq 0.18$; Table 3.9) of maternal MP supplementation on initial BW; DM, NDF, ADF, or N digestibility; daily fecal N excretion; or daily N balance. Daily daily DMI, daily NDF intake, ADF intake, and daily N intake tended to decrease linearly as maternal MP increased in the diet. Daily urinary N excretion per unit of initial BW was linearly reduced ($P = 0.02$) as MP intake during late gestation increased. Daily digested N retained increased linearly ($P = 0.04$) as maternal MP increased. There was a treatment × day interaction ($P = 0.004$; Figure 3.1) for serum urea N concentrations. The 60MP1 wethers had greater serum urea N concentrations on d 16, 18, 19, and 20 ($P \leq 0.04$) than 80MP1 and 100MP1 wethers; and on d 17 ($P \leq 0.05$) compared with 80MP1 wethers. In year 2, there was no effect ($P \geq 0.46$; Table 3.10) of maternal dietary treatment on N balance parameters of wethers. There was no treatment × day ($P = 0.34$; Figure 3.2) interaction for serum urea N concentrations. However, there was a day effect ($P = 0.02$; data not shown). Serum urea N concentrations were greater ($P \leq 0.04$) on d 15 than d 18, 20, and 21; and on d 17 ($P \leq 0.04$) than d 20 and 21.

There has been limited research conducted on the effects of maternal nutrition on wether lamb N balance and nutrient digestibility. Neville et al. (2010) did not observe any differences in N balance parameters in wethers due to maternal dietary nutrition provided at 60, 100, or 140% of NRC (1985) requirements during gestation. To our knowledge, this is the only study published determining the effects of maternal nutrition during gestation on wether lamb digestibility and N retention. We hypothesized that wethers from MP restricted dams would be less efficient in N utilization and digestibility, resulting in reduced N retention. The results in

Table 3.9. Effects of maternal metabolizable protein supplementation on nitrogen balance of wethers in year 1

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP1	80MP1	100MP1	SEM[2]	*P* – value[3]	Linear	Quadratic
Initial BW, kg	31.5	32.3	31.8	0.78	0.77	0.80	0.52
Daily DMI, g/kg BW	40.19	35.86	35.94	1.55	0.14	0.09	0.28
Daily NDF intake, g/kg BW	6.19	5.51	5.53	0.23	0.12	0.08	0.25
Daily ADF intake, g/kg BW	1.50	1.30	1.33	0.06	0.09	0.07	0.15
Daily N intake, g/kg BW	0.97	0.83	0.85	0.04	0.08	0.07	0.13
Total tract digestibility, %							
DM	98.38	97.98	98.31	0.17	0.25	0.79	0.11
NDF	73.55	65.19	70.36	3.77	0.34	0.57	0.18
ADF	63.14	59.41	63.92	2.96	0.54	0.86	0.29
N	80.02	73.86	78.44	2.21	0.18	0.63	0.08
Daily N excretion, g/kg BW							
Fecal	0.19	0.21	0.18	0.01	0.35	0.56	0.19
Urinary	0.54	0.30	0.30	0.06	0.03	0.02	0.14
Daily N balance, g/kg BW	0.24	0.32	0.37	0.06	0.34	0.15	0.90
Daily digested N retained,[5] %	31.10	50.92	56.30	7.06	0.08	0.04	0.43
Serum urea N, m*M*	10.14	7.74	8.34	0.62	0.06	0.07	0.08

[1] Maternal dietary treatment: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of the metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements.

[2] Greatest SEM presented (n = 5).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Calculated as (Daily N retention, g/kg BW/Daily N digested, g/kg BW) × 100.

Table 3.10. Effects of maternal metabolizable protein supplementation on nitrogen balance of wethers in year 2

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP2	100MP2	140MP2	SEM[2]	*P* – value[3]	Linear	Quadratic
Initial BW, kg	29.9	27.9	29.3	1.49	0.63	0.75	0.38
Daily DMI, g/kg BW	36.83	37.59	37.92	1.41	0.86	0.60	0.90
Daily NDF intake, g/kg BW	7.41	7.67	7.71	0.26	0.70	0.45	0.73
Daily ADF intake, g/kg BW	1.45	1.51	1.54	0.06	0.51	0.27	0.77
Daily N intake, g/kg BW	0.71	0.76	0.77	0.03	0.46	0.24	0.76
Total tract digestibility, %							
DM	98.00	98.11	98.19	0.14	0.64	0.36	0.93
NDF	73.94	75.76	77.05	2.95	0.76	0.48	0.94
ADF	73.53	74.91	77.11	2.82	0.68	0.40	0.91
N	56.50	57.13	60.73	4.35	0.77	0.51	0.79
Daily N excretion, g/kg BW							
Fecal	0.18	0.19	0.18	0.02	0.81	0.70	0.62
Urinary	0.27	0.38	0.34	0.07	0.57	0.51	0.42
Daily N balance, g/kg BW	0.25	0.18	0.26	0.08	0.77	0.99	0.48
Daily digested N retained,[5] %	47.92	33.49	41.28	12.46	0.72	0.72	0.49
Serum urea N, m*M*	6.27	6.30	6.80	0.63	0.80	0.56	0.76

[1] Maternal dietary treatment: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirements; and 140MP2: 140% of the metabolizable protein requirements.

[2] Greatest SEM presented (n = 5).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Calculated as (Daily N retention, g/kg BW/Daily N digested, g/kg BW) × 100.

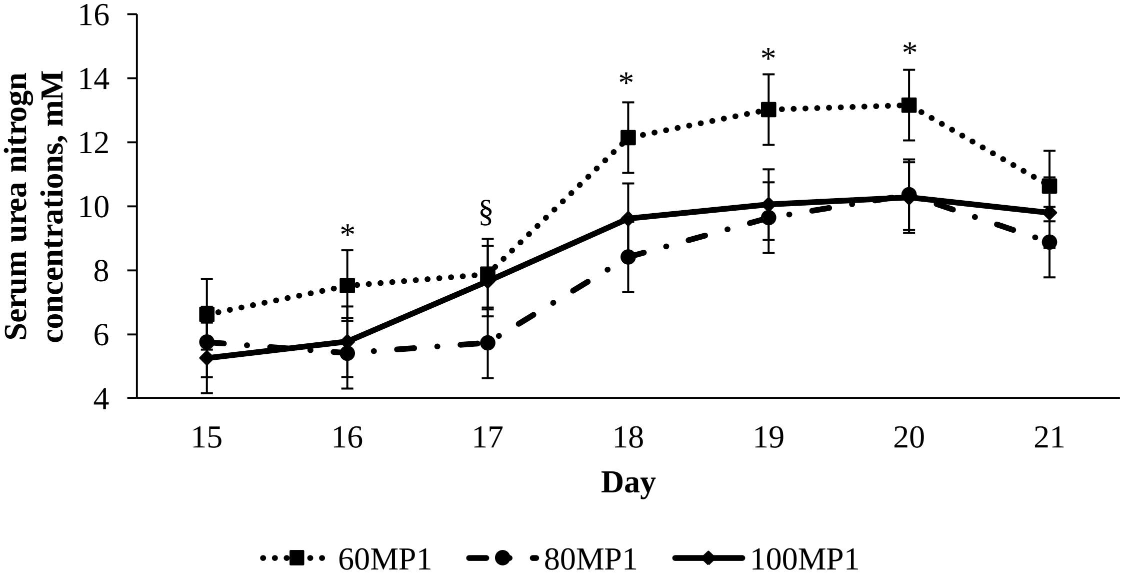

Figure 3.1. Effects of maternal metabolizable protein supplementation during late gestation on wether offspring serum urea nitrogen concentrations in year 1. Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of the metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements. Asterix (*) indicates greater ($P \leq 0.05$) concentrations in 60MP1 compared with both 80MP1 and 100MP1 on those days. The section (§) symbol indicates greater ($P = 0.05$) concentrations in 60MP1 than 80MP1. Treatment: $P = 0.06$; Day: $P < 0.001$; Treatment × day: $P = 0.004$.

year 1 agreed with our hypothesis, but the results in year 2 did not. One possible explanation for the differences observed in year 1 would be the effects of maternal MP restriction in utero. Trahair et al. (1997) observed a reduction in fetal gastrointestinal tracts and small intestinal weights from ewes restricted from 2 mo prior to breeding through mid-gestation compared with ewes fed adequately. Trahair et al. (1997) also observed a reduction in the apical endocytic complex in the proximal small intestine and shorter microvilli in fetuses from ewes that were restricted from 2 mo prior to breeding through d 90 of gestation compared with ewes fed adequately. Although restriction in the trial of Trahair et al. (1997) took place prior to d 100 of gestation, this may in part explain the reduction in N retention in 60MP1 wether lambs. Organ

