The effect of escape protein and carbohydrate source on performance, metabolism and wool production of ewes during mid-gestation
by Robert Francis Padula

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal Science
Montana State University

Abstract:
The objective of this experiment was to evaluate the influence of diets differing in quantity of escape protein (EP) and energy (carbohydrate; CHO) source on metabolism of Targhee ewes during mid-gestation. Ewes were allocated by randomization to one of six treatment (TRT) groups utilizing a 2 x 3 factorial arrangement that included either urea (U), soybean meal (SBM) or blood meal (BM), and starch (STAR) or cellulose (CELL). Trial duration was 63 d with two experimental periods. Ewes fed BM gained more ($P < .10$) weight during the experiment than those fed LI or SBM. A significant protein by energy interaction was detected with U-CELL ewes gaining less ($P < .05$) total weight than the other treatment combinations. BM ewes had greater ($P < .05$) albumin (ALB) concentrations than U and SBM during period 1 or U in period 2. Total protein (TP) concentrations tended to be higher ($P > .10$) for BM than U or SBM with no differences ($P > .10$) for blood urea N (BUN) between TRT. Higher TP and ALB and similar BUN concentrations for BM may be indicative of increased amino acid absorption from the gut and efficient utilization of them by the liver. Lambs born to BM ewes had greater ($P < .05$) 90 d weights than U or SBM lambs. Energy source had no influence ($P > .10$) on ewe weight change. Ewes fed CELL had lower ($P < .05$) TP and BUN concentrations in period 1 and BUN in period 2 than STAR ewes. This is related to lower microbial protein production and less EP reaching the small intestine for CELL compared to STAR. Ewes fed CELL in period 2 retained less ($P < .05$) dietary N than STAR ewes. Ewes fed EP had blood metabolite profiles indicative of improved quality and/or quantity of N reaching the small intestine for absorption and metabolism in the liver.

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ABSTRACT

The objective of this experiment was to evaluate the influence of diets differing in quantity of escape protein (EP) and energy (carbohydrate; CHO) source on metabolism of Targhee ewes during mid-gestation. Ewes were allocated by randomization to one of six treatment (TRT) groups utilizing a 2 x 3 factorial arrangement that included either urea (U), soybean meal (SBM) or blood meal (BM), and starch (STAR) or cellulose (CELL). Trial duration was 63 d with two experimental periods. Ewes fed BM gained more ($P < .10$) weight during the experiment than those fed U or SBM. A significant protein by energy interaction was detected with U-CELL ewes gaining less ($P < .05$) total weight than the other treatment combinations. BM ewes had greater ($P < .05$) albumin (ALB) concentrations than U and SBM during period 1 or U in period 2. Total protein (TP) concentrations tended to be higher ($P > .10$) for BM than U or SBM with no differences ($P > .10$) for blood urea N (BUN) between TRT. Higher TP and ALB and similar BUN concentrations for BM may be indicative of increased amino acid absorption from the gut and efficient utilization of them by the liver. Lambs born to BM ewes had greater ($P < .05$) 90 d weights than U or SBM lambs. Energy source had no influence ($P > .10$) on ewe weight change. Ewes fed CELL had lower ($P < .05$) TP and BUN concentrations in period 1 and BUN in period 2 than STAR ewes. This is related to lower microbial protein production and less EP reaching the small intestine for CELL compared to STAR. Ewes fed CELL in period 2 retained less ($P < .05$) dietary N than STAR ewes. Ewes fed EP had blood metabolite profiles indicative of improved quality and/or quantity of N reaching the small intestine for absorption and metabolism in the liver.

INTRODUCTION

Montana native range provides much of the nutrition for gestating ewes during winter because of the absence of snow cover. Early work by Van Horn et al. (1959b) reported it was profitable to supplement gestating ewes grazing Montana winter range two out of every three years with .15 kg of a cereal-based, 18-20% crude protein supplement. More recently, Harris et al. (1989) reported that pregnant ewes grazing winter range did not receive adequate protein nutrition, and protein appears to be more limiting than energy. However, these studies did not evaluate protein sources not degraded extensively in the rumen (escape protein, EP). Hoaglund et al. (1989) reported that pregnant ewes fed straw diets supplemented with blood meal had improved N balance, ewe weight and body condition score changes, and wool growth in comparison to those fed urea or soybean meal. They speculated that EP reaching the small intestine in blood meal ewes was the primary reason for improved metabolism and performance.

Diets containing starch as the primary carbohydrate (CHO) source provide a readily digestible energy source for microbial protein synthesis (Merchen et al., 1987; Rooke and Armstrong, 1989). Increased microbial protein production should provide additional N in the form of bacterial or

protozoal amino acids for absorption by the small intestine (Stern and Hoover, 1979). Diets high in cellulose provide a lower digestible energy source and may reduce microbial protein synthesis, resulting in an increased demand for amino acids from EP to maintain production (Polan, 1988).

The objective of this study was to evaluate the influence of supplements differing in quantity of EP and CHO source on ewe metabolism and productivity during mid-gestation.

LITERATURE REVIEW

Ewe Nutrient Requirements

Nutrient requirements for livestock have traditionally separated maintenance from production. Maintenance requirements are determined by live weight of the animal and environmental conditions. Production requirements are determined by the amount and nature of production (van Es, 1972).

Maintenance is a relatively constant state in mature animals and can be fed so there is no gain or loss of weight over a period of time (Graham, 1982). An animal's energy requirement for maintenance is the amount of energy the animal must consume to neither gain nor lose weight. Fasting heat production is used as a baseline in assessing energy requirements independent of the diet fed. The net energy required for maintenance (NE_m) is the daily quantity of energy resulting in a zero change in body energy (NRC, 1985a). The requirement for maintenance is not static. Animal weight, activity and thermal homeostasis all affect NE_m (Graham, 1982).

Heat losses due to shearing will increase NE_m, as wool is a very effective insulator. At a given feeding level, the shorter the fleece the higher the lower critical temperature (LCT) of the sheep (Graham, 1982). Shearing will increase NE_m if environmental temperature is below the LCT (NRC, 1985a).

Van Es (1972) and NRC (1985a) did not mention a specific energy requirement for wool growth. NRC (1985a) stated the energy requirement for wool production represents a small fraction of the total energy consumed. Graham (1982) contended that the efficiency of energy utilization for wool growth is not known and protein rather than energy supply determines wool growth rate.

The most common method for reporting protein requirements is based on the concentration of protein as a percentage of dry matter in terms of biological value (Ørskov, 1982; NRC, 1985b). For absolute maintenance, tissue protein degradation and synthesis need to take place at equal rates. To define a maintenance protein requirement, one must consider unavoidable-N losses from the body and amount fed to offset these losses.

Unavoidable-N losses occur in the form of metabolic fecal N (MFN), endogenous urinary N (EUN) and excretions from the skin. A comparison of 10 systems for assessing protein requirements for ruminants has been reviewed (NRC, 1985b). Calculation of MFN and EUN is quite variable between systems; however, certain principles are fundamental. MFN is based on the animal's intake feed, while EUN is a function of animal weight.

NRC (1985a) separates skin N losses into dermal loss and loss due to wool growth. Loss of N due to wool growth on maintenance rations may vary at least two-fold depending on genotype and amount of S-amino acids absorbed from the small intestine (Graham, 1982).

The nutrient requirements of the pregnant ewe are higher than maintenance due to the products of conception and mammary gland development. Increase in fetal weight during early pregnancy is small, with the majority of fetal growth (approximately 70%) occurring during the last four weeks of gestation (NRC, 1985a). During early gestation, most research has focused on the degree of nutrient restriction that can be applied before embryo and fetal survival is affected. Blockey et al. (1974) concluded that fasting for 3 d from either day 1, 5, 8, 10 or 12 after mating has no adverse effect on fertility in twin-ovulating ewes.

During the third and fourth weeks of gestation (implantation stage), there is a strengthening of the bond between the embryo cotyledons and the maternal caruncles. Many of the nutritionally induced deaths occurring between days 15 and 30 after mating arise from undernutrition following mating (Robinson, 1983). McDonald et al. (1981) reported that death of one or more embryo during the third and fourth weeks of gestation tends to disturb the balance in the distribution of fetuses in the uterine horns. This imbalance results in inability of the surviving embryos to utilize the vacated maternal cotyledons (Robinson, 1983). This results in a higher proportion of ewes rebreeding at more than 19 days after a fertile mating, reduced lambing percentage, and smaller lambs at birth.

Research by Doney and Gunn (1981) indicated that changes in nutritional levels post-mating, either up or down, may induce greater ova losses than

nutritional levels held constant at an intermediate level. Thomas et al. (1989) reported a lower percentage of lambs born per ewe exposed for range ewes supplemented on alternate days compared to ewes supplemented on a daily basis. They speculated that an abrupt change in nutrient intake from breeding to a lower plane of nutrition on winter range and lack of a constant nutrient supply to those supplemented on alternate days may have predisposed them to more reproductive wastage.

Robinson (1982) indicated fetal losses due to a low plane of nutrition are more prevalent in young ewes or those in poor condition at mating. Embryonic mortality is also increased as ovulation rate increases.

Earlier research by El-Shiek et al. (1955) and Foote et al. (1959) demonstrated increases in embryonic mortality when ewes were overfed during early gestation. More recently, Parr et al. (1987) conducted a study in which Merino ewes were fed at 25%, 100% and 200% maintenance on days 2 to 14 post-mating. They reported a significant reduction ($P < .05$) in pregnancy rate (48% vs. 68%; 68% vs. 67%) for ewes fed at the high level when compared to those fed at a medium or low level. A decline in peripheral progesterone concentration with increasing nutrition was reported. They concluded that effect of nutrition on plasma progesterone concentrations may be due to a higher clearance rate of progesterone since blood flow to the liver increases with feeding and the liver is a major site of progesterone catabolism. If the ovary does not compensate for this increase in catabolism,

progesterone concentrations could fall below the threshold necessary for embryo survival.

The placenta and fluids (allantoic and amniotic) are also products of conception that increase the ewe's nutritional requirement. Placental weight appears to plateau at about day 100. Severe undernutrition during the first 100 d can reduce the number of cotyledons and total weight of cotyledonary tissue (Robinson, 1977). Faichney and White (1987) reported moderate dietary restrictions resulted in increased placental size from day 50, even when imposed after day 100.

