The effect of non-rumen degradable protein and metabolizable energy level on metabolism and performance of gestating ewes

by Cheryl Marie Hoaglund

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

Abstract:
Objectives of this experiment were to evaluate the effects of nonrumen degradable protein (NRDP) and metabolizable energy (ME) requirement on metabolism and performance of ewes during early to midgestation. Forty-two ewes were allocated by randomization in a 2 X 3 factorial design and fed individually for 84 days at 80 or 100% NRC (1985) ME requirement and supplemented with either urea (U), soybean meal (SEM), or blood meal+SEM (EMfSEM). All diets were formulated to be isorumen degradable for protein with seven ewes per treatment combination. Blood meal+SEM supplemented ewes gained more (Pc.05) weight and had greater (Pc.05) wool growth than either U or SEM ewes during the investigation. Ewes fed EMfSEM and SEM had higher (P>.05) serum glucose concentrations than U. Total protein, albumin and blood urea N concentrations were different (P<.05) among treatments, with EMfSEM being greater than SEM and SEM greater than U. Urea ewes had increased (Pc.05) alkaline phosphatase concentrations compared to SEM and EMfSEM ewes. Urea ewes also lost more (Pc.05) weight and body condition than other treatments. Ewes fed EMfSEM retained more (Pc.05) g of N daily than ewes fed either U or SEM. Soybean meal and EMfSEM X 80% ME requirement had improved protein: energy ratios compared to other treatment combinations. However, U and SEM fed 100% ME intake had protein: energy ratios that may have been insufficient for utilization of available energy. Number of lambs bom, 21 day and lamb weaning weights were not affected (P>.05) by protein supplement or ME intake. Even though ewes fed 80% ME requirement had increased (Pc.05) 21 day milk production compared to 100% ME, composition was not different (P>.05), with the exception of lactose. In conclusion, feeding a protein supplement containing a NRDP. source (EM+SEM) to ewes in early to mid-gestation elicited a positive response in N balance, ewe weight, body condition score change and wool growth. Crude protein:energy ratios influenced ewe metabolism and performance more than ME intake alone. Metabolizable energy requirement appeared to have less influence on ewe metabolism or performance substantiated by ME requirement not affecting ewe weight, body condition score and serum metabolite concentrations.

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This thesis is dedicated to
Darrell A. and Nell J. Hoaglund

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ABSTRACT

Objectives of this experiment were to evaluate the effects of non-rumen degradable protein (NRDP) and metabolizable energy (ME) requirement on metabolism and performance of ewes during early to mid-gestation. Forty-two ewes were allocated by randomization in a 2 X 3 factorial design and fed individually for 84 days at 80 or 100% NRC (1985) ME requirement and supplemented with either urea (U), soybean meal (SBM), or blood meal+SBM (BM+SBM). All diets were formulated to be isorumen degradable for protein with seven ewes per treatment combination. Blood meal+SBM supplemented ewes gained more (P<.05) weight and had greater (P<.05) wool growth than either U or SBM ewes during the investigation. Ewes fed BM+SBM and SBM had higher (P>.05) serum glucose concentrations than U. Total protein, albumin and blood urea N concentrations were different (P<.05) among treatments, with BM+SBM being greater than SBM and SBM greater than U. Urea ewes had increased (P<.05) alkaline phosphatase concentrations compared to SBM and BM+SBM ewes. Urea ewes also lost more (P<.05) weight and body condition than other treatments. Ewes fed BM+SBM retained more (P<.05) g of N daily than ewes fed either U or SBM. Soybean meal and BM+SBM X 80% ME requirement had improved protein:energy ratios compared to other treatment combinations. However, U and SBM fed 100% ME intake had protein:energy ratios that may have been insufficient for utilization of available energy. Number of lambs born, 21 day and lamb weaning weights were not affected (P>.05) by protein supplement or ME intake. Even though ewes fed 80% ME requirement had increased (P<.05) 21 day milk production compared to 100% ME, composition was not different (P>.05), with the exception of lactose. In conclusion, feeding a protein supplement containing a NRDP source (BM+SBM) to ewes in early to mid-gestation elicited a positive response in N balance, ewe weight, body condition score change and wool growth. Crude protein:energy ratios influenced ewe metabolism and performance more than ME intake alone. Metabolizable energy requirement appeared to have less influence on ewe metabolism or performance substantiated by ME requirement not affecting ewe weight, body condition score and serum metabolite concentrations.