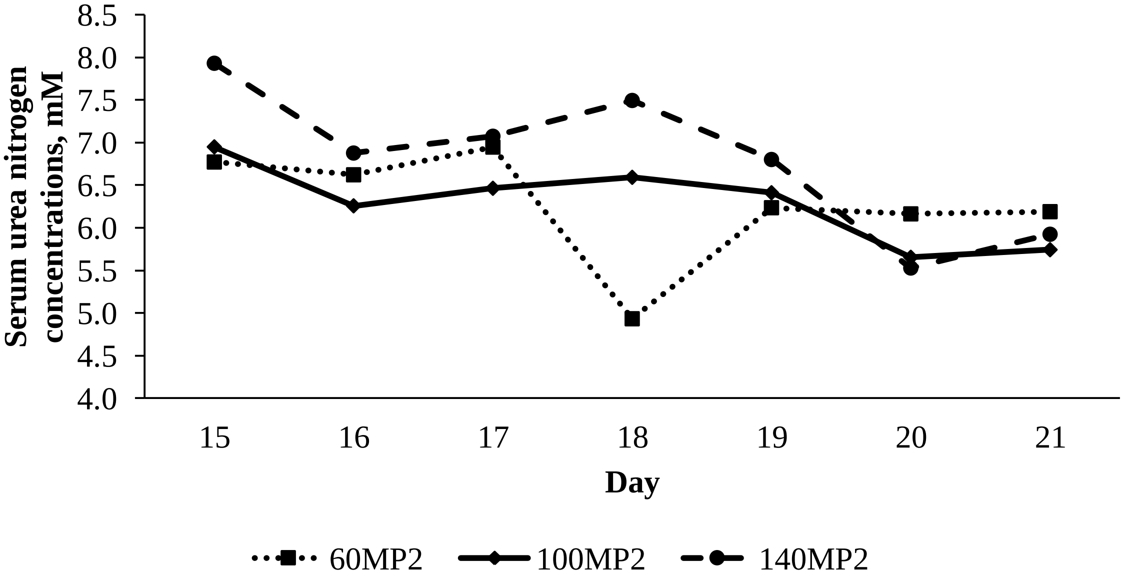

Figure 3.2. Effects of maternal metabolizable protein supplementation during late gestation on wether offspring serum urea nitrogen concentrations in year 2. Maternal dietary treatment: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirements; and 140MP2: 140% of the metabolizable protein requirements. Treatment: *P* = 0.80; Day: *P* = 0.02; Treatment × day: *P* = 0.34.

weights were collected from a subset of wethers (n = 30; 10 wethers/maternal treatment; data not shown), with no differences observed in small intestinal weights due to maternal dietary treatment. However, microvilli length and the apical endocytic complex were not measured; therefore, this may be a potential cause of the reduction in N retention in the 60MP1 wethers. Although there was a linear reduction in N retention in the wethers as MP intake decreased in the maternal diet, this did not negatively impact feedlot performance of wethers from 60MP1 and 80MP1 dams. The 60MP1 wethers were only in the feedlot on average 4 d longer than the 100MP1 wethers and had similar DMI with the 100MP1 wethers. However, the DMI results were not mimicked in the N balance trials in either year. In year 1, there were linear increases in DM, NDF, ADF, and N intakes in year 1 as MP was reduced in the maternal diet. The increased N intake, urinary N excretion, and serum urea N concentrations and reduction in N retention in the 60MP1 wethers suggests that these wethers had reduced N use efficiency compared with the 80MP1 and 100MP1 wethers. However, this reduced N retention did not negatively impact feedlot performance. Ewes in year 2 were fed a similar MP restrictive diet as in year 1, but the results in year 2 did not follow the same trend as in year 1. This response may be due to ewes in year 2 being in better condition (2.9 vs. 3.0, in years 1 and 2, respectively) upon beginning the dietary treatments at d 100 of gestation (Chapter 2). This may not be a large difference across years for BCS of ewes, but in year 1 there was a larger variation of BCS at onset of dietary treatments. Therefore, the MP restriction in year 2 may not have had a large impact on fetal growth due to the increase in availability of maternal reserves. There was a day effect for serum urea N concentrations in year 2, which may have been due to slight alterations in individual day DMI. However, to our knowledge this is the first study conducted on the effects of maternal MP intake during late gestation on wether offspring N balance, and a definitive conclusion on the effects of maternal MP intake cannot be reached.

Implications

To our knowledge this is the first study conducted on the effects of maternal MP intake during late gestation on male offspring performance post-weaning. Metabolizable protein intake in isocaloric diets during late gestation appears to have little influence on male offspring feedlot performance or carcass characteristics. A reduction in maternal MP intake during late gestation may reduce wether lamb N retention, but maternal MP supplementation above requirements will likely not enhance N retention of wether offspring. However, this reduction in N retention did not ultimately impact wether offspring feedlot performance. Therefore, more research needs to be conducted to determine the ultimate effects of MP supplementation throughout pregnancy on male offspring performance.

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CHAPTER 4. SUPPLEMENTING METABOLIZABLE PROTEIN TO EWES DURING LATE GESTATION: III. EFFECTS ON EWE LAMB PERFORMANCE AND REPRODUCTIVE EFFICIENCY

Abstract

The objective of the current study was to determine the effects of maternal MP intake in isocaloric diets during late gestation on female offspring growth from birth to breeding and measure reproductive performance of those offspring in the first breeding season. Maternal dietary treatments were applied at d 100 of gestation and in year 1 were isocaloric and contained: **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation for a ewe bearing twins. In year 2, maternal dietary treatments were isocaloric and contained: **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements on a DM basis of a ewe bearing twins during the last 4 weeks gestation. While there was a quadratic effect ($P = 0.003$) for ewe lamb birth weight, with the ewe lambs from 80MP1 ewes having increased birth weights compared with ewe lambs from 60MP1 and 100MP1 ewes in year 1, there was no effect ($P \geq 0.22$) of maternal diet on growth of ewe lamb offspring thereafter. A quadratic effect ($P = 0.02$) was observed for the percentage of ewe lambs being marked as bred during the first 17 days of breeding, with ewe lambs born to ewes fed 80MP1 being increased compared with ewe lambs born to ewes fed 60MP1 and 100MP1. Ewe lambs giving birth within the first 17 days of lambing season increased ($P = 0.001$) linearly as MP intake increased in the maternal diet. In year 2, there was no effect ($P \geq 0.17$) of maternal MP treatment during late gestation on growth of ewe lambs and reproductive performance except ADG from birth to weaning. There was a quadratic effect ($P = 0.01$) for ADG from birth to weaning of ewe lambs from ewes consuming 100MP2 being increased compared with ewe lambs from ewes fed 60MP2 and 140MP2. There was a linear (*P* = 0.04) reduction in birth weight of lambs born to ewe lambs as maternal dietary MP intake increased. The data from the current study suggests that feeding 100% of MP requirements during late gestation may have greatest positive impacts on female reproductive performance.

Key words: ewe lambs, late gestation, metabolizable protein

Introduction

As reviewed by Rhind et al. (2001) and Rhind (2004), maternal nutrition during gestation is crucial to maintaining offspring reproductive success. Although the review focuses on total nutrient intake during gestation, it suggests that maternal nutrition is crucial throughout pregnancy to maintain fetal reproductive organ development (reviewed in Rhind et al., 2001; Rhind, 2004). However, to our knowledge, the information available on the effects of specific nutrient restriction, i. e. CP, is limited. To our knowledge there has been no research conducted on the effects of maternal MP intake during late gestation on female offspring reproductive performance.

While CP supplementation during late gestation improved maternal BW and BCS (Larson et al., 2009; Stalker et al., 2006; Bohnert et al., 2002), little is known about how protein supplementation can impact female offspring growth and reproductive performance. Martin et al. (2007) observed increased adjusted weaning weight and prebreeding BW in heifers born to cows that were supplemented with CP during late gestation compared with those that were not. The improved growth may have led to increased pregnancy rates and percentage of heifers calving to the first 21 d breeding cycle in heifers born to cows supplemented with CP during late gestation (Martin et al., 2007). Therefore, maternal CP supplementation during late gestation may improve female offspring reproductive efficiency directly or indirectly by enhancing postnatal growth.

Based on the previous research conducted utilizing CP supplementation during late gestation, we hypothesized that feeding ewes MP at or above requirements would improve female offspring growth and reproductive performance. The objective of the current study was to determine the effects of maternal MP intake in isocaloric diets during late gestation on female offspring growth from birth to breeding and measure reproductive performance of those offspring in the first breeding season.

Materials and Methods

All procedures were approved by the North Dakota State University Animal Care and Use Committee (#A0921).