Both allantoic and amniotic fluid increase rapidly in early pregnancy, followed by a leveling off in mid-gestation (Robinson, 1982). Urine formed in the mesonephros of the fetal lamb passes into the allantoic cavity until about day 90 of gestation. Thereafter, urine passes in increasing quantities into the amniotic sac due to occlusion of the urachus and patency of the urethra (Hafez, 1987). As fetal growth and metabolism increase as gestation progresses, a second increase in fluid volume is observed. During late gestation, daily gains in fetal fluids of 250 $g*d^{-1}$ have been observed in quadruplet-bearing ewes (Robinson, 1982).

Absolute growth rates of the fetus place virtually no additional requirements on the ewe during the first month of gestation. Fetal weights (Joulbert, 1956) at 25 and 40 days are approximately .3 and 5 g, respectively. Hulet et al. (1969) offered ewes either 75% or 150% of their estimated maintenance

energy requirements from mating until day 21 or 30, without affecting fetal weight. Similar results were reported earlier by Foote et al. (1959), El-Shiek et al. (1955) and Wallace (1948).

Requirements listed in NRC's (1985a) "Nutrient Requirements of Sheep" for ewes during the first 15 to 17 weeks of gestation are intended to provide for maintenance, wool growth and small (30 g) daily gains. Wallace (1948) indicated fetal weight was not affected by ewe weight decreases of up to 7% of body weight. Russel et al. (1977) suggested that unless undernutrition in mid-gestation was severe, mature ewes would compensate for inadequate nutrition during late gestation. However, inadequate nutrition during mid-gestation in the young primiparous ewe did have a significant effect on fetal weights. Chestnutt (1989) concluded that high quality silage fed during mid-gestation only improved levels of body reserves, with little effect on fetal weight. In addition, he found that feeding high quality silage during mid-gestation appeared to reduce intake during the last week of gestation.

Ewe nutrient requirements increase in late gestation due to increased demands for fetal growth and udder development. Results of undernutrition during late gestation include impaired milk production capability, reduced mothering instinct and lower birth weights leading to reduced lamb viability (NRC, 1985a). Faichney and White (1987) compared fetal growth of ewes on a maintenance ration (M) to those subjected to moderate dietary restriction from days 50 to 100 (RM), days 100 to 135 (MR), or days 50 to 135 (RR). RR

fetuses were smaller, RM fetuses larger, with MR fetuses unaffected compared to those of ewes fed M.

Mellor and Matheson (1979) indicated that sustained severe undernutrition for three to four weeks in late gestation progressively decreased fetal growth rate. Abrupt severe undernutrition during late gestation can slow down or in some instances reduce fetal growth by 50% within three days. However, even when cessation of fetal growth was maintained for one week, growth rates returned to normal when ewes were reintroduced to a high plane of feeding.

Sykes and Field (1972) reported undernutrition of ewes in late gestation causing a 25% decrease in lamb birth weight had no detrimental effect on the fetus. This is in support of Robinson (1977) who indicated the undernourished lamb at birth appears malproportioned in relationship to a well fed lamb simply because it is lighter and at an earlier stage of differential growth and development.

Rattray (1974) presented estimates for metabolizable energy (ME) requirements for gestating ewes with a breeding weight of 55 kg according to stage of gestation and fetal number (Table 1). These values demonstrate the influence of stage of gestation and fetal number on nutrient requirements. Meeting the nutritional requirement (particularly towards the end of gestation and with multiple fetuses) can be both difficult and uneconomical.

Table 1. Multiple of maintenance requirements for gestating ewes based on stage of gestation and fetal number.[a]

Gestation (d)	Single	Twin	Triplet
100	1.2	1.5	1.6
120	1.4	1.9	2.1
140	2.0	2.6	2.8

[a]Values based on total birth weight of 4.9, 7.9 and 9.1 Kg for single, twin and triplet lambs, respectively.

Publications on nutrient requirements for sheep (ARC, 1980; NRC, 1985a) recommend the utilization of body reserves when energy requirements of the prolific ewe exceed those supplied by voluntary intake of high quality diets.

Jordan and Hanke (1988) fed ewes above (32%) or below (10%) the NRC recommended total digestible nutrient (TDN) requirements for early and late gestation (1.8 and 2.8 lb TDN, respectively) during the last 90 d of gestation. Ewes were in above average body condition at time of breeding (3.9 score on a scale of 1=thin to 5=fat). All ewes, regardless of energy level, gained weight and improved in body condition score. Ewes fed at the higher intake level gained more ($P < .05$) weight, but no significant differences were detected in lamb birth weight. They concluded fat reserves minimized the effects of inadequate energy intakes during gestation.

Rumen Microorganisms

Much of the current information regarding the predominant bacteria in the rumen deals with a population that is free or detached from plant material.

However, microscopic studies indicate a second population is firmly attached to and within feed particles (Van Soest, 1982). A third group attached to the epithelial cells of the reticulo-rumen mucosa is also present. More than 200 species and strains of microorganisms have been isolated from the rumen (Baldwin and Allison, 1983). Hungate (1966) classified ruminal microbes according to type of substrate they attack in the rumen. They were: cellulolytic, hemicellulolytic, amylolytic, fermentors of sugars, bacteria utilizing acids, methanogenic, proteolytic and lipolytic.

Baldwin and Allison (1983) generalized that cellulolytic bacteria do not ferment monosaccharides and are restricted to di- and trisaccharides and oligosaccharides released during the hydrolysis of cellulose as carbon and energy sources. A number of cellulolytic bacteria are also amylolytic, utilizing starch as an energy source (Hungate, 1966). Baldwin and Allison (1983) reported that starch digesting bacteria vary in numbers due to variation in starch content of diets. They also indicated bacteria utilizing soluble sugars as energy sources are also present, with their population dependent on dietary sugar content.

Hemicellulose constitutes a large percentage of forage consumed by ruminants (Van Soest, 1982). The ability to digest hemicellulose is characteristic of all cellulolytic strains, with hemicellulose being digested to about the same extent as cellulose (Hungate, 1966).

All rumen bacteria which digest polysaccharides are capable of utilizing mono- or disaccharides (Hungate, 1966) and play a role in fermenting simple sugars. Simple sugars are available for a short duration after food is ingested; therefore, bacterial species which solely utilize simple sugars are handicapped with cellulolytic and hemicellulolytic bacteria having an advantage compared to bacteria capable of utilizing polysaccharides (Hungate, 1966).

Hungate (1966) identified bacteria with the capability of utilizing acids in the rumen. He reported both succinate and formate are produced by many rumen bacteria, with unknown bacteria having the ability to decompose these acids since they do not accumulate in the rumen. Methanogenic bacteria have been the most difficult to isolate due to their sensitivity to oxygen (Hungate, 1966). Fortunately, methanogenic bacteria are low in numbers (Hungate, 1966), since conversion of valuable substrate to methane and carbon dioxide would seriously deplete the quantity of fermentable product oxidized by the host animal.

Van Soest (1982) indicated some bacterial strains are limited in their spectrum of energy sources, others are more versatile, and much overlapping of bacterial function exists. Baldwin and Allison (1983) noted often times bacteria are dependent upon other species for supplying nutrients.

Ogimoto and Imai (1981) noted rumen protozoa were discovered in 1843, and that many taxonomical, morphological and nutritional investigations have

been conducted. However, understanding of their role and significance is still unclear (Van Soest, 1982). Partial uncertainty arises because in the defaunated animal, the role of protozoa is mainly taken over by bacteria (Lindsay and Hogan, 1972).

Russell and Hespell (1981) reported some protozoa prefer soluble carbohydrates whereas others engulf particulate carbohydrates. Engulfed bacterial cells can serve as the major N source for most species, but particulate proteins, amino acids, peptides and ammonia are also utilized depending on the particular species.

Ruminal protozoa are fermentative aneorobes, and their fermentation products include acetate, butyrate, lactate, carbon dioxide, and hydrogen (Russell and Hespell, 1981). In addition to volatile fatty acid production, protozoa aid in sequestering carbohydrates from rapid bacterial attack; without this a significant portion of the carbohydrate would be fermented to lactate and lower ruminal pH, both of which hinder overall rumen function. An analogous situation also occurs with particulate proteins, whereby engulfment allows for extended proteolysis, slower release of products, and less catabolism of amino acids/peptides to volatile fatty acids (Russell and Hespell, 1981). The extent of protozoal engulfment of rumen bacteria depends on species and bacteria density. Depending on engulfment rate and protozoa concentration, Russell and Hespell (1981) indicated between 2.4 and 45 g bacteria could be digested protozoally per day in a sheep's rumen.

Meyer et al. (1986) reported rumen protozoa numbers, flow of NAN and amino acids increased with increasing amounts of corn in the diet. Also, more feed and endogenous NAN reached the duodenum with increased corn intake. Hino and Russell (1987) reported incubations containing bacteria and protozoa resulted in synergistic increases in ammonia and decreases in nonammonia-nonprotein N, when compared to incubations of bacteria or protozoa alone. They concluded soluble proteins were primarily degraded by bacteria whereas protozoa contribute to the degradation of insoluble proteins.

Ffoulkes and Leng (1988) reported presence of a large population of protozoa in the rumen decreases the amount of microbial and dietary protein that becomes available for digestion in the small intestine. In addition, they indicated protozoa are likely to decrease the efficiency of net microbial growth since they utilize nutrients that are potentially available to the host animal and increase the VFA:amino acid ratios that are absorbed. Volatile fatty acid proportions are often changed by the presence or absence of protozoa. The molar proportion of acetate is less affected than either propionate or butyrate, but has a tendency to be slightly lower in the rumen of ciliate-free animals (Veira, 1986). The implications of VFA proportion shift associated with the presence or absence of protozoa are of importance to the lactating animal. Whitelaw et al. (1984b) reported defaunation resulted in a doubling of the proportion of propionate, methane production was decreased by 50%, and the metabolizability of gross energy increased by 5%. Shifts to lower molar

proportions of acetate and butyrate through defaunation of lactating cows have resulted in depressions of milk fat (Chalupa et al., 1967).

Veira et al. (1983) reported protozoal protein is not a large component of ruminal outflow and supported the observation of Harrison et al. (1979) of preferential retention of protozoa in the rumen. Bird and Leng (1984) reported that increased wool growth resulting from defaunation is an indication of increased absorption of sulfur amino acids.