Ewes

Year 1. Maternal nutrition study and design has been previously reported in Chapter 2. Briefly, on ~ d 50 of gestation, pregnant ewes (n = 295) were moved to and maintained in a common group pasture at the Hettinger Research Extension Center (Hettinger, ND). Time of breeding was confirmed when pregnancy was determined via ultrasonography (B – Mode; Aloka SSD-500V, Aloka America, Wallingford, CT) 30 and 60 days after ram introduction. All ewes selected for the project were bred within the first 34 days of the breeding season. On ~ d 90 of gestation, ewes were moved to a total confinement barn and placed into 21 pens (n = 7; 14 ewes/pen) and acclimated to low-quality hay (Table 4.1) and the 100MP1 supplement (100% of the MP requirements; NRC, 2007; Table 4.2) for 7 d prior to starting dietary treatments. Ewes were weighed on two consecutive days (d 99 and 100 of gestation) prior to the initiation of treatments. On d 99 of gestation, ewes were body condition scored on a scale of 1 to 5 (1 =

Table 4.1. Nutrient composition of fescue straw and lactation ration in years 1 and 2

	Fescue Straw[1]		
Item	Year 1	Year 2	Lactation Ration[2]
Diet, % DM	64.51	56.51	100.00
DM, %	83.05	77.61	64.37
NEm, Mcal/kg	2.22	2.12	—
CP, % of DM	3.04	3.07	11.52
MP, % of DM	1.95	1.97	—
NDF, % of DM	79.85	81.13	48.05
ADF, % of DM	48.97	51.10	27.16
Ash, % of DM	9.49	7.78	8.59

[1] Ewes were fed fescue straw in each year to limit metabolizable protein intake.

[2] Ewes were fed a common ration during lactation across all dietary treatments; 28.5% oats, 28.5% haylage, 42.9% chopped hay.

emaciated, 5 = obese; Russell, 1984). Expected lambing date was determined by breeding marks obtained 3× weekly during the 34 d breeding season. On d 100 ± 8 (SD) of gestation, ewes were stratified by BW, age, BCS, and expected lambing date to one of three isocaloric dietary treatments (Table 4.2): **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation of a ewe carrying twins (NRC, 2007). On d 100 ± 8 (SD), treatments were initiated. Supplementation was determined by the average body weight of the pen and offered once daily at 0800 h. Ewes were given one hour to consume the supplement before the low-quality hay was offered. Body weights and BCS were collected every 14 days throughout the dietary treatment period, and a two day weight and BCS was obtained at and after lambing. Supplement intake was adjusted for changes in average pen body weight every 14 days. Trace mineral was supplemented once weekly to allow for 8.5 g·ewe^{-1}·day^{-1} consumption. Trace mineral

Table 4.2. Ingredients and nutrient composition of dietary supplements fed to ewes in year 1 and 2

	Year 1[1]			Year 2[2]		
Item	60MP1	80MP1	100MP1	60MP2	100MP2	140MP2
Ingredient, % DM						
Corn	18.50	15.00	5.00	30.00	19.00	—
DDGS[3]	7.00	20.00	30.00	4.00	24.00	43.00
Soyhulls	9.50	—	—	9.00	—	—
Trace mineral[4]	0.49	0.49	0.49	0.49	0.49	0.49
Nutrient composition						
DM, %	88.75	89.34	89.68	88.64	90.19	92.16
NEm, Mcal/kg		2.22	2.14	2.05	2.19	2.06
CP, % of DM	13.16	20.21	25.13	10.21	18.67	28.68
MP, % of DM	8.41	13.01	16.31	6.54	11.96	18.37
NDF, % of DM	31.03	30.73	39.79	29.64	31.40	45.34
ADF, % of DM	15.69	7.45	10.49	13.87	8.68	13.34
Ash, % of DM	3.22	3.48	4.55	3.53	3.80	5.13

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of the metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements.

[2] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of the metabolizable protein requirements; and 140MP2: 140% of the metabolizable protein requirements.

[3] Dried distillers grains with solubles

[4] Trace mineral content: 16.0-17.0% Ca; 8.0% P; 21.0-23.0% Salt; 2.75% Mg; 3 ppm Co; 5 ppm Cu; 100 ppm I; 1,400 ppm Mn; 20 ppm Se; 3,000 ppm Zn; 113,500 IU/kg Vitamin A; 11,350 IU/kg Vitamin D; and 227 IU/kg Vitamin E.

composition was 16% Ca, 8% P, 21% Salt, 2.75% Mg, 3 ppm Co, 5 ppm Cu, 100 ppm I, 1400 ppm Mn, 20 ppm Se, 3000 ppm Zn, 113,500 IU/kg vitamin A, 11,350 IU/kg vitamin D, and 227 IU/kg vitamin E. Upon lambing, ewe-lamb pairs were moved to grouping pens and were intermingled between dietary treatments where they were maintained on a lactation ration (Table 4.1) which was formulated to meet or exceed nutritional requirements until weaning.

Year 2. Thirty three days after ram introduction, 229 ewes were moved to, and maintained in a common group pasture at the Hettinger Research Extension Center (Hettinger, ND). Pregnancy diagnosis was performed via ultrasonography (Aloka SSD-500V, B-Mode; Aloka America, Wallingford, CT) 75 days after ram introduction and ewes that were determined to be bred during the first 34 day of the breeding season were moved and maintained in a common group pasture (n = 169). On d 90 of gestation, pregnant ewes were moved to a total confinement barn, placed into 12 pens (n = 4; 14 ewes/pen), and acclimated to a low-quality hay (Table 4.1) and a supplement that met 100% of the MP requirements for a ewe carrying twins during the last third of gestation (Table 4.2). Ewes were weighed on two consecutive days (d 99 and 100 of gestation) prior to the initiation of treatments. On d 100 of gestation, ewes were stratified by weight, age, body condition score, and expected lambing date to one of three isocaloric dietary treatments (Table 4.2): **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements on a DM basis of a ewe carrying twins during the last 4 weeks gestation (NRC, 2007). Dietary treatment application and lambing was similar to year 1.

Lambs

In both years, lambs were weighed and tagged within 24 h of birth. Sex, birth type, lambing assistance, and lamb vigor (0 = extremely active and vigorous; 4 = very weak and little movement; Matheson et al., 2011) were also recorded. Lambs were then moved with the ewes to grouping pens and had full-access to creep pellet and water prior to weaning. At 14 days of age all lambs were vaccinated for tetanus and *Clostridium Perfringens* types C and D (CD-T; Bar Vac CD-T, Boehringer Ingelhein, Ridgefield, CT), tails were docked, and ram lambs were castrated. From birth through weaning, lambs had ad libitum access to a lamb grower pellet (crude fat: 2%, crude fiber: 15%; Ca: 1.5%; P: 0.35%; salt: 1%; Se: 0.2 ppm; Vitamin A: 1134 IU/kg; Vitamin D: 114 IU/kg; and Vitamin E: 2.3 IU/kg). Lambs were weaned at 69 ± 5 (SD) day of age in year 1 and 63 ± 13 (SD) day of age in year 2, and vaccinated again for tetanus and *Clostridium Perfringens* types C and D (CD-T; Bar Vac CD-T, Boehringer Ingelhein, Ridgefield, CT), and weighed. Once removed from ewes, lambs were moved to feedlot pens and were comingled across maternal dietary treatments.

Ewe Lambs

In both years after weaning, all ewe lambs (**F1**) were separated from wether lambs and placed into a growing pen (year 1: n = 30 for 60MP1, n = 25 for 80MP1, and n = 36 for 100MP1; year 2: n = 31 for 60MP2, n = 18 for 100MP2, and n = 23 for 140MP2). In both years, F1 lambs were fed a mixed diet ad libitum via bulk feeders (Table 4.3).

In year 1, between 108 ± 10 (SD) and 236 ± 10 (SD) days of age, F1 growth performance was measured. Body weights were taken every 14 days throughout the 128 day period. Growth performance in year 2 was measured from 63 ± 13 (SD) day of age to 191 ± 20 (SD) days of age. Body weights were taken at the beginning (d 0) and at the end (d 128) of the 128 day period.

Table 4.3. Ingredients and nutrient composition of diets fed to ewe lambs in years 1 and 2.

Item	
Ingredient	
Oats, %	60.0
Whole, shelled corn, %	20.0
Market lamb pellet,[1] %	20.0
Nutrient composition	
DM, %	91.1
CP, % of DM	22.3
NDF, % of DM	23.8
ADF, % of DM	10.1
Ash, % of DM	10.5

[1] Commercial Market Lamb Pellet contained: 0.22 g/kg Chlortetracycline; 38.0% CP; 3.75-4.75% Ca; 0.6% P; 3.0-4.0% salt; 1.2 ppm Se; 52,863 IU/kg Vitamin A; 5,286 IU/kg Vitamin D; and 209 IU/kg Vitamin E.

In year 1, F1 breeding began at 259 ± 10 (SD) days of age. All ewe lambs were cycling prior to the onset of breeding (progesterone: 1.73 ± 0.33 ng/mL SD). F1 were stratified by maternal dietary treatment and body weight into 1 of 5 breeding groups (n = 18 / breeding group). F1 were synchronized utilizing controlled intravaginal drug release (CIDR; Eazi-Breed^{TM} CIDR$^{®}$, Pharmacia & Upjohn Pty Limited, Rydalmere, Australia) devices. Controlled intravaginal drug release devices were inserted on d -14. Day 0 is denoted by the day CIDRs were removed. Rambouillet rams (n = 2 / breeding group) were fitted with marking harnesses and were introduced to each breeding group at the first day of CIDR removal. Breeding marks were observed daily to determine the day of breeding. Breeding harness crayons were changed to a different color on d 18 and 35 days post-CIDR removal. On d 35 of the breeding season, F1 lambs were moved into one pen and comingled for the remaining 17 days. In year 2, F1 breeding began at 256 ± 9 (SD) days of age. F1 were maintained in a single flock during the 51 day breeding period. Day 0 is denoted as the day of ram introduction. Rambouillet rams (n = 10) were fitted with marking harnesses and were introduced to the flock. Breeding marks were observed on d 1, 17, 18, 34, 35, and 51. Breeding harness crayons were changed to a different color on d 18 and 35 days post-CIDR removal. Rams were removed from the pen 51 days after the rams were introduced. In both years, pregnancy was confirmed via ultrasonography (B – Mode; Aloka SSD-500V, Aloka America, Wallingford, CT) 45 days after the rams were removed.

After removal of the rams, F1 lambs were maintained in a single flock until lambing. Approximately 30 days prior to lambing, F1 lambs were moved to a total confinement barn and placed into 6 pens (15 F1 lambs / pen) in year 1 and 5 pens (14 F1 lambs / pen) in year 2.

During this 30 day period prior to lambing and after lambing, F1 lambs were fed lactation ration, which was similar to the ration provided to ewes after birth (Table 4.2).

Lambing

In both years, lambs of F1 dams (**F2**) were weighed and tagged within 24 h of birth; sex, birth type, lambing difficulty, and lamb vigor were also recorded. At 14 days of age all lambs were vaccinated for tetanus and *Clostridium Perfringens* types C and D (CD-T; Bar Vac CD-T, Boehringer Ingelhein, Ridgefield, CT), tails were docked, and ram lambs were castrated. From birth through weaning, lambs had ad libitum access to a lamb grower pellet (crude fat: 2%, crude fiber: 15%; Ca: 1.5%; P: 0.35%; salt: 1%; Se: 0.2 ppm; Vitamin A: 1134 IU/kg; Vitamin D: 114 IU/kg; and Vitamin E: 2.3 IU/kg).

Statistical Analyses

In both years, F1 growth and performance from birth to breeding and birth weights of F2 were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model included the main effects of maternal dietary treatment, birth type (singleton or twin), and the interaction. Animal served as the experimental unit. The GLIMMIX procedure of SAS was used to analyze the percentage of F1 breeding in the first 17 days of the breeding season, and the percentage of F1 lambing in each 17 day period of the breeding season. If the interaction was found to be clearly not significant ($P > 0.20$), it was removed from the model. When a significant F-test was observed ($P \leq 0.15$), pre-planned comparisons of linear and quadratic contrasts were utilized to partition treatment effects. Significance was set at $P \leq 0.05$ and tendencies at $P \leq 0.10$.

Results

Growth Performance

Weaning BW and ADG from birth to weaning, weaning to the end of the 128 d growth period, and birth to the end of the 128 d growth period were not altered ($P \geq 0.37$; Table 4.4) due to maternal MP dietary treatment in year 1. Initial BW at the beginning of the 128 day growth period was not different ($P = 0.29$) due to maternal dietary treatment. Both final BW and ADG in the growth period were also no affected ($P \geq 0.22$) by maternal MP treatment. In year 1, there was a quadratic effect ($P = 0.003$) for F1 birth weight, with the F1 from 80MP1 ewes having increased birth weights compared with F1 from 60MP1 and 100MP1 ewes. Regardless of maternal dietary treatment, singletons were heavier (5.3 ± 0.1 kg vs. 4.4 ± 0.1 kg; $P < 0.001$) at birth than twins.

In year 2, ADG during the 128 day growth period and from birth to the end of the 128 day growth period were not altered ($P \geq 0.17$; Table 4.5) by maternal MP treatment. In year 2, birth weights of F1 were not altered ($P = 0.62$) due to maternal dietary treatment during late gestation. However, there tended ($P = 0.09$) to be a quadratic effect on weaning weights, where F1 from 100MP2 ewes tended to be increased compared with F1 from 60MP2 and 140MP2 ewes. Singleton lambs at weaning were heavier (17.1 ± 0.6 vs. 14.6 ± 0.5; $P = 0.002$) at weaning than twin lambs regardless of maternal MP treatment. There was a quadratic effect ($P = 0.01$) for ADG from birth to weaning of F1 from ewes consuming 100% of MP requirements being increased compared with F1 from ewes fed 60 and 140% of MP requirements. Average daily gain from birth to weaning, during the growth period, and birth to the end of the growth period was greater ($P \leq 0.05$) in singletons than twins. There tended to be a quadratic effect ($P = 0.07$)

Table 4.4. Effects of maternal metabolizable protein supplementation on ewe lamb growth performance in year 1

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP1	80MP1	100MP1	SEM[2]	*P* – value[3]	Linear	Quadratic
Birth weight, kg	4.5	5.2	4.9	0.14	0.002	0.05	0.003
Weaning BW, kg	18.2	19.9	19.2	0.98	0.41	0.41	0.28
ADG, kg/d							
Birth to weaning	0.19	0.22	0.21	0.013	0.37	0.36	0.26
Weaning to final[5]	0.27	0.27	0.27	0.007	0.78	0.55	0.74
Birth to final[5]	0.25	0.26	0.25	0.006	0.43	0.86	0.20
Growth period[6]							
Initial BW, kg	31.1	33.5	30.5	1.50	0.29	0.22	0.13
Final BW, kg	63.3	66.6	63.1	1.67	0.22	0.16	0.08
ADG, kg/d	0.25	0.26	0.26	0.008	0.80	0.61	0.55

[1] Maternal dietary treatment: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of metabolizable protein requirements; and 100MP1: 100% of metabolizable protein requirements.

[2] Greatest SEM presented (n = 30 for 60MP1, n = 25 for 80MP1, and n = 36 for 100MP1).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Weaning to final indicates the ADG from weaning to the final BW measured on d 128 of the 128 day growth period. Birth to final indicates the ADG from birth to the final BW measured on d 128 of the 128 day growth period.

[6] Growth period that was 128 days in length to measure growth performance of the ewe lambs.

Table 4.5. Effects of maternal metabolizable protein supplementation on ewe lamb growth performance in year 2

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP2	100MP2	140MP2	SEM[2]	*P* – value[3]	Linear	Quadratic
Birth weight, kg	4.5	4.5	4.7	0.21	0.62	0.43	0.52
Weaning BW, kg	14.7	16.9	16.0	0.73	0.07	0.14	0.09
Final BW,[5] kg	59.5	63.1	57.2	2.16	0.14	0.37	0.07
ADG, kg/d							
Birth to weaning	0.18	0.20	0.17	0.01	0.03	0.25	0.01
Weaning to final[6]	0.23	0.25	0.23	0.01	0.48	0.79	0.23
Birth to final[6]	0.22	0.23	0.21	0.01	0.17	0.55	0.07

[1] Maternal dietary treatment: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of metabolizable protein requirements; and 140MP2: 140% of metabolizable protein requirements.

[2] Greatest SEM presented (n = 31 for 60MP2, n = 18 for 100MP2, and n = 23 for 140MP2).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Final BW observed at the end of the 128 day growth period beginning at weaning.

[6] Weaning to final indicates the ADG from weaning to the final BW measured on d 128 of the 128 day growth period. Birth to final indicates the ADG from birth to the final BW measured on d 128 of the 128 day growth period.

for final BW at the end of the growth period, where F1 from 100MP2 ewes weighed more on d 128 of the growth period compared with F1 from 60MP2 and 140MP2 ewes.

Reproductive Performance

The total percentage of F1 lambing was not different (*P* = 0.96; Table 4.6) due to maternal dietary treatment in year 1. There was no effect (*P* ≥ 0.24) of maternal MP treatment on F1 lambing in the third 17 days of the lambing period, lambing rate, or on birth weight of F2. However, a quadratic effect (*P* = 0.02) was observed for the percentage of F1 being marked for breeding during the first 17 day breeding cycle with F1 born to ewes fed 80MP1 being increased compared with F1 born to ewes fed 60MP1 and 100MP1. F1 lambing to the first 17 day breeding cycle was increased linearly (*P* = 0.001) as MP intake increased in the maternal diet during late gestation. The percentage of F1 lambing during the second 17 day breeding cycle decreased linearly (*P* = 0.02) as MP intake in the maternal diet increased during late gestation. Singleton lambs born to F1 were heavier (5.2 ± 0.1 vs. 4.3 ± 0.3; *P* < 0.001) at birth than twin lambs regardless of grand-dam dietary treatment. However, there was no effect (*P* = 0.29; data not shown) of maternal MP intake on the percentage of twins born to F1.