There is evidence that protozoa are at least a nitrogen source having better amino acid balance than bacteria for host animal nutrition (Hungate, 1978). Also present in the rumen are anaerobic fungi (Bauchop, 1979) and bacteriophages (Ogimoto and Imai, 1981); however, the net contribution of these microorganisms to overall rumen fermentation is not known.

Microbial Protein Synthesis

Various techniques have been used to estimate the amount of microbial digesta leaving the ruminant stomach. Digesta entering the duodenum of ruminants is composed of material of feed, microbial and endogenous origins. Contribution of any one component can be estimated by measuring the concentration of a marker in whole digesta which is specific to and of known concentration in the component (Siddons et al., 1979). The majority of these methods are based on determination of a single chemical marker representing microbial contents.

Diaminopimelic acid (DAPA) was used by Weller et al. (1958) to estimate rate of bacterial protein synthesis. Cell membranes of rumen bacteria contain DAPA, which is absent from plant material (Stern and Hoover, 1979). Stern et al. (1977) indicated that traces of DAPA can be found in protozoa, through protozoal "feeding" upon rumen bacteria.

The DAPA technique involves estimating the ratio of DAPA:N in mixed rumen bacteria in relationship to DAPA in digesta. Ibrahim and Ingralls (1972) used DAPA to measure bacterial protein synthesis and aminoethylphosphoric acid (AEP; found in the lipid fraction of protozoa) to estimate protozoal synthesis. More recently, Whitelaw et al. (1984b) compared DAPA and AEP as markers of microbial protein. They fed three concentrate to forage ratios (50:50, 90:10, 100:0) and found DAPA values of duodenal digesta were similar for all treatments. However, estimates of bacterial N based on DAPA concentrations were highly variable and frequently impossibly high. They reported AEP was also variable, finding no differences between treatments in AEP content of duodenal digesta or protozoal weight (mg/g N). They concluded AEP was an unsuitable marker for rumen protozoa as AEP was also found in rumen bacteria. Both methods (DAPA and AEP) produced variable results, indicating a need for a more reliable marker.

Accuracy of DAPA is dependent upon a constant DAPA:N ratio among rumen microbes or maintaining a constant ratio of microbial species in the rumen (Stern and Hoover, 1979; Whitelaw et al., 1984b). This may explain the

variability among experiments, as it is virtually impossible to maintain constant microbial ratios in the rumen.

Smith and McAllan (1970) used the ratio of ribonucleic acid (RNA) to total N in rumen fluid and rumen microbes to estimate the extent of dietary N converted to bacterial and protozoal N. This technique assumes nearly all dietary RNA is degraded ruminally (Smith and McAllan, 1974) and suggests that microbial protein flow may be overestimated, particularly when protein sources and RNA have been altered to escape ruminal degradation (Buttrey and Cole, 1977). Similar to DAPA, the RNA method is dependent upon uniform bacterial populations, which are altered by diet and rumen environment (Smith and McAllan, 1974).

In comparing DAPA and RNA as microbial markers for microbial N in duodenal digesta, Smith and McAllan (1974) found both methods comparable using a protozoa-free calf. However, using a faunated cow, they found microbial N:non-ammonia N ratios of .78 and .40 for RNA and DAPA methods, respectively. They concluded either considerable amounts of dietary RNA escaped rumen degradation or the DAPA method neglected to account for protozoa. More recently, McAllan and Smith (1984) reported RNA and DAPA techniques for estimating abomasal microbial N flow gave different absolute results but similar relative patterns when different dietary treatments were compared. They attributed these differences to variable composition of the microbial fraction flowing to the omasum.

The benefits and limitations of radioisotopes (^{35}S, ^{15}N and ^{32}P) as tracers to distinguish between microbial and dietary protein have been reviewed by Stern and Hoover (1979). They reported that ^{35}S has been used most frequently. In comparing ^{35}S to DAPA and AEP, Whitelaw et al. (1984b) reported only ^{35}S gave sensible and reproducible results. This is in agreement with Ling and Buttrey (1978) who suggested using ^{35}S where accurate estimates of microbial N are needed; however, the RNA method would be adequate for more general and comparative estimates.

Microbial Yield

The overall concept of microbial maintenance is analogous to maintenance for animals, with growth not occurring until the maintenance requirement is met. Hespell and Bryant (1979) stated maintenance requirement varies according to bacterial species and growth conditions. Early work of Bauchop and Eldsen (1960) compared growth yields of several microorganisms with the theoretical amount of ATP available using g bacterial DM/mole ATP as Y_{ATP}. They suggested Y_{ATP} was relatively constant and proposed a value of 10.5 for rumen bacteria. Hespell and Bryant (1979) suggested theoretical Y_{ATP} yields as high as 26 should be attainable. However, observed yields are generally lower than theoretical (Smith, 1979; NRC, 1985b) with some of the ATP available being used for microbial maintenance (Hespell and Bryant, 1979; Stern and Hoover, 1979).

Changes in cell composition and/or growth media can increase maintenance for cell formation, resulting in decreases in Y_{ATP} from theoretical yields (Hespell and Bryant, 1979). Bacteria usually contain approximately 50% protein, 20% RNA, 3% DNA, 9% lipid and 18% carbohydrate (Nocek and Russell, 1988). Table 2, which was adapted from Hespell and Bryant (1979), demonstrates the change in bacterial composition depending on growth media.

Table 2. Composition of bacteria as affected by growth media (percent dry weight).

Component	Growth Media			
	General	Carbohydrate	Lipid	Protein/Lipid
Protein	47.5	47.5	47.5	65.0
RNA	24.2	8.0	10.0	8.0
DNA	3.4	1.0	1.6	1.0
Lipid	7.0	7.0	25.0	12.0
Carbohydrate	13.5	32.1	11.5	9.6

Nitrogen

Although the major N source for bacterial growth is ammonia, peptides and amino acids are also important (Russell and Hespell, 1981). Nocek and Russell (1988) state ruminal bacteria can incorporate amino acids into microbial protein or ferment them as an energy source giving rise to ammonia. The percentage of microbial nitrogen derived from ruminal ammonia has been reported to range from 40 to 100% (Stern and Hoover,

1979), and is dependent on dietary protein and carbohydrate source (Nocek and Russell, 1988). Satter and Slyter (1974) suggested minimum ammonia N concentration of 5 mg/100 ml is required to support optimal bacterial growth and fermentation. Argyle and Baldwin (1989) reported little growth occurred in mixed rumen bacterial cultures when ammonia was used as the sole N source. Polan (1988) suggested substitution of intact protein for urea (source of ammonia) usually stimulates microbial production.

Although dietary N may appear to be adequate for microbial growth, resistance to ruminal degradation may result in N deficiency (Stern and Hoover, 1979). Soluble proteins are more rapidly degraded in the rumen (Orskov, 1982; NRC, 1985b; Nocek and Russell, 1988); however, specific feedstuffs containing soluble true protein resist degradation (Nocek et al., 1983). Insoluble proteins may or may not be degraded by rumen microorganisms (Nocek and Russell, 1988). Tertiary structure (folding caused by disulfide bridges) of insoluble proteins renders them less vulnerable to degradation (ZuBay, 1988; Nocek and Russell, 1988). However, relatively insoluble proteins can be extensively degraded in the rumen, given adequate time (NRC, 1985b). Polan (1988) reported protein sources such as soybean meal appear to optimize microbial growth *in vivo* possibly due to degradation rate.

Rooke et al. (1986) reported that efficiency of rumen microbial protein synthesis decreased as soybean meal (SBM) intake increased. They

concluded that the decrease was related to increased organic matter fermentation within the rumen and decreased microbial amino acid N synthesized.

Bas et al. (1989) compared the influence of either soybean meal (SBM) or blood meal (BM) on *in vitro* ruminal microbial fermentation. They found ammonia N concentration was significantly higher for SBM (19.2 mg/ 100 ml) than BM diet (4.1 mg/100 ml), probably due to more amino acid deamination. They suppressed microbial effluent flow with BM (.92 $g*d^{-1}$) in comparison to SBM (1.22 $g*d^{-1}$). They concluded that the ammonia concentration of the BM diet (4.1 mg/100 ml) did not meet the minimum recommended concentration (5 mg/ 100 ml; Satter and Slyter, 1974), resulting in decreased organic matter fermentation and microbial protein synthesis. This is in agreement with Polan (1988), who reported that protein sources, more undegradable than soybean meal, sometimes reduce microbial growth rate.

Stock et al. (1986) compared the effects of supplementation with urea (U), SBM-U and BM-U based diets with dried delactosed whey (DDW), a rumen degradable protein source, on microbial protein synthesis. Supplementation of the urea diet with DDW increased ($P < .09$) bacterial N flow. However, supplementation of SBM or BM-U diets with DDW did not increase microbial protein synthesis. They concluded when U supplied all the supplemental N in low protein-high roughage diets, DDW increased microbial protein synthesis. They speculated amino acids from the DDW may have

been degraded to branched chain volatile fatty acids which are required for certain bacteria for optimum growth.

Argyle and Baldwin (1989) reported that complete amino acid (AA) mixtures stimulated microbial growth alone but when added to casein, AA subgroups did not. They concluded growth stimulation was due to the number of amino acids provided in a given mixture rather than specific growth limiting amino acid.

Carbohydrate

According to NRC (1985b), dietary energy is considered to be the main factor limiting microbial growth. Plant carbohydrates (CHO) can be classified as structural or non-structural (Baldwin and Denham, 1979). Non-structural CHO are composed of sugars, starches and pectins. Structural CHO are associated with the plant cell wall and include cellulose, hemicellulose and ligins. All CHO are composed of repeating units of sugars or sugar derivatives. Several studies (Merchen et al., 1987; Meissner and Todtenhöfer, 1989; Rooke and Armstrong, 1989) have indicated diets containing starch as the primary carbohydrate source provide a readily fermentable energy source for microbial protein synthesis, while diets high in cellulose provide a lower digestible energy source and may reduce microbial protein synthesis (Stern and Hoover, 1979; Horton and Nicholson, 1981). The ability of individual sugars to form several types of bonds with other units, and lack of reagents

causing specific or sequential degradation, have confounded the study of plant CHO (Nocek and Russell, 1988).

The optimum flow of microbial nitrogen to the duodenum may be affected by both the type and source of CHO; more research is needed to identify the combinations that result in optimum microbial efficiency and rumen digestibility (Hoover et al., 1990).

Protein-Carbohydrate Interactions

Seemingly appropriate amounts of dietary protein and CHO may not provide an ideal balance of protein and CHO to the rumen microorganisms (Nocek and Russell, 1988). They conducted a study using iso-caloric, iso-nitrogenous diets which varied in ruminal CHO fermentation and protein degradation rates. Diets were as follows: slow carbohydrate-slow protein (SC-SP), slow carbohydrate-fast protein (SC-FP), fast carbohydrate-slow protein (FC-SP), and fast carbohydrate-fast protein (FC-FP). Diets FC-SP and FC-FP had the highest microbial crude protein (CP) synthesized. In diet SC-SP, nearly all of the ruminal CP could have been used for microbial growth, whereas in diet FC-SP there was insufficient N at the time of energy substrate availability to support maximal microbial protein synthesis. In the FC-SP and SC-SP diets, amino acid N passing undegraded to the SI was increased, and less amino acid N was converted to ammonia.

Owens and Bergen (1983) reported replacing a high proportion of dietary forage with grain reduced microbial efficiency; however, total microbial N flow

to the duodenum was increased because increased organic matter digestion in the rumen offset decreased efficiency (Hoover et al., 1990).

Wool Growth

In most sheep operations, wool is a valuable by-product which can make a significant contribution to operational income. By applying existing knowledge of wool growth, the producer has the potential to improve the quantity and quality of the wool clip. Extensive biological information on wool production is available; however, Doney (1983) stated that "very few new factors have been reported since the intensive period of investigation in the 1960s and 1970s."

Maximum wool production is ultimately determined genetically; however, maximum growth is seldom achieved due to a variety of factors (Thomas and Rook, 1983). It is well recognized and documented that climatic, environmental, seasonal and hormonal changes can affect wool production (Black and Reis, 1979). This section will focus on wool growth as influenced by animal nutrition.

Doney (1983) reported the full effect of feeding changes on wool growth may take three to four weeks before being established. More recently, Hynd and Allden (1984) suggested that six weeks may be required for wool growth to truly reflect dietary changes. Using radio labeled ^{35}S-cystine to determine emergence time for wool fiber requires 5-10 days (Downes and Sharry, 1971).

Drummond et al. (1957) cited numerous experiments from 1926 to 1955 in which increased wool production was obtained by altering level of and/or source of protein in sheep diets. Slen and Whiting (1951) reported a curvilinear response to increasing the level of protein in the basal ration which increased wool production and then plateaued. However, Ferguson (1972) reported that previous research indicates wool growth is insensitive to dietary crude protein percentage. Early work of Drummond et al. (1957) indicated fiber diameter was not affected by different amounts of crude protein (11, 19, 25 or 38%) as a supplement to ewes grazing winter range. However, they did not compare supplemented to unsupplemented animals. Harris et al. (1956) reported protein supplementation to ewes grazing Utah winter range increased grease fleece weight. Van Horn et al. (1959b) reported increasing feed levels resulted in increased grease fleece weights and clean fleece weight. Van Horn et al. (1959a) found no difference in grease fleece weight in ewes fed 150 g of supplement that contained either 19, 28 or 36% crude protein; however, grease fleece weights were higher than if fed 150 g of an 11% protein supplement.

When compared to unsupplemented controls, Shetaewi and Ross (1987) found supplementation had no effect on wool growth of ewes during late gestation and lactation fed a 50:50 mixture of alfalfa and prairie hay *ad libitum* (20% digestible protein supplement). Kenney and Roberts (1984) supplemented ewes fed hay (10.8% crude protein) with whole grains (170 g

DM/hd/d) from two weeks before until six weeks after lambing. They reported increased grease fleece weights of 90, 220 and 230 grams for wheat, oats and lupines, respectively.

Early work conducted by Marston (1932) indicated increased wool production was obtainable by administering cystine subcutaneously or fed in the diet. However, he was unable to demonstrate increased wool production through feeding elemental S or injecting methionine. Reis and Schinckel (1964) indicated increases in wool growth were due to essential amino acids flowing to the small intestine, in particular the S-amino acids.

Reis (1970) indicated the supply of non-sulfur amino acids are unlikely to be limiting for wool growth as abomasal supplementation had no effect on wool growth. Whole proteins that contain a full complement of essential amino acids have stimulated wool growth when given abomasally (Colebrook and Reis, 1969). Numerous studies have been conducted to evaluate the effects that S-containing amino acids have on wool growth when given abomasally. Studies by Reis and Schnickle (1962) and Reis (1967) indicated that abomasal infusion of 2 $g*d^{-1}$ of cysteine improved wool growth. However, larger doses of cysteine (6 to 8 $g*d^{-1}$) reduced wool growth below the maximum response (Reis, 1967). When D-L methionine (2 $g*d^{-1}$) was infused into the abomasum for six weeks, wool growth rates increased 130% above controls (Reis and Schnickle, 1962). Reis (1967) found administering 6 to 8 $g*d^{-1}$ of D-L methionine caused a marked reduction in wool growth.

Supplementing milk-fed lambs with methionine (dietary) had no effect on lamb wool growth from 3 d to 42 d of age (Reis, 1970). Schelling et al. (1973) reported that older, growing lambs (35 kg) post-ruminally infused with D-L methionine (2 to 3 $g*d^{-1}$) had improved N retention compared to controls. However, lambs infused with 4 $g*d^{-1}$ methionine demonstrated decreased N retention and a severe depression in N retention was observed when lambs were administered 6 $g*d^{-1}$ methionine. These decreases in N retention resulted in decreased wool production. Doyle and Bird (1975) provided dietary supplements of 0, 1.9, 3.8, 7.7 and 15.4 $g*d^{-1}$ of D-L methionine to ewes fed roughage diets. Only the 3.8 $g*d^{-1}$ level of methionine improved wool growth and was accompanied by increased N retention.

Reis and Tunks (1974) reported sheep fed roughage diets infused with 2 $g*d^{-1}$ methionine had improved wool growth. However, infusions of 6 to 10 $g*d^{-1}$ methionine caused decreased wool growth. They also indicated when wheat was substituted for roughage, all levels of methionine decreased wool growth. Reis (1967) indicated the adverse effects of high levels of methionine on wool growth rate may be associated with an amino acid imbalance or toxicity. He indicated reduction in feed intake may also accompany high levels of methionine resulting in depressed wool growth. Another possible mechanism by which high levels of methionine could depress wool growth would be through effects on amino acid transport.

In order to overcome the ruminal degradation of S-amino acids, experiments have been conducted with analogues resistant to ruminal degradation. Reis (1967, 1970) reported similar wool growth when methionine hydroxy analog was fed as a dietary supplement. However, L-cysteine ethyl ester hydrochloride did increase wool growth over controls when offered as a dietary supplement (Radcliffe et al., 1985).

Hynd and Allden (1984) reported wool growth varied in direct proportion to post-ruminal protein supply. They reported ewes with higher N flow to the small intestine (increased microbial protein synthesis) had increased wool growth. This is in agreement with Bird and Leng (1984) who found defaunated lambs grew 37% more wool than lambs with high populations of rumen protozoa. Ffoulkes and Leng (1988) reported protozoa decrease the amount of microbial and dietary protein available for small intestine absorption needed for wool production. Diets higher in readily fermentable CHO are associated with increased rumen protozoa (Russell and Hespell, 1981). Cottle (1988a, 1988b, 1988c, 1988d) reported defaunation increased clean wool production by 6.5, 6.5, 6.0, 6.9%, respectively. Cottle (1988a) reported higher sulfur content of greasy wool from defaunated sheep. He also reported protozoal protein contains lower concentrations of sulfur amino acids than does bacterial protein, and the flow of methionine and cystine to the intestines could be expected to be higher in defaunated animals, as there is a higher outflow of bacterial protein from the rumen. Cottle (1988b) reported

methionine supplementation increased clean wool production 23% and 13% for faunated and defaunated sheep, respectively. In addition, supplementation with protected methionine resulted in greater wool production on an all-roughage diet than on high grain diets.

Nitrogen Metabolism

Nitrogen entering the small intestine is a combination of microbial, undegraded intake protein and endogenous protein (NRC, 1985b). Oldham and Tamminga (1980) described the proportional distribution of N in duodenal contents as essential amino acids (EEA), 0.35; non-essential amino acids (NEAA), 0.30; amides, 0.04; nucleic acids, 0.11; ammonia, 0.06; and unknown, 0.14. Amino acid composition of intake protein (EEA:NEAA ratio) can influence the balance of AA available for absorption (Laughren and Young, 1979). The most active site of AA absorption in sheep is the mid to lower ileum, but the highest rate of digesta disappearance occurs in the mid-jejunum (NRC, 1985b). The uptake of AA occurs against a concentration gradient requiring metabolic energy (Johns and Bergen, 1973).

The disappearance of N and AA between the duodenum and ileum can be used as an estimation of apparent absorption. The apparent absorption of non-ammonia N (NAN) and AA from the small intestine is 65 and 70%, respectively, for the amount entering the duodenum (NRC, 1985b).

Tamminga (1980) reported the apparent absorption of EAA is approximately 5% greater than NEAA.

In order to calculate the true absorption of N in the small intestine, a correction must be made for endogenous N that is not reabsorbed from the small intestine. Swanson (1982) reported sources of endogenous N enter the small intestine as enzymes, bile, mucus, serum albumin, lymph, epithelial cells, and other degradable products from the gastrointestinal lining. Nolan (1975) characterized the input of NAN ($g*d^{-1}$) to the small intestine as undegraded intake protein, 6.5; bacterial crude protein, 10.3; and intestinal secretions, 17.0. NRC (1985b) reported the true absorption of NAN and AA in the small intestine are 75% and 80%, respectively.

Fecal N is typically the greatest source of N loss in a ruminant (NRC, 1985b). Nitrogen entering the large intestine consists of undigested feed protein, indigestible feed protein, undigested bacterial protein, plus endogenous N secreted or sloughed from the earlier sections of the intestinal tract. Under most feeding situations, more N enters the large intestine from the ileum than leaves as fecal protein (FP) leading to a net absorption (NRC, 1985b).

Metabolic fecal protein (FPN), or nondietary fecal N, is the loss of N associated with the production of feces. In ruminants, much of the FPN excreted has been regarded as microbial N either synthesized in the large intestine and cecum or indigestible bacterial N passed from the rumen

(Mason and Fredericksen, 1979). Metabolic fecal protein is also considered to represent endogenous proteins lost through the digestive tract as a result of feed intake (NRC, 1985b). It consists of enzymes, mucus, epithelial cellular debris, serum, lymph, bile and urea.