In year 2, there was no effect (*P* ≥ 0.76; Table 4.7) of maternal MP treatment on the total percentage of F1 lambing or the percentage of F1 lambing to the first, second 17 days of the lambing season, and lambing rate. There tended to be a quadratic effect (*P* = 0.09) for F1 from ewes fed 100MP2 having increased F1 breeding during the first 17 days of breeding compared with F1 from 60MP2 and 140MP2 ewes. F1 from 60MP2 and 100MP2 fed ewes gave birth to heavier (*P* = 0.05) lambs than F1 from 140MP2 fed ewes. Birth weights of F2 born to F1 were reduced linearly (*P* = 0.04) as grand-dam MP intake increased during late gestation. However, there was no difference (P = 0.63; data not shown) in the percentage of twins born to F1 due to maternal dietary treatment.

Discussion

As our results suggest, restricting MP intake to 60% of requirements to ewes during late gestation may negatively impact F1 offspring growth and reproductive performance, beginning with F1 birth weights. However, much of the current research in maternal CP supplementation does not distinguish between heifers and steer progeny birth weights. However, the research available indicates protein supplementation during the last third of gestation may not impact heifer calf birth weight (Funston et al., 2010). Therefore, solely supplementing CP during late gestation may not positively impact female offspring birth weights. However, the similar birth weights could be due to genetics to minimize the instances of dystocia. Increased birth weights were observed in ewes fed to have moderate growth rates (75 g/day) during the first 100 days of gestation compared with ewe lambs from ewes fed to have rapid growth rates (Da Silva et al., 2001). This may suggest that feeding to achieve rapid growth rates in ewes may negatively impact ewe lamb growth and development *in utero*. Therefore, ewes gaining at moderate growth rates from early to mid- gestation may be more beneficial to offspring birth weights due to the minimal fetal energy requirements during early and mid-gestation and the rapid growth rates may have increased the fat deposition on the dams and reduced early fetal development.

To our knowledge, there has been little research conducted evaluating the feeding of MP or CP during late gestation in ruminants on their effects of female offspring post-weaning. However, previous research has indicated that female offspring growth and development may be improved by maternal CP supplementation during late gestation. Martin et al. (2007) observed an increase in adjusted 205 d BW, prebreeding BW, and BW at pregnancy diagnosis in heifers

Table 4.6. Effects of maternal metabolizable protein supplementation on ewe lamb reproductive performance in year 1

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[3]	
Item	60MP1	80MP1	100MP1	SEM[2]	*P* – value[3]	Linear	Quadratic
Breeding in first 17 days,[5] %	50	84	67	9.3	0.03	0.15	0.02
Total lambing,[6] %	70	68	67	9.5	0.96	0.78	0.98
Lambing to first 17 days,[7] %	0	0	32	7.3	0.001	0.001	0.07
Lambing to second 17 days,[7] %	86	65	52	11.2	0.05	0.02	0.75
Lambing to third 17 days,[7] %	14	35	16	9.8	0.22	0.89	0.08
Lamb birth weight, kg	4.8	4.8	4.7	0.20	0.85	0.64	0.78

[1] Maternal dietary treatment: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of metabolizable protein requirements; and 100MP1: 100% of metabolizable protein requirements.

[2] Greatest SEM presented (n = 30 for 60MP1, n = 25 for 80MP1, and n = 36 for 100MP1).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Percentage of ewe lambs per treatment having breeding marks in the first 17 days of the breeding season.

[6] Total percentage of ewe lambs lambing per ewe lamb exposed per maternal dietary treatment.

[7] Percentage of ewe lambs lambing that were bred during the first 17 days post-ram turnout, the second 17 days post-ram turnout, or the third 17 days post-ram turnout.

born to cows that were supplemented with CP during late gestation. Although birth weight was no affected, heifer weaning weight was increased in those born to cows supplemented with CP during late gestation (Funston et al., 2010). In our experiment, variable results were observed. In year 1 improved growth was not observed, however, in year 2, weaning BW reacted quadratically; with 100MP2 tending to have F1 with increased weaning weights. The lack of differences in weaning weights in year 1 may have been due to the smaller spread of MP intake in our treatment groups compared with dietary treatments in year 2. The tendency for increased weaning weights was mainly due to the significant increase in ADG from birth to weaning compared with ewe lambs from ewes consuming 140% of MP requirements during late gestation. Similar to our results in year 2, heifers from cows supplemented with CP during late gestation tended to have increased BW upon evaluating feed efficiency, but these heifers did not experience increased growth during the feeding trial (Funston et al., 2010). However, Martin et al. (2007) did not observe any differences during a heifer growth trial due to maternal CP supplementation during late gestation. Similar to Martin et al. (2007), in both years, we observed no differences in growth rates or final BW in ewe lambs during the growth performance evaluation due to maternal MP treatment. Although weaning weights and ADG from birth to weaning were improved in ewe lambs by feeding 100% of MP requirements to dams, overall performance in the growth period was not positively enhanced. The results in year 2 may suggest that the increased MP provided to the dams during late gestation may have been excreted prior to being absorbed in the small intestine.

Similar to the results in year 2 in the current study, at 21 and 70 days of age, female rat pups from dams that were fed a 20% casein diet during gestation and either fed 20% or restricted to a 10% diet during lactation had increased BW compared with female offspring from dams

Table 4.7. Effects of maternal metabolizable protein supplementation on ewe lamb reproductive performance in year 2

	Maternal Dietary Treatment[1]					Orthogonal Contrasts[4]	
Item	60MP2	100MP2	140MP2	SEM[2]	*P* – value[3]	Linear	Quadratic
Breeding in first 17 days,[5] %	84	94	70	9.0	0.12	0.18	0.09
Total lambing,[6] %	19	28	26	10.2	0.76	0.57	0.65
Lambing to first 17 days,[7] %	86	88	83	15.4	0.98	0.91	0.86
Lambing to second 17 days,[7] %	14	13	17	15.4	0.98	0.91	0.86
Lamb birth weight, kg	4.7	4.7	3.6	0.39	0.05	0.04	0.14

[1] Maternal dietary treatment: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of metabolizable protein requirements; and 140MP2: 140% of metabolizable protein requirements.

[2] Greatest SEM presented (n = 31 for 60MP2, n = 18 for 100MP2, and n = 23 for 140MP2).

[3] *P*-value for the F test of the mean.

[4] *P*-value for linear and quadratic effects of increasing metabolizable protein concentrations.

[5] Percentage of ewe lambs per treatment having breeding marks in the first 17 days of the breeding season.

[6] Total percentage of ewe lambs lambing per ewe lamb exposed per maternal dietary treatment.

[7] Percentage of ewe lambs lambing that were bred during the first 17 days post-ram turnout and the second 17 days post-ram turnout.

restricted to 10% casein during gestation and either restricted to 10% or fed 20% casein during lactation (Guzmán et al., 2006). However, by 22 months of age, female offspring BW was no longer affected by maternal CP fed during gestation or lactation (Guzmán et al., 2006). This suggests that although female offspring BW may be negatively impacted by protein restriction in the dam during gestation, as the offspring age, the progeny may overcome that reduced BW to be similar to females from dams that were fed adequate protein.

Maternal nutrition during late gestation can also alter female offspring reproductive performance. Although not measured in the current studies, Funston et al. (2010) observed that heifers from cows supplemented with CP during late gestation tended to reach puberty at a younger age than those born to unsupplemented cows. Improved pubertal status could lead to improved reproduction performance during the breeding season, mainly through decreased time to first estrus and increase in conception rates during the first cycle. Female pups from dams that were CP restricted during both gestation and lactation and dams fed adequate protein during gestation and restricted during lactation were older at vaginal opening and at first estrus, as well as having lighter BW than female pups from dams fed adequate CP during gestation and lactation and dams restricted in protein during gestation and fed adequate protein during lactation (Guzmán et al., 2006). This suggests that postnatal nutrition may have a larger impact on female offspring reproductive performance than maternal nutrition during gestation. At 21 days of age, ovarian weights were increased in female pups from dams that were fed restricted CP during pregnancy and adequate CP during lactation compared with those from dams that were restricted during both gestation and lactation and those that were fed adequate protein during gestation and restricted during lactation (Guzmán et al., 2006). Ovarian weights at 70 days of age were increased in female pups from dams that were fed adequate protein during gestation and lactation and dams that were restricted in protein during gestation and fed adequate protein during lactation compared with female pups from dams that were restricted in protein during gestation and lactation (Guzmán et al., 2006). Suggesting that providing adequate protein during gestation and lactation is crucial to maintaining ovarian growth, which could potentially impact female offspring reproductive efficiency. Similar to female offspring BW, as the offspring age, differences in uterine and ovarian weights due to maternal protein restriction may also become negligible.