Fecal N excretion has been related to: (1) intake of nitrogen, and (2) either dry matter (DM) intake or fecal DM output in order to estimate true digestibility of N fed and/or the amount of FPN lost by the animal (NRC, 1985b). Swanson (1982) estimated FPN as $g*d^{-1} = 0.03 *$ dry matter intake ($g*d^{-1}$), or $g*d^{-1} = 0.068 *$ fecal dry matter. When animals are fed N-free diets, FPN is of body origin, but when animals are fed protein, the origin of N in the lower gastrointestinal tract is unclear. Therefore, NRC (1985b) suggested FPN be regarded as a true maintenance requirement rather than as a second excretory pathway for waste N arising from the inefficient use of absorbed nitrogen.

Another N requirement that needs to be accounted for when assessing N status is endogenous urinary protein (UPN), the N lost in the urine of animals. Sources of UPN include: creatinine, urea, ammonia, allantoin, uric acid, hippuric acid, and amino acids. After five to seven days of feeding N-free diets, UPN remains relatively constant (NRC, 1985b). Swanson (1982) estimated UPN, $g*d^{-1} = 1.125\ wt^{0.55}$.

Koeln and Paterson (1986) used heifer calves with abomasal and ileal canulae to evaluate AA disappearance in the small intestine. Forty-three

percent of the total dietary N was supplied by three test protein sources: soybean meal (SBM), toasted soybean meal (TSBM), or corn gluten meal (CGM). They reported all treatments were similar in N digestibility and N retention. However, greater quantities of EAA, NEAA and total N reached the small intestine in those animals fed the TSBM and CGM as compared with the SBM. Total AA flow to the SI was 100, 120 and 128% of intake for SBM, TSBM and CGM, respectively. They concluded that although TSBM and CGM resulted in greater total AA reaching the small intestine, these AA may be less digestible as no differences were observed in N balance.

Using growing lambs, Merchen et al. (1987) studied the effect of supplemental protein source (U, SBM, CGM) on nutrient digestibility and N balance. They found protein source had no effect on nutrient digestibility or N balance. From their study they concluded overall protein supply to the small intestine might be increased with SBM or CGM, but the supply of key limiting AA may not have been increased enough to elicit a response.

Hassan and Bryant (1986) reported protein supplementation of NaOH treated straw with fish meal promoted a linear increase in live weight gain and N retention in growing lambs. They reported that microbial protein supply of the basal diet was unable to support lambs at their production level and fish meal supplemented lambs were able to meet their tissue N requirements through the dietary supply of undegraded nitrogen. They suggested that AA

contributed by undegraded N of fish meal may have been used as glycolytic precursors and not for protein accretion.

Hoaglund et al. (1989) reported no differences were detected in N output of straw fed ewes supplemented with blood meal + soybean meal (BM+SBM), SBM or urea (U), even though total N intake was higher for BM+SBM ewes. In addition, BM+SBM ewes gained more weight and had improved wool growth in comparison to SBM or U ewes in response to the increase in daily N retention.

Hoaglund et al. (1989) reported that gestating ewes fed at 80% of NRC (1985a) μE requirement had improved N retention when compared to ewes fed at 100% of NRC. However, Guada et al. (1975) reported increasing the proportion of concentrate (energy intake) in diets of pregnant ewes caused a linear increase in N retention and efficiency of N utilization. However, their dietary metabolizable energy level was 1.4 * maintenance. Therefore, energy intake was not limiting. They concluded increasing the concentrate ratio in the diet increased microbial protein synthesis which increased the quantity of N available for absorption.

Coffey et al. (1989) compared AA utilization in pregnant and non-pregnant ewes. They reported that with similar voluntary intakes, pregnant ewes had greater apparent AA absorption and digestion. In addition, pregnant ewes had greater particulate flow rates. They concluded pregnant ewes meet their increased nutrient demands by increasing flow rates and the

pregnant ewe seems to be more efficient in apparent absorption from the small intestine than the non-pregnant ewe. Other research (NRC, 1985b) reported pregnant ewes increase protein retention for fetal and uterine growth from 6 to 20 $g*d^{-1}$ between weeks 14 and 20 of gestation.

Oldham (1981) suggested pregnant animals may have a greater absorptive area in the small intestine than non-pregnant animals. Forbes (1983) indicated that decreased intake in gestating animals may be due to abdominal fat and/or fetal tissues limiting rumen capacity. Gestating ewes may compensate for limited rumen capacity by increasing passage rate and are more efficient in nutrient absorption, possibly due to a greater absorptive area.

EXPERIMENTAL PROCEDURES

On October 14, 1988, 54 mature Targhee ewes (4 to 8 years old) were selected from the Montana State University flock and maintained on pasture at the Fort Ellis Agricultural Research Station, four miles east of Bozeman, Montana. Ewes were crutched and estrus synchronized on November 1, 1988, with Veramix® pessaries (medroxyprogesterone acetate USP) in accordance with product recommendations (Upjohn). Pessaries were removed 14 d following insertion and ewes were injected intramuscularly with 454 IU pregnant mare serum gonadotropin (PMSG).

Concomitant with estrus synchronization, ewe body condition scores (CS) were recorded and ewes were separated into two groups based upon those scores: CS less than 3.0 and CS greater than 3.0, and fed *ad libitum* alfalfa hay and either .46 or .23 kg barley$*hd^{-1}*d^{-1}$, respectively, in an attempt to equalize body condition at the start of the experimental period. Ewes were CS by two technicians using a 1 to 5 scale with 1=severely emaciated and 5=extremely good condition (Russel et al., 1969).

Ewes were assigned to one of two breeding groups (n_1=28, n_2=26) on November 16, 1988, and exposed to a Targhee ram fitted with a marking harness for a 35-d breeding season. Breeding marks were recorded daily the

first 7 d and every 3 d thereafter. Fourteen days following ram introduction, marking harness crayon color was changed to detect second cycle matings. During breeding and until December 22, 1988, ewes were fed alfalfa hay *ad libitum* and .35 kg barley$*hd^{-1}*d^{-1}$. Beginning on December 23, 1988, ewes were group fed 1.8 kg of barley straw (BS)$*hd^{-1}*d^{-1}$.

Iso-nitrogenous and iso-energetic pelleted diets (Table 3) were formulated to provide 90% of the NRC (1985a) daily protein and 100% daily metabolizable energy requirements for a 70 kg non-lactating ewe during the first 15 weeks of gestation, while at the same time differing in the level of EP and STAR to CELL ratio (Table 4). Protein degradability differences were obtained using either urea (U), soybean meal (SBM), or blood meal (BM). Levels of BS and barley grain were adjusted to provide diets differing in STAR and CELL concentration.

A total of 42 ewes were randomly assigned to a 2 x 3 factorial arrangement of treatments, with 7 ewes per treatment combination. Ewes with CS less than 2.5, body weight $\leq$ 60 kg, or body weight $\geq$ 80 kg were not used. In addition, one ewe per treatment exhibited second cycle mating. Treatments included U, SBM or BM as the supplemental protein source and two STAR to CELL ratios. A 14 d adjustment period was used to acclimate animals to confinement and feeding conditions of the experiment. Ewes were individually fed twice daily (0700 and 1600 hrs) in 1.2 x 1.5 m pens in an open front barn. Diets were weighed at each feeding with orts weighed

and recorded at the morning feeding. Following the morning feeding (approximately 1 h), ewes were allowed access to water in a group setting and re-penned prior to the evening feeding.

Table 3. Ingredient composition of diets (DM basis).

Item	Carbohydrate Source					
	Starch			Cellulose		
	Protein Source			Protein Source		
	U	SBM	BM	U	SBM	BM
Dry matter, %	96.2	96.9	96.4	96.1	96.4	96.8
Ingredient, %						
Barley, straw	67.5	68.5	66.0	81.1	82.1	83.9
Barley	10.5	10.6	10.2			
Wheat mill run	8.4			8.0		
Corn starch			7.9			
Molasses	8.8	8.6	6.6	5.9	5.1	7.8
Urea	.9			.9		
Soybean meal		8.2			8.4	
Blood meal			4.6			4.0
Dicalcium phosphate	.1	.3	.7	.1	.5	.5
Gypsum	.3	.3	.4	.3	.2	.2
Bentonite	3.2	3.1	3.0	3.2	3.3	3.2
Salt, iodized	.2	.2	.2	.2	.2	.2
Salt, trace mineral	.2	.2	.2	.2	.2	.2

Table 4. Nutrient composition of diets (DM basis).

Item	Carbohydrate Source					
	Starch			Cellulose		
	Protein Source			Protein Source		
	U	SBM	BM	U	SBM	BM
Carbohydrate, %						
NDF	53.3	57.9	58.5	61.7	54.8	61.4
ADF	34.6	34.8	36.6	41.4	33.4	41.3
STAR	11.7	7.5	13.8	4.1	4.4	3.6
CELL	26.5	28.4	27.8	31.4	26.1	31.4
STAR:CELL ratio	.4	.3	.5	.1	.2	.1
GE, Mcal	3.8	3.8	3.9	3.8	3.4	3.9
Protein, %	8.5	7.9	8.1	7.7	6.9	7.3
Nitrogen[a]						
Microbial	13.5	13.8	15.8	14.7	11.6	11.2
NH_3-N	.9	.9	.8	1.1	.7	.5
Escape	9.1	7.8	10.0	4.5	7.2	10.6
Nitrogen[b]						
Rumen degradable	8.0	7.0	4.6	9.6	6.3	3.9
Escape	5.6	5.8	8.4	2.8	4.8	7.9

[a]N = g/kg DM entering duodenum
[b]N = g/kg DM intake

Pregnancy status was determined using an Oviscan 3® real-time sector scanner ultrasound, January 10, 1989. Three ewes were diagnosed non-pregnant, and one ewe from each treatment group was removed. An SBM-STAR ewe expired due to an occluded esophagus (January 19, 1990). In

addition, the continual choking and inadequate consumption by one BM-CELL ewe resulted in removal of that ewe's data from the study. Therefore, data used for analysis were obtained on a total of 34 ewes.

Period 1, January 13 to February 18, 1990, approximates days 60 through 95 of gestation for ewes mated the first two days of the breeding cycle. Period 2, February 19 to March 18, 1990, approximates day 95 to 125 of gestation for first cycle matings. Ewes were weighed on January 13 and 14, after a 12-h fast. Two fasted weights were averaged to determine initial weight. Fasted weights were collected at the beginning and end of each experimental period (February 18 and March 17-18, 1989). Two fasted weights were averaged to obtain a final weight. Condition scores (Russel et al., 1969) were determined on each ewe when weighed.

Ewes were dye banded to assess wool growth with an aqueous solution of Durafur Black R (Icianz Pty., Ltd.) on January 14, 1989, with length measured (mm rule) from the base of the fiber at the skin to the bottom of dye band (March 18, 1989). Wool mid-side samples were collected with Oster size 40 surgical clippers as described by Langelands and Wheeler (1968) on January 14 and at the beginning and end of each experimental period. Mid-side samples were scoured in ethanol, oven dried and conditioned for three days. Fiber diameter was determined according to American Society for Testing and Materials standards (ASTM, 1987).

Blood samples were collected in a semi-fasted state (Lindsay, 1978) via jugular puncture prior to the morning feeding at the beginning and end of each experimental period. Blood samples were centrifuged at 3000 g for 15 min; plasma was decanted and frozen (-20° C) until analyzed for glucose (GLC). Serum samples were analyzed by the Montana State University Marsh Diagnostic Laboratory for total protein (TP), albumin (ALB), blood urea nitrogen (BUN) and creatinine (CRE) using an Ames Pacer semi-automated analyzer. Three beta-hydroxybutyrate (β-OH) concentrations were measured from whole blood samples collected in hepranized tubes according to procedures outlined by Williamson and Mellanby (1974).

During each experimental period, a four d metabolism trial was conducted. Three ewes per treatment group were fitted with fecal and urine collection bags double-lined with plastic sacks. Twenty-four h total fecal and urine output was collected daily, weighed and hand-mixed with a 10% (by weight) sub-sample preserved in a frozen state. Daily sub-samples were compiled and a 25% (weight) sample was frozen. Excreta samples were air dried, ground in a Wiley mill (5 mm screen), and sub-sampled for analyses. Diet and excreta samples were analyzed for dry matter, total nitrogen (%N x 6.25 = crude protein) using macro Kjeldahl N analysis (AOAC, 1984) and gross energy (Parr adiabatic oxygen bomb calorimetry). Nitrogen and GE intake, output and subsequent balances were calculated.

At the end of the experimental feeding period on March 19, 1989, ewes were dewormed and group fed until parturition (approximately three weeks). Ewes were fed .45 kg barley$*hd^{-1}*d^{-1}$ and offered *ad libitum* grass-alfalfa hay, water and trace mineralized (TM) salt. Immediately following parturition, ewe body weight and lamb(s) birth weights were recorded. Ewes were individually jugged with lamb(s) for at least 24 h and moved into mixing pens after a strong maternal bond was established between ewe and offspring. Ewes were maintained on *ad libitum* alfalfa pellets and water in the jugs; had access to *ad libitum* hay, water and TM salt; and received .67 kg barley$*hd^{-1}*d^{-1}$. Lambs were not creep fed, but did have access to hay, water and TM salt. Ewes and lambs were weighed on May 19, 1989, with lamb weights adjusted to 28 d. Lambs were weaned July 13, 1989, and ewe and lamb weights recorded. Lamb weaning weights were adjusted to 90 d.

A digestion trial was conducted with ruminal and duodenal fistulated ewes (n=4) to determine ruminal degradation and microbial protein synthesis of each of the diets (Table 4). Two ewes were individually fed each diet for a 13 d adjustment period at 0800 and 1700 hrs. At each feeding ewes were intra-ruminally administered gelatin capsules containing 2.5 g chromium oxide to monitor passage rate. On day 14, rumen extrusa were collected during the 0800 feeding and microbial pellets prepared as described by Smith and McAllan (1970). Purine concentrations of microbial pellets were determined to estimate microbial protein synthesis (Zinn and Owens, 1986). Duodenal

extrusa samples were collected at 0, 3, 6 and 9 h after the 0800 feeding, with individual 50 ml samples frozen (-20° C) until analyzed for ammonia N. Duodenal samples were freeze-dried and ground through a Wiley mill (2 mm screen), with macro Kjeldahl nitrogen (AOAC, 1984) analyses conducted. Chromium oxide concentration was determined on duodenal extrusa (Fenton and Fenton, 1979).

Diets were analyzed for dry matter (Table 3) and nitrogen (Table 4) (AOAC, 1984). Gross energy (Table 4) was determined by Parr adiabatic oxygen bomb calorimetry. Acid detergent fiber, neutral detergent fiber and acid detergent lignin were determined (Van Soest and Robertson, 1980), with cellulose determined by subtraction. Percent soluble sugars were determined using techniques described by Åman and Hesselman (1984).

Ewe weight, CS and N metabolism data were analyzed using a completely randomized design with analysis of variance by the general linear model (GLM) procedure of the Statistical Analysis System (SAS, 1987). The model included the fixed effects of PTN, CHO and type of birth. Date of parturition was used as a covariate and the PTN * CHO interaction was included. A similar model was used for lamb traits, except lamb sex was included in the model and type of birth (or rearing) used as a covariate. Stepwise analysis was conducted on wool traits and gross energy data, with initial micron and initial ewe weight used as covariates. Blood metabolite concentrations at periods 1 and 2 were analyzed using a multivariate repeated measures

procedure (SAS, 1987). The model included the fixed effects of PTN, CHO, number born, all two-way interactions, period and period by fixed effect interaction. Initial metabolite concentration was used as a covariate.

RESULTS

No differences were detected in ewe weight change (Table 5) in periods 1 and 2. However, a significant ($P < .01$) PTN by CHO interaction was detected for total weight change (BW) (Table 6). Consequently, comparisons were made within PTN or CHO. Protein had no effect ($P > .05$) on ewe weight gains when STAR was the CHO. However, when CELL was the CHO, ewes fed U gained less ($P < .05$) BW than SBM or BM ewes.

Table 5. Effect of protein or carbohydrate source on within-period ewe weight change (kg).

Item	PERIOD	
	1	2
Protein Source		
U	.30	1.59
SBM	.09	2.73
BM	1.14	2.62
SE[a]	.53	.45
Carbohydrate Source		
STAR	.83	2.41
CELL	.19	2.21
SE[a]	.43	.37

[a]SE = standard error of least squares means

Table 6. Effect of protein and carbohydrate source on total ewe weight change (kg).

Protein Source	Carbohydrate		SE[a]
	STAR	CELL	
U	3.67[b]	.10[c]	.80
SBM	2.15[bc]	3.48[b]	.82
BM	3.89[b]	3.62[b]	.83
SE[a]	.81	.82	.82

[a]SE = standard error of least squares means
[b,c]Means with uncommon superscripts differ (P < .01)

Protein or CHO had no effect (P > .10) on ewe CS change, while ewes lost body condition during the experiment (Table 7). Average CS at the beginning and end of the experimental period was 3.4 and 2.8, respectively, with no difference (P > .10) detected between treatment groups.

Protein or CHO had no effect (P = .26 and .23, respectively) on longitudinal wool growth (Table 8). However, ewes fed BM tended (P = .26) to have greater wool growth (15.4 mm) than U or SBM ewes (15.0 and 14.6 mm, respectively). Also, ewes fed CELL had a tendency (P = .23) toward greater wool growth (15.5 mm) than ewes fed STAR (14.4 mm). The increase in length did not affect (P > .05) grease fleece weights. Initial fiber diameter was not different (P > .10), with an average fiber diameter of 24.0 μm for all treatment combinations. Fiber diameter was smaller at the conclusion of the study (Table 9). A significant (P < .05) PTN by CHO interaction was detected for final fiber diameter. Ewes fed BM-CELL had larger fiber diameters than the other treatment combinations.

Table 7. Effect of protein or carbohydrate source on body condition score change.

Item	PERIOD		Total
	1	2	
Protein Source			
U	-.22	-.42	-.64
SBM	-.17	-.34	-.51
BM	-.20	-.45	-.65
SE[a]	.16	.14	.17
Carbohydrate Source			
STAR	-.15	-.40	-.56
CELL	-.24	-.40	-.65
SE[a]	.13	.11	.14

[a]SE = standard error of least squares means

Table 8. Effect of protein or carbohydrate source on wool growth (mm) and grease fleece weight (kg).

Item	Wool Growth	Fleece Weight
Protein Source		
U	15.00	4.00
SBM	14.60	3.80
BM	15.40	4.10
SE[a]	.52	.18
Carbohydrate Source		
STAR	14.40	4.00
CELL	15.50	4.00
SE[a]	.44	.14

[a]SE = standard error of least squares means

Table 9. Effect of protein and carbohydrate source on final wool fiber diameter (μm).

Protein Source	Fiber Diameter		SE[a]
	STAR	CELL	
U	21.00[b]	20.00[b]	.59
SBM	21.30[b]	20.50[b]	.61
BM	20.70[b]	22.90[c]	.62
SE[a]	.61	.61	.61

[a]SE = standard error of least squares means
[b,c]Means with uncommon superscripts differ (P < .05)

Protein source had no effect (P > .10) on TP concentration (Table 10). Ewes fed STAR had higher (P < .05) TP concentrations than CELL (6.59 vs. 6.13, respectively) in period 1. However, no differences (P > .10) were detected in period 2.

Carbohydrate source had no effect (P > .10) on ALB concentrations during the experiment (Table 10). However, ewes fed BM (period 1) and BM and SBM (period 2) had higher (P < .05) ALB concentrations than those fed U.

Blood urea nitrogen (BUN) values were not affected (P > .05) by PTN (Table 11). Ewes fed STAR had higher (P < .05) BUN values (15.81) than ewes fed CELL (12.32).

Creatinine values (mg/dl) were higher (P < .05) for ewes fed BM than those fed either U or SBM during period 1, with the trend (P > .10) continuing in the second period. Creatinine concentration was not affected (P > .10) by CHO (Table 11).

Table 10. Least squares means of serum protein and albumin concentration as influenced by protein or carbohydrate source (mg/dl).