Alterations in puberty and reproductive organ weights may also impact female offspring breeding and conception rates. Heifers born to cows supplemented with CP during late gestation had increased pregnancy rates and percentage of heifers calving in the first 21 d compared with heifers born to cows that were not supplemented during late gestation (Martin et al., 2007). Similar to these results, F1 from ewes fed 80MP1 had increased percentage of lambs breeding in the first 17 days; however, this did not improve lambing during the first 17 days. The majority of F1 from 80MP1 lambed during the second 17 d post-ram turnout, indicating that although more F1 had breeding marks, pregnancy was not maintained in all of them. Although breeding was reduced in the F1 from 100MP1 ewes in the first 17 days post-ram turnout, providing 100% of MP requirements may have programmed female offspring to have increased percentage of F1 maintaining pregnancy to the first 17 d post-ram turnout. Moreover, Guzmán et al. (2006) observed an increase in estrus cycle length at 140 days of age in female pups from dams that were restricted in CP during gestation and fed adequate CP during lactation compared with female offspring from dams that were fed adequate or restricted CP during gestation and lactation as well as dams that were fed adequate CP during gestation and restricted CP during lactation. At 1 year of age, cycle length was increased in female pups that were from dams fed restricted protein during both gestation and lactation compared with those from dams fed adequate CP during gestation and restricted protein during lactation (Guzmán et al., 2006). Increased cycle lengths could lead to an overall reduction in reproductive efficiency in female offspring. This could reduce the number of litters per year and reduce potential income from those reduced numbers. Therefore, supplying adequate protein during gestation and lactation may lead to increased female offspring reproductive performance.

Moderate maternal growth rate improved female offspring birth weights and this could lead to enhanced reproductive status and onset of puberty earlier in life. However, Da Silva et al. (2001) did not observe any differences of maternal growth rate on age of first ovulation, first cycle duration, number of ewe lambs exhibiting cyclicity, number of ovulatory cycles in the first season, or the duration of the first breeding season. Although ewe lamb birth weights were increased, this did not lead to an improvement in reproductive status in the ewe lambs from ewes fed at moderate intakes. Increased maternal growth rates during the first 100 days of gestation also did not improve female offspring reproductive status (Da Silva et al., 2001). This may indicate that female offspring may not be programmed *in utero* by increased maternal growth rates to have improved performance compared with female offspring from adequately fed dams.

Improved reproductive potential of female offspring enhances herd/flock development. However, increased cycle lengths may also lead reductions in fertility rates. Guzmán et al. (2006) observed a reduction in fertility rate at 1 year of age in female offspring from dams CP restricted during gestation fed adequate protein during lactation and dams that were fed adequate protein during gestation and restricted during lactation. This reduction in fertility can lead to reduced number of litters per year and ultimately lead to a reduction in net returns from those offspring. Also at 1 year of age, litter size was drastically reduced compared with litter sizes at

150 days of age (Guzmán et al., 2006). These results suggest that supplying protein above requirements may negatively impact birth weight due to the excretion of the excess protein prior to absorption and utilization. Therefore, feeding adequate MP during late gestation may provide the greatest benefits on reproductive performance.

Much of the research available on female offspring performance reproduction has been conducted by restricting energy or total nutrients, and to our knowledge, there has been no research conducted utilizing MP intake during gestation. In a study conducted by Rae et al. (2001), reductions at d 50 of gestation in ovarian weights of female fetuses from dams fed at 100% of ME requirements from d 0 to 30 of gestation and restricted to 50% of ME requirements from d 31 to 50 of gestation were observed compared with female fetuses restricted t o50% of ME requirements from d 0 to 50 of gestation. These data suggest that restriction in ME after d 30 of gestation may result in reductions in fetal ovarian mass. Female offspring are under nutritional stress during breeding, as they have not reached their mature BW and are providing nutrients to the fetus for growth and development; therefore, providing increased ME during gestation may program female offspring to be more efficient in nutrient utilization during breeding. This could reduce overall female offspring reproductive performance throughout life. Maternal ME restriction to d 65 or 110 of gestation did not alter ovarian weights in female fetuses (Rae et al., 2001). Maternal ME restriction during early and/or mid-gestation led to reductions in ovarian type 2 follicles, type 3 follicles, and type 4 follicles compared with female offspring from dams fed 100% of ME requirements from d 0 to 110 of gestation (Rae et al., 2001). However, the total number of oocytes was not altered by maternal ME restriction during early and/or mid-gestation compared with fetuses from dams fed 100% of ME requirements from d 0 to 110 of gestation (Rae et al., 2001). The reduction in mature follicles in the ovaries could lead to reduced reproductive performance in those offspring throughout life. Metabolizable energy restriction during early and/or mid-gestation may negatively impact female offspring reproductive organ growth and development and ultimately retard reproductive performance throughout life. Although our diets were isocaloric, Rae et al. (2001) does indicate that female offspring reproductive performance can be altered by maternal nutrition during gestation. Therefore, more research needs to be conducted on the utilization of nutrition during gestation to alter female offspring reproductive efficiency.

Although CP is not the same as energy, CP supplementation can provide both a protein and energy source for the dam. The CP could then lead to an increase in energy provided during gestation and enhance fetal growth and development, which could lead to improved female reproductive performance. The minimal effects on lamb birth and weaning weights during the postnatal period may explain the lack of maternal nutrition effects on female offspring BW and BCS during female development for reproduction. Female offspring conception rates, litter size, litter weight at birth, number of lambs weaned, and lamb BW at weaning were not affected by maternal energy restriction or supplementation from early to mid-pregnancy (Muñoz et al., 2009). Since female offspring growth was not altered by maternal nutrition from early to mid-gestation, those fetuses from compromised pregnancies may not have been programmed to have reduced reproductive efficiency. However, ewe lambs from ewes consuming 200% of ME requirements during early pregnancy had heavier lambs at birth than those from ewes fed at 100% of ME requirements (Muñoz et al., 2009). Although female offspring reproductive efficiency was not altered, those females from uncompromised pregnancies were programmed to provide increased nutrients to their fetus and produce heavier lambs.

Implications

To our knowledge there has been no research conducted on the effects of MP intake during gestation on female offspring growth and reproductive efficiency. The data from the current study suggests that feeding 100% of MP requirements during late gestation may have greatest positive impacts on female reproductive performance. Any excess MP provided to the dam may be excreted prior to absorption and utilization in improving fetal growth and development *in utero*. However, there has been minimal research conducted in the area of CP supplementation during late gestation on female offspring performance and reproductive efficiency. Therefore, more research needs to be conducted in supplementing dams with MP in isocaloric diets.

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CHAPTER 5. ECONOMIC ANALYSIS OF WETHER LAMBS FROM EWES SUPPLEMENTED WITH METABOLIZABLE PROTEIN DURING LATE GESTATION DURING THE FEEDLOT PHASE

Abstract

Our objective was to determine the profitability of wether lambs from ewes supplemented with metabolizable protein (MP) during late gestation during the feedlot phase. Maternal dietary treatments were applied at d 100 of gestation and in year 1 were isocaloric and contained: **60MP1**: 60% of MP requirements; **80MP1**: 80% of MP requirements; and **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation for a ewe bearing twins. In year 2, maternal dietary treatments were isocaloric and contained: **60MP2**: 60% of MP requirements; **100MP2**: 100% of the MP requirements; and **140MP2**: 140% of MP requirements on a DM basis of a ewe bearing twins during the last 4 weeks gestation. In year 1, the 60MP1 wethers had increased total revenue compared with the 80MP1 and 100MP1 wethers. However, the 80MP1 wethers had reduced total costs compared with the 60MP1 and 100MP1 wethers. The wethers born to 60MP1 ewes were $3.49/wether more profitable than the 80MP1 wethers and $10.97/wether more profitable than the 100MP1 wethers. In year 2, the 60MP2 wethers had increased total revenue than the 100MP2 and 140MP2 wethers. The wethers born to ewes consuming 60MP2 had reduced total costs which led to increased profitability compared with the 100MP2 and 140MP2 wethers, $20.68 and $30.55 more per wether, respectively. Therefore, wether lambs from ewes that are restricted to either 60% or 80% of MP requirements may be more profitable during the feedlot phase, but the costs of the feedlot and profitability varied widely across years.