Item	Period 1		Period 2	
	Metabolite		Metabolite	
	TP	ALB	TP	ALB
Protein Source				
U	6.18	3.53[b]	5.44	2.97[b]
SBM	6.41	3.63[b]	5.52	3.25[c]
BM	6.49	3.82[c]	5.69	3.34[c]
SE[a]	.14	.06	.10	.07
Carbohydrate Source				
STAR	6.59[b]	3.63	5.65	3.20
CELL	6.13[c]	3.69	5.46	3.17
SE[a]	.12	.05	.08	.05

[a]SE = standard error of least squares means
[b,c]Means with uncommon superscripts differ (P < .05)

During period 1, β-OH levels (mM/l) were greater (P < .05) for ewes fed U (.33) than SBM or BM (.21 and .22, respectively; Table 11). Ewes fed STAR had greater (P < .05) β-OH levels (.29) compared to CELL (.22). No differences for PTN or CHO (P > .05) were detected during period 2, with β-OH concentrations greater (P < .05) than in period 1. During period 1, ewes bearing multiple fetuses tended (P = .15) to have higher β-OH levels (Table 12) than ewes carrying a single fetus (.27 vs. .24). In period 2, ewes bearing multiple fetuses had greater (P < .05) levels of β-OH than single bearing ewes (.59 and .32, respectively). Values of β-OH ranged from .21 to .59 mM/l.

Table 11. Least squares means of blood metabolite concentrations as influenced by protein or carbohydrate source.

Item	PERIOD							
	1				2			
	Metabolite[a]				Metabolite[a]			
	BUN	CRE	β-OH	GLC	BUN	CRE	β-OH	GLC
Protein Source								
U	13.60	1.48[c]	.33[d]	50.60	14.55	1.44	.46	42.70
SBM	13.41	1.45[c]	.21[c]	50.70	14.55	1.46	.43	37.60
BM	13.75	1.60[d]	.22[c]	49.60	13.09	1.51	.47	36.50
SE[b]	.85	.04	.02	1.79	.88	.06	.09	2.13
Carbohyd Source								
STAR	14.50	1.53	.29[d]	48.50	15.81[c]	1.51	.50	37.90
CELL	12.67	1.50	.22[c]	52.10	12.32[d]	1.43	.40	40.00
SE[b]	.67	.03	.02	1.47	.69	.05	.07	1.75

[a]Blood metabolite concentration reported as mg/dl with the exception of β-OH, which is reported as mM/l

[b]SE = standard error of least squares means

[c,d]Means in same column within period without a common superscript differ ($P < .05$)

Table 12. Least squares means of β-hydroxybutyrate (mM/l) as influenced by number born.

Number Born[a]	PERIOD	
	1	2
S	.24	.32[b]
M	.27	.59[c]
SE[d]	.02	.07

[a]S = single births; M = multiple births

[b,c]Means in same column without a common superscript differ ($P < .05$)

[d]SE = standard error of least squares means

Plasma glucose concentrations (GLC) were not affected (P > .05) by PTN or CHO (Table 11). An interaction between number born and CHO was detected (P < .05). Ewes bearing multiple fetuses fed STAR had lower (P < .05) GLC concentrations than ewes fed STAR carrying a single fetus in both periods 1 and 2 (Table 13). Ewes bearing multiple fetuses and fed CELL in periods 1 and 2 demonstrated higher (P < .05) GLC concentrations than ewes bearing multiple fetuses fed STAR.

Nitrogen intakes were similar (P > .50) for PTN throughout the experiment (Table 14). During period 1, N output tended to be higher (P = .06) for BM ewes than U and SBM. Although subsequent N balances were similar (P > .05) for PTN, the percentage of dietary N retained (%N) was lower (P < .05) for BM than U and SBM ewes. During period 2, PTN had no effect (P > .05) on N balance.

Table 13. Least squares means of plasma glucose concentration (mg/dl) as influenced by carbohydrate source and number born (period 1).

Carbohydrate Source	Number Born[a]	Period 1
STAR	S	52.11[b]
STAR	M	44.86[c]
CELL	S	51.03[bc]
CELL	M	53.24[b]
SE[d]		2.02

[a]S = single births; M = multiple births
[b,c]Means in same column without a common superscript differ (P < .05)
[d]SE = standard error of least squares means

Table 14. Least squares means for effect of protein source on nitrogen (g/d) balance.

Item	Period 1				Period 2			
	Protein Source				Protein Source			
	U	SBM	BM	SE[a]	U	SBM	BM	SE[a]
Nitrogen g/d								
Intake	19.0	18.1	18.3	.55	19.0	18.1	18.3	.55
Output	8.1	7.4	8.9	.37	9.4	8.6	9.5	.41
Balance	10.9	10.7	9.4	.54	9.6	9.5	8.7	.40
Dietary N Retained (%)	57.4[b]	59.0[b]	51.3[c]	1.95	50.7	52.3	47.9	1.50

[a]SE = standard error of least squares means
[b,c]Means in same row within period without a common superscript differ ($P < .05$)

Carbohydrate source had no effect ($P > .05$) on N metabolism during period 1 (Table 15). However, during period 2, STAR ewes retained more ($P < .05$) dietary N than CELL ewes (52.7% vs. 47.9%, respectively).

Table 15. Least squares means for effect of carbohydrate source on nitrogen (g/d) balance.

Item	Period 1			Period 2		
	Carbohydrate Source			Carbohydrate Source		
	STAR	CELL	SE[a]	STAR	CELL	SE[a]
Nitrogen (g/d)						
Intake	18.4	18.6	.43	18.4	18.6	.43
Output	8.1	8.1	.29	8.7[b]	9.7[c]	.32
Balance	10.3	10.5	.43	9.7	8.9	.31
Dietary N Retained (%)	55.6	56.2	1.54	52.7[b]	47.9[c]	1.18

[a]SE = standard error of least squares means
[b,c]Means within rows and period with uncommon superscripts differ ($P < .05$)

Iso-nitrogenous dietary intakes at 90% NRC resulted in the CELL ewes consuming more ($P < .05$) GE than STAR (Table 16). Although GE intake by the STAR ewes was lower, the percentage of dietary GE retained was similar ($P > .05$) throughout the experiment for both STAR and CELL ewes. Protein source had no effect ($P > .05$) on GE intakes, output, balances, or percent dietary GE retained (Table 17).

Table 16. Least squares means for effect of carbohydrate source on gross energy (Mcal/d) balance.

Item	Period 1			Period 2		
	Carbohydrate Source			Carbohydrate Source		
	STAR	CELL	SE[a]	STAR	CELL	SE[a]
Energy (Mcal/d)						
Intake	5.4[b]	6.1[c]	.05	5.4[b]	6.1[c]	.05
Output	2.3	2.5	.08	2.6[b]	3.1[c]	.07
Balance	3.1[b]	3.6[c]	.10	2.8	3.0	.07
Dietary Energy Retained (%)	57.9	59.7	1.40	51.7	48.9	1.07

[a]SE = standard error of least squares means
[b,c]Means within rows and period with uncommon superscripts differ ($P < .05$)

Protein or CHO source had no effect on ewe weights at lambing, 28 d, weaning (Table 18), or average lamb birth weight and weight changes from 0-28 d and 29-90 d (Table 19). Carbohydrate source had no influence ($P > .05$) on lamb performance from birth to weaning; however, lambs of BM ewes gained more ($P < .05$) total weight than lambs of U ewes, with SBM being intermediate. Ewes fed BM during gestation tended to be heavier than U ewes during the experiment and during lactation.

Table 17. Least squares means for effect of protein source on gross energy (Mcal/d) balance.

Item	Period 1				Period 2			
	Protein Source				Protein Source			
	U	SBM	BM	SE[a]	U	SBM	BM	SE[a]
Energy (Mcal/d)								
Intake	5.7	5.7	5.9	.06	5.7	5.7	5.9	.06
Output	2.4	2.2	2.5	.10	2.9	2.8	2.9	.09
Balance	3.3	3.5	3.4	.12	2.8	2.9	3.0	.09
Dietary Energy Retained (%)	57.4	60.5	58.4	1.78	48.3	51.3	51.3	1.35

[a]SE = standard error of least squares means

Table 18. Effect of protein or carbohydrate source on ewe lambing, 28 d and weaning weights (kg).

Item	Lambing	28 d	Weaning
Protein Source			
Urea	61.60	62.90	69.30
SBM	63.50	61.40	68.40
BM	63.00	64.10	70.60
SE[a]	1.78	2.08	2.20
Carbohydrate Source			
STAR	62.30	62.40	70.00
CELL	63.00	63.20	69.00
SE[a]	1.42	1.66	1.74

[a]SE = standard error of least squares means

Table 19. Effect of protein or carbohydrate source on average lamb birth weight and lamb weight change (kg).

Item	Birth	0-28 d	28-90 d	Overall
Protein Source				
Urea	4.20	5.60	15.60	20.90[a]
SBM	4.50	6.50	16.60	23.10[ab]
BM	4.70	7.10	18.00	25.10[b]
SE[c]	.25	1.18	1.35	1.68
Carbohydrate Source				
STAR	4.60	6.50	17.00	23.50
CELL	4.30	6.30	16.50	22.50
SE[c]	.22	1.10	1.25	1.55

[a,b]Means within columns with uncommon superscripts differ ($P < .05$)
[c]SE = standard error of least squares means

DISCUSSION

Total BW gains between protein sources were similar when STAR was the CHO. However, when CELL was the CHO, ewes fed U gained less BW than SBM or BM ewes. These data suggest no benefit in ewe weight gain to feeding EP in conjunction with a readily fermentable CHO. Starch should be utilized efficiently by the rumen microbes as an energy source for microbial protein synthesis. Merchen et al. (1987), Meissner and Todtenhöfer (1989), and Rooke and Armstrong (1989) indicated that diets high in starch provide a readily fermentable energy source used for microbial protein synthesis. Ewes fed STAR had greater microbial protein (g N$*$kg^{-1} DM entering the duodenum $*$ 6.25) flow d^{-1} than CELL ewes (90 vs. 78 g, respectively; Table 4). When CELL was the primary CHO, ewe BW gain was similar if BM or SBM were fed (Tables 5 and 6), indicating that the EP being provided by these PTN sources was utilized efficiently. Hoaglund et al. (1989) reported supplementing ewes fed straw with an EP increased ewe weight gain. However, in their study, diets were designed to be iso-rumen degradable, with BM+SBM ewes having more total N reaching the small intestine for absorption and subsequent utilization than other treatment combinations.