Key words: economic analysis, feedlot, metabolizable protein, wethers

Introduction

There has been little research conducted on the profitability of maternal nutrition during gestation on the offspring during the feedlot phase. In a study conducted by Larson et al. (2009), carcass values of steers born to cows that were supplemented with CP during late gestation were increased compared with carcass values of steers born to cows that were not supplemented with CP. These increased carcass values led to increased net returns in the feedlot phase for steers from cows that were supplemented with CP during late gestation (Larson et al., 2009). However, in a similar study conducted by Stalker et al. (2006), there were no differences in net returns on the feedlot phase of steers from cows that were supplemented or not supplemented with CP during late gestation. These results may suggest that there are factors that determine the profitability of offspring in the feedlot other than maternal nutrition during late gestation.

With the little information available, we hypothesized that offspring from ewes with increased MP intake would be more profitable during the feedlot phase than wethers from ewes that had restricted MP intake during late gestation. Therefore, our objective was to evaluate total cost and revenue of wethers during the feedlot phase and develop enterprise budgets for each year of the trial to determine profitability.

Materials and Methods

Ewes

Year 1. Maternal nutrition study and design has been previously reported in Chapter 2. On d 100 ± 8 (SD) of gestation, using the average of the start weights (d 99 and 100 of gestation), ewes were stratified by BW, age, BCS, and expected lambing date to one of three isocaloric dietary treatments: **100MP1**: 100% of the MP requirements on a DM basis during the last 4 weeks of gestation of a ewe carrying twins (NRC, 2007); **60MP1**: 60% of 100MP1; and **80MP1**: 80% of 100MP1.

Year 2. On d 100 of gestation, using the average of the start weights, ewes were stratified by weight, age, body condition score, and expected lambing date to one of three isocaloric dietary treatments (Table 2): **60MP2**: 60% of MP requirements; **140MP2**: 140% of MP requirements; and **100MP2**: 100% of the MP requirements on a DM basis of a ewe carrying twins during the last 4 weeks gestation (NRC, 2007).

Feedlot

In year 1, at 89 ± 5 (SD) days of age (n = 31 for 60MP1, n = 33 for 80MP1, and n = 24 for 100MP1), and in year 2, at 102 ± 11 (SD) days of age (n = 20 for 60MP2, n = 22 for 100MP2, and n = 20 for 140MP2), wether lambs were revaccinated for tetanus and *Clostridium Perfringens* types C and D and placed in the feedlot. In both years, wethers were allotted by maternal dietary treatment and blocked by weight (heavy and light) into one of two pens per maternal dietary treatment. Wethers were fed approximately 85% whole, shelled corn and 15% commercial market lamb pellet diet. The feedlot ration was balanced to meet or exceed CP and NE requirements of growing lambs (NRC, 2007). Wethers were fed a mixed diet ad libitum via bulk feeders. Lambs had continuous access to fresh water and shade. Water troughs were cleaned at least once weekly and animal health was monitored daily. Lambs treated for respiratory and gastrointestinal issues were noted. Bulk feeders were cleaned and the feed refusals were weighed every 28 days to calculate DMI. In year 1, wethers were weighed on two consecutive days at the beginning (d 0, 1) and end (d 109, 110 and d 143, 144) of the feedlot phase, and on d 28, 56, 84, 110, and 144. In year 2, wethers were weighed on two consecutive days at the beginning (d 0, 1) and end (d 137, 138) of the feedlot phase, and on d 28, 56, 84, 112, and 138. Therefore, in year 2, days on feed were similar for all wethers.

Carcass Characteristics

In year 1, all wethers weighing at least 69 kg were shipped for harvest to a commercial abattoir (Iowa Lamb Corporation, Hawarden, IA) on d 110 after entering the feedlot and all remaining wethers were shipped to the same commercial abattoir on d 144 of the trial. Hot carcass weight was collected immediately post-exsanguination. In year 2, wethers (n = 14 for 60MP2, n = 18 for 100MP2, and n = 17 for 140MP2) were shipped for harvest to a commercial abattoir (Superior Farms, Denver, CO) on d 138 of the trial. Wethers not shipped for harvest in year 2 were removed from the trial due to non-treatment related issues.

Economic Analysis

An enterprise budget was used to evaluate the effect of MP supplementation during late gestation on wether offspring profitability. Total revenue was based on the HCW of the lambs after slaughter, $5.87/kg in year 1 (Table 5.1) and $7.96/kg in year 2 (Table 5.2) from the USDA National Weekly Lamb Market Summary for the week the wethers were slaughtered (year 1: 10 September 2010; year 2: 21 October 2011). Purchase price of the lambs (year 1: $3.48/kg; year 2: $5.59/kg) was calculated using the USDA National Weekly Lamb Market Summary for the week of study initiation and the initial BW of the wethers entering the feedlot (year 1: 30 April 2010; year 2: 27 May 2011). Feed costs on an as fed basis included whole, shelled corn (year 1: $0.15/kg; year 2: $0.27/kg) and market lamb pellet (years 1 and 2: $0.36/kg). The price of corn was averaged between cash price from the USDA Agricultural Marketing Service and Grain and Feed Market News in Chicago, IL and Minneapolis, MN from May through September in 2010 and 2011 for years 1 and 2, respectively. Feed costs for each year were calculated using the average daily as fed intake per wether throughout the feedlot phase and days on feed in the feedlot for each dietary treatment (Chapter 3). Veterinary and medical costs included the medication, syringe, needle, and labor costs for each treatment and are expressed on a per head basis. These costs varied depending upon illness treatment and the percentage of morbidity in each dietary treatment in each year (Chapter 3). Yardage rate was estimated based on commercial rates ($0.04 head^{-1}d^{-1}) and accounted for the fixed costs of infrastructure, mixer wagon and tractor, and labor for feeding and daily health checks. Trucking costs included the cost to transport the lambs to slaughter ($0.02/kg). The value lost due to a 3% shrink during transport for slaughter to Iowa Lamb Corporation in Hawarden, IA in year 1 and Superior Farms in Denver, CO in year 2 was included in the total cost. Total cost was the sum of the lamb purchase price, feed costs, veterinary and medical expenses, yardage rate, trucking costs, and the cost of the 3% shrink during transport. Profit was then calculated as the total revenue minus the total cost.

Results and Discussion

The enterprise budget for year 1 is presented in table 5.1. In year 1, the wethers born to 60MP1 ewes were $3.49/wether more profitable than the 80MP1 wethers and $10.97/wether more profitable than the 100MP1 wethers. This increased profitability was mainly due to the increased total revenue associated with 60MP1 lambs. The total revenue of wethers was determined from their HCW; with 60MP1 having the heaviest weights at slaughter and the 100MP1 wethers having the least. Although the 80MP1 lambs were on feed longer than the 60MP1 and 100MP1 lambs, this did not negatively impact feed costs. The reduction in the profits of 100MP1 wethers was due to increased purchase cost and reduced total revenue. The increased purchase cost of the 100MP1 wethers was due to the increased initial BW entering the

Table 5.1. Economic analysis of wether lambs (per head basis) from dams supplemented with metabolizable protein during late gestation in year 1

	Maternal Dietary Treatment[1]		
Item	60MP1	80MP1	100MP1
Initial BW, kg	29.2	28.2	29.8
HCW, kg	36.1	35.0	34.3
Revenue, $			
Total Revenue[2]	211.91	205.45	201.34
Costs, $			
Lamb Purchased[3]	101.62	98.14	103.70
Feed[4]	39.37	39.90	38.13
Veterinary and medical[5]	0.28	0.28	0.38
Yardage[6]	5.08	5.32	4.92
Trucking[7]	0.67	0.66	0.61
Shrink[8]	6.36	6.16	6.04
Total Cost, $	153.37	150.41	153.78
Profit (Loss), $	58.53	55.04	47.56

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP1: 60% of metabolizable protein requirements; 80MP1: 80% of metabolizable protein requirements; and 100MP1: 100% of the metabolizable protein requirements.

[2] Total revenue ($5.87/kg) was estimated from the carcass value of the USDA weekly national lamb market summary for the week the lambs were slaughtered and HCW (10 September 2010).

[3] Lamb purchase price ($3.48/kg) was estimated from the USDA weekly national lamb market summary for the week of trial initiation and initial BW (30 April 2010).

[4] Feed costs included the feedlot ration: whole, shelled corn (84.4%; $0.15/kg As Fed) and market lamb pellet (15.6%; $0.36/kg As Fed).

[5] Veterinary and medical costs included the costs of the syringe, needle, and medication administered.

[6] Yardage rate was $0.04/lamb/day and accounted for the fixed costs of infrastructure, mixer wagon and tractor, and labor of feeding and daily health checks.

[7] Trucking costs ($0.02/kg) accounted for transporting lambs to Iowa Lamb Corporation in Hawarden, IA for slaughter.

[8] Shrink costs included a 3% shrink during transportation.

feedlot, but having reduced HCW at slaughter. Our results suggest that wethers born to ewes fed 60% of MP requirements were more profitable than wethers from ewes fed 80 or 100% of MP requirements.