Ewes fed STAR exhibited higher TP and BUN concentrations than ewes fed CELL. The higher TP and BUN concentrations are related to increased microbial protein synthesis. The increase in protein reaching the small intestine was absorbed and transported to the liver where deamination resulted in increased urea production. The trend towards higher TP and ALB with similar BUN concentrations for BM ewes is indicative of improved quality or quantity of protein absorbed from the small intestine. Higher ALB in SBM and BM ewes is probably related to more AA being transported to the liver which resulted in increased ALB synthesis. This is in agreement with Hoaglund et al. (1989) in which ewes fed BM+SBM or SBM had elevated ALB concentrations.

Although N balances were similar for PTN, during period 1 the percentage of dietary N retained was lower for BM than U or SBM. This may be related to the EP providing more AA for absorption in the small intestine, with the excess being excreted. Higher CRE concentrations for ewes fed BM during period 1 with the trend continuing into the second period may also indicate an increase in AA reaching the gut for absorption. Total fecal and urine collections were used for the N metabolism trial. NRC (1985b) indicates CRE to be one of the sources of endogenous urinary N. An excess in the phosphocreatinine could have been excreted in the blood and subsequently eliminated. This is contradictory to the findings of Hoaglund et al. (1989) who reported higher CRE concentrations in ewes fed rumen degradable PTN.

They reported elevated CRE concentrations were indicative of tissue catabolism, with ewes in weight loss having higher CRE. As gestation progresses and the demand for AA by the products of conception (YPN) increases, AA reaching the small intestine may be utilized for YPN rather than the synthesis of CRE. During period 2, PTN had no effect on N outputs, balances, percent N retained, or CRE. This would indicate that as gestation progressed, the increased AA reaching the small intestine of the BM ewes was being utilized more efficiently. This agrees with Oldham (1981) and Coffey et al. (1989) who reported the pregnant ewe is more efficient in AA utilization than the non-pregnant ewe.

Carbohydrate source had no effect on nitrogen balance during period 1. However, ewes fed STAR retained more N than ewes fed CELL during period 2. Although dietary N intakes were similar, by design the STAR diets contained a higher STAR:CELL ratio than CELL. This increased STAR:CELL ratio provided a more readily fermentable CHO for VFA production and microbial growth. Therefore, the quantity of N reaching the small intestine was greater for the STAR ewes. It appears during early gestation, when N requirements for fetal tissue growth are low, microbial protein synthesis on either CHO was sufficient to meet the ewes' N requirements. However, as gestation progressed and YPN demand increased, STAR ewes retained more N than CELL ewes. This is consistent with the STAR ewes tending to gain more total weight and lose less condition that CELL ewes.

All ewes demonstrated a decrease in CS during the experiment. Faichney and White (1987) reported that placental size increased in ewes fed restricted diets, which may partially explain ewe weight gains with a reduction in CS. As gestation progressed, ewes tended to lose more CS and gain BW. Increased fetal demand for energy caused a further reduction in CS. As fetal mass increased with gestation, BW gain increased. This is supported by the increase in β-OH concentrations. Increased β-OH concentrations from period 1 to period 2 suggest that ewe body fat reserves were reduced as gestation progressed and fetal demand increased. Russel (1984) indicated inadequate energy intake resulted in β-OH levels greater than .8 mM/1. Thus, ewes were not subjected to inadequate energy intake. The decrease in GLC as gestation progresses is a result of demand by YPN. Increases in GLC of ewes fed CELL may be due to an increase in gluconeogenesis necessitated by lower amount of readily fermentable CHO. Ewes fed CELL tended to gain less total weight and lose more CS than ewes fed STAR, indicating a need to utilize more body reserves.

Fetal number had no influence on β-OH during period 1. This was not unexpected, as ewes were 95 d into gestation by the end of period 1. However, β-OH concentration increased and was affected by fetal number at the conclusion of period 2. Ewes bearing multiple fetuses had higher β-OH concentrations than ewes with singles. The increased demand for energy by the additional fetus resulted in a greater depletion of body reserves. This is

in agreement with Hove and Blom (1976), who reported ketone body concentration increased as gestation progressed and fetal number increased.

Although GE intake by STAR ewes was lower, the percentage of dietary GE retained was similar throughout the experiment for both STAR and CELL. Hoaglund et al. (1989) reported ewes fed at .8 maintenance for ME were as efficient as ewes fed at maintenance in energy retention. Protein source had no effect on energy intake, output, balance or percent energy retained. It appears that the STAR diets provided additional AA which were utilized for gluconeogenic purposes rather than tissue N. Protein intake increases insulin secretion. Prior and Smith (1982) reported insulin stimulates uptake and incorporation of AA and decreases liver glucose output. This is in agreement with STAR ewes tending to have decreased glucose concentrations and increased blood urea nitrogen concentrations. This is also in agreement with the decrease in N retention during period 2 for CELL compared to STAR.

Due to time limitations of the experiment and the time required for wool growth to truly reflect dietary changes (Doney, 1983), extraordinary changes in wool growth rate were not expected. Wool growth and grease fleece weights were unaffected by PTN or CHO. However, there was a tendency for the BM towards greater longitudinal wool growth. Dietary treatments were administered for 63 d but grease fleece weights represent 365 d. Therefore, grease fleece weight combined with small experimental numbers result in an unfair assessment of the nutritional effects of the study on fleece weight.

Hoaglund et al. (1989) reported a similar trend to feeding EP. Hynd and Allden (1984) reported wool growth varies with post-ruminal protein supply. Blood meal contains 1.35% cystine and .97% methionine (NRC, 1985a). Blood meal appeared to offer a more optimum balance of amino acids for wool production. Decreased change in fiber diameter by the BM-CELL ewes may be related to nutrient supply as affected by rumen protozoa. Russell and Hespell (1981) reported diets high in fermentable CHO are associated with increased rumen protozoa. Cottle (1988a) reported protozoa contain lower concentrations of S-AA than bacteria. Therefore, STAR diets may have contained higher rumen protozoal populations than the CELL diets which provide more S-AA for wood growth. Ffoulkes and Leng (1988) indicated large populations of protozoa in the rumen decreases the amount of microbial and dietary protein available for the host animal. Veira (1986) reported VFA proportions are often changed by the presence or absence of protozoa. Lowering of the protozoal population in the CELL may have resulted in a shift in VFA production and more bacterial nitrogen reaching the small intestine. The combination of decreased protozoa and the increase in S-AA made available from the BM appears to be the reason for BM-CELL ewes having larger fiber diameters at the end of the study.

Protein or CHO source had no effect on ewe weights at lambing, 28 d, or weaning weight, although ewes fed BM tended to be heavier throughout the experiment. Average lamb birth weight and weight changes from 0-28 d

and 28-90 d were not affected by PTN or CHO. However, lambs of BM ewes gained more total weight than U ewes, with SBM being intermediate. Increased ewe body weight at lambing and the tendency toward heavier weight at 28 d may have influenced milk production, which may account for the higher lamb weight changes. Hoaglund (1989) reported feeding ewes a non-rumen degradable protein source during mid-gestation had no effect on ewe or lamb weights following parturition. Because of the small size of the data set, the increased post-parturition gain by lambs of BM ewes is most likely due to statistical drift.

CONCLUSION

In order to optimize microbial protein synthesis, both energy and N sources need to be available simultaneously. Feeding highly fermentable CHO sources (STAR) stimulated microbial protein synthesis which improved ewe metabolism and performance. However, ewes fed diets high in CELL gained similarly to those fed STAR if an escape protein source was fed. When CELL was used as the primary CHO source, ewes tended to lose more body condition and appeared to have less protein reaching the small intestine. Feeding BM resulted in blood metabolite profiles indicative of improved quantity and/or quality of protein being absorbed by the small intestine and metabolized in the liver. Feeding escape protein tended to increase wool growth.

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APPENDIX

Table 20. Analysis of variance for effect of protein and carbohydrate source on ewe weight change (period 1).[a]

Source of Variation	Degrees of Freedom		Sums of Squares		Mean Squares		F-Ratio		PR > F	
Corrected total	33		106.6							
Model	7		31.5		4.5		1.56		.19	
Protein		2		6.4		3.2		1.11		.34
Carbohydrate		1		3.3		3.3		1.13		.30
Type of birth		1		1.1		1.1		.37		.55
Protein*Carbohydrate		2		12.1		6.0		2.10		.14
Parturition date		1		4.9		4.9		1.70		.20
Error	26		75.1		2.9					

[a]Type III sums of squares from SAS were used.

Table 21. Analysis of variance for effect of protein and carbohydrate source on ewe weight change (period 2).[a]

Source of Variation	Degrees of Freedom		Sums of Squares		Mean Squares		F-Ratio		PR > F	
Corrected total	33		90.0							
Model	7		35.2		5.0		2.39		.05	
Protein		2		8.9		4.4		2.10		.14
Carbohydrate		1		.3		.3		.15		.70
Type of birth		1		12.4		12.4		5.89		.02
Protein*Carbohydrate		2		12.4		6.2		2.95		.07
Parturition date		1		4.0		4.0		1.91		.18
Error	26		54.8		2.1					

[a]Type III sums of squares from SAS were used.

Table 22. Analysis of variance for effect of protein and carbohydrate source on ewe weight change (total).[a]

Source of Variation	Degrees of Freedom		Sums of Squares		Mean Squares		F-Ratio		PR > F	
Corrected total	33		173.0							
Model	7		80.6		11.5		3.24		.01	
Protein		2		19.8		47.8		2.78		.08
Carbohydrate		1		5.6		5.6		1.58		.22
Type of birth		1		20.8		20.8		5.84		.02
Protein*Carbohydrate		2		35.0		17.5		4.93		.01
Parturition date		1		<.1		<.1		.01		.91
Error	26		92.4		3.5					

[a]Type III sums of squares from SAS were used.

Table 23. Analysis of variance for effect of protein and carbohydrate source on ewe weight at parturition.[a]

Source of Variation	Degrees of Freedom		Sums of Squares		Mean Squares		F-Ratio		PR > F	
Corrected total	28		870.5							
Model	7		277.8		39.7		1.41		.25	
Protein		2		17.4		8.7		.31		.74
Carbohydrate		1		3.4		3.4		.12		.73
Type of birth		1		21.0		21.0		.75		.40
Protein*Carbohydrate		2		1.6		.8		.03		.97
Parturition date		1		120.1		120.1		4.25		.05
Error	21		592.8		28.2					

[a]Type III sums of squares from SAS were used.