The enterprise budget for year 2 is presented in table 5.2. In year 2, the wethers born to 60MP2 ewes were the most profitable, earning $20.68/wether more than the 100MP2 wethers and $30.55/wether more than 140MP2 wethers. The greater profits of the 60MP2 wethers were due to the reduced purchase price of those lambs due to the reduced initial BW of the lambs. The large reduction in profits of the 140MP2 wethers was due to the increased purchase price, due to the increased initial BW of the wethers. Although all lambs were on feed for 138 d for the trial, the as fed daily intake was different between maternal dietary treatments, which altered the feed costs. Total revenue was greatest for the wethers born to 60MP2 ewes compared with the 100MP2 and 140MP2 wethers, which was due to the increased HCW of those wethers. The increased total revenue in the 60MP1 wethers was due to the increased HCW at slaughter; however, this only accounted for a small increase in the total revenue in the lambs. Similar to year 1, the wethers born to ewes fed 60% of MP requirements were the most profitable compared with wethers born to ewes fed 100 or 140% of MP requirements.

The differences in initial BW entering the feedlot and HCW are not statistically significant (Chapter 3), but they do suggest that wethers born to ewes consuming 60MP1 experience a period of compensatory gain in the feedlot. This period of compensatory gain leads to the increased HCW at slaughter to increase profits. Therefore, the profitability of wethers may be determined by initial BW entering the feedlot than the HCW at slaughter. However, this can only be applied to our study; as these results may change depending on previous nutrition, maternal nutrition, environment, or nutrition within the feedlot.

This economic analysis strictly looks at wethers within the feedlot and does not account for the maternal MP supplementation during late gestation. Ewe performance during late gestation was improved by increased MP intake (Chapter 2), which may lead to alterations in the

Table 5.2. Economic analysis of wether lambs (per head basis) from dams supplemented with metabolizable protein during late gestation in year 2

	Maternal Dietary Treatment[1]		
Item	60MP2	100MP2	140MP2
Initial BW, kg	25.3	28.3	29.5
HCW, kg	32.6	32.3	32.3
Revenue, $			
Total Revenue[2]	259.15	256.92	257.23
Costs, $			
Lamb Purchased[3]	141.43	158.20	164.63
Feed[4]	45.54	46.92	51.06
Vet. and medical[5]	0.12	0.48	0.11
Yardage[6]	5.52	5.52	5.52
Trucking[7]	0.57	0.57	0.56
Shrink[8]	7.77	7.71	7.72
Total Cost, $	200.95	219.39	229.59
Profit (Loss), $	58.20	37.52	27.65

[1] Maternal diets (DM basis) were balanced for mature ewes baring twins during the last 4 weeks of gestation according to NRC (2007). Treatments: 60MP2: 60% of metabolizable protein requirements; 100MP2: 100% of metabolizable protein requirements; and 140MP2: 140% of metabolizable protein requirements.

[2] Total revenue ($7.96/kg) was estimated from the carcass value of the USDA weekly national lamb market summary for the week the lambs were slaughtered and HCW (21 October 2011).

[3] Lamb purchase price ($5.59/kg) was estimated from the USDA weekly national lamb market summary for the week of trial initiation and initial BW (27 May 2011).

[4] Feed costs included the feedlot ration: whole, shelled corn (84.7%; $0.27/kg As Fed) and market lamb pellet (15.3%; $0.36/kg As Fed).

[5] Veterinary and medical costs included the costs of the syringe, needle, and medication administered.

[6] Yardage rate was $0.04/lamb/day and accounted for the fixed costs of infrastructure, mixer wagon and tractor, and labor of feeding and daily health checks.

[7] Trucking costs ($0.02/kg) accounted for transporting lambs to Superior Farms in Denver, CO for slaughter.

[8] Shrink costs included a 3% shrink during transportation.

economic analysis. Increased performance could lead to increased conception and pregnancy rates in the following breeding cycles, as well as improved milk production, which could lead to a longer life span within the flock. Improved life-long performance of ewes consuming MP at or above requirements could lead to increased profits throughout her life. However, to our knowledge there has not been any research into the life-long profitability of dams receiving a protein supplement during late gestation, whether it was CP or MP.

Minimal research conducted on CP supplementation during late gestation has analyzed the profitability of the offspring through the feedlot. However, Larson et al. (2009) observed increased profits on steer carcasses from those born to cows that were supplemented with CP during late gestation than steers from cows that were not CP supplemented. Larson et al. (2009) explained this difference on the increase in percentage of carcasses from steers born to CP supplemented cows grading USDA Choice. This increased carcass value also led to increased net return during the feedlot phase of steers born to cows that were supplemented with CP during late gestation (Larson et al., 2009). According to our results of the carcass characteristics (Chapter 3), both quality and yield grades were not altered by maternal MP intake during late gestation, so this may not have altered our total revenue of the lambs. In a similar study conducted by Stalker et al. (2006), there was no difference on the net return in steers born to cows either CP supplemented or unsupplemented during late gestation. The available research indicates that feedlot costs and profitability are highly variable due to feed and lamb prices.

Purchase price of feed and total revenue of lambs were factors in the difference between profits in both years. Purchase price of corn almost doubled from year 1 to year 2, which increased the total feed costs in year 2 compared with year 1. Our results suggest that many factors, such as feed, days on feed, year, growth rate, genetics, purchase costs of the animal, etc. all cause variation in the profitability during the feedlot phase. These factors vary from year to year and across regions, which are limitations of economic analysis, as it only accounts for the specific variables of a study. This economic analysis does not account for all scenarios within the feedlot; therefore, there may be more cost effective rations that could reduce feed costs. However, this would not change the total revenue and purchase costs of the wethers, but would increase profits.

Implications

In the economic analysis of the current study, the cost of the maternal MP supplement during late gestation was not taken into account. Ewes consuming increased MP intake (100 or 140% of requirements) had improved performance during late gestation compared with the ewes fed 60% of MP requirements, which could alter life-long profitability of the ewe. However, this analysis was strictly to determine the profitability of wether offspring alone during the feedlot phase based on their BW entering the feedlot and their performance. These profits also do not reflect all possible feedlot and the least cost scenarios. However, based on these results, maternal MP intake during late gestation may play a role in the profitability of the offspring through the feedlot phase. The wethers born to ewes fed 60% of MP requirements were the most profitable in both years, due to reduced BW entering the feedlot and increased HCW at slaughter.

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CHAPTER 6. GENERAL CONCLUSIONS AND FUTURE DIRECTIONS

General Conclusion

Our results have contributed to the small amount of information available on the effects of maternal MP intake during gestation on dam and offspring performance. Overall, increasing maternal MP intake above requirements during late gestation did not improve offspring performance compared with offspring from ewes consuming reduced MP during late gestation. However, supplementing MP at or above ewe requirements enhanced dam growth and condition during late gestation. Although providing MP at 60% of requirements during late gestation negatively impacted dam performance, these effects did not alter male offspring performance throughout life. However, restricting MP intake to 60% of requirements to ewes during late gestation negatively affected female offspring performance. Providing MP intake at 100% of requirements positively impacted ewe lamb offspring breeding and lambing in the first 17 days post-ram turnout. Therefore, feeding ewes 100% of MP requirements during late gestation may be the most beneficial to ensure positive dam and offspring performance.

Future Directions

Much of the previous research conducted in the area of protein intake during gestation has focused on CP supplementation during late gestation (Martin et al., 2007; Larson et al., 2009; Funston et al., 2010). Previous research on protein supplementation has also been limited in its effects on offspring performance beyond weaning. However, it is difficult to determine what specific aspect of CP is being used by the dam to improve both dam and offspring performance. Therefore, continuous research with MP is needed to evaluate how the N that is directly available to the dam may be used during late gestation.

As this is one of the few studies of its kind, more research should be conducted into the effects maternal MP intake during late gestation has on metabolic pathways and physiological development of the fetus. In general, our results for dam and offspring performance were similar to both Amanlou et al. (2011) and Patterson et al. (2003). Since MP is the protein directly available for absorption and utilization by the dam, more information is needed on if the available MP is being utilized as a N source by the dam prior to excretion, as well as if the N from MP is being used for fetal development. Basically, it needs to be determined how the dam is utilizing increased MP during late gestation to increase maternal growth.

Offspring growth, similar to Amanlou et al. (2011), was not impacted by maternal MP intake during late gestation. According to Du et al. (2010), muscle fiber numbers are not altered by maternal nutrient restriction during late gestation because fetal muscle has matured from early to mid-gestation. Due to the lack of differences in feedlot growth and carcass characteristics, a possible next step would be to alter the timing of increased MP intake to early or mid-gestation. Shifting the time of increased MP intake to early pregnancy may alter muscle fiber formation, and in turn feedlot growth and carcass characteristics.

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