INTRODUCTION

Limited information exists concerning feeding of non-rumen degradable protein (NRDP) to ewes in early to mid-gestation. The majority of research investigating NRDP research has occurred either with ewes in late gestation (Prior and Christenson, 1976; Robinson, 1983; Orr et al., 1985) concomitant with rapid fetal growth and development or during early lactation (Gonzales et al., 1979; Loerch et al., 1985; Coffey et al., 1986). Ørskov and Robinson (1981) proposed microbial protein synthesis will meet the net protein requirements of ewes during early and mid-gestation with little benefit to feeding NRDP. However, in experiments by Coombe et al. (1971, 1987) they reported improved performance and increased wool growth in mature wethers and ewes when NRDP (formaldehyde protected sunflower and rape seed meals) was fed.

Few studies have evaluated the effects of NRDP on serum metabolites in addition to wool growth and development during early to mid-gestation, both of which are sensitive to dietary NRDP levels (Sykes and Field, 1972; Miner et al., 1986; Thomas et al., 1987). Feeding strategies during early and mid-gestation are designed to ensure accumulation of body reserves to be mobilized during nutritional inadequacies of late gestation and early lactation. Therefore, objectives of this study were to evaluate effects of NRDP and ME concentration on nitrogen (N) and energy balance and retention, fiber length and diameter as well as ewe body weight and condition score changes during early to mid-gestation.

LITERATURE REVIEW

Benefits of Feeding Non-rumen Degradable Protein

Non-rumen degradable protein provides a greater concentration of protein and amino acids (AA) at the intestinal level than rumen soluble protein sources (Corbett and Edey, 1977; Kempton et al., 1977; Kirby et al., 1983; Rooke, 1985). Escaping rumen degradation enables feedstuffs of high biological value containing an excellent quantity and balance of essential amino acids to escape conversion to low and medium biological value by ruminal microbial protein.

Microbial protein requirements must be fulfilled with some type of rumen degradable nitrogen (N) fed in conjunction with adequate energy (Robinson, 1983). Thus, a combination of rumen degradable protein and NRDP may provide a feasible alternative to improving quantity and quality of protein available for duodenal absorption. Feeding additional quantities of cereal grain and oil meal supplements when nutritional inadequacies exist may be alleviated by incorporating dietary NRDP along with rumen degradable protein.

An article reviewing NRDP (Chalupa, 1975) indicated AA absorbed at the small intestine came from various sources--rumen microbial synthesis, NRDP and endogenous AA secreted intestinally. It may be possible to increase available AA's at the small intestine through manipulation of rumen microbial synthesis or by providing increased NRDP (Chalupa, 1973). Non-rumen degradable protein is a more efficient protein than rumen degradable protein since utilization of nutrients protein losses incurred in transforming dietary protein to microbial protein (Black, 1971). Protein from microbial synthesis is less digestible than several plant proteins commonly utilized by ruminants (Chalupa, 1974). Black (1971) and Chalupa (1974) estimated efficiency of converting dietary protein into microbial protein to be slightly greater than fifty percent. Under most conditions, 20 to 60% of dietary protein escapes rumen degradation, providing a combination of microbial protein and NRDP (Young et al., 1973).

Although normal levels of microbial protein may be adequate for finishing cattle (Young et al., 1973) increased quantities of NRDP and AA's (Nelson, 1970; Chalupa et al., 1973; Johnson, 1974) elicited responses greater than expected in growing cattle, sheep and lactating ewes. This suggests genetic potentials of cattle and sheep for growth, early fattening, early lactation and wool growth are limited by inadequate quantities of absorbable AA. Research by Schelling et al. (1973) and Nimrick et al. (1970) indicated methionine was the first limiting AA for growing lambs. Buttery and Foulds (1985) reported inadequate ruminal AA flows may be corrected by feeding NRDP and protected amino acids. Various methods employed to protect AA from ruminal breakdown include blocking amine groups (Kenna and Schwab, 1981), blocking carboxyl groups by ester formation (Ayoade et al., 1982), synthesis of AA analogues (Belasco, 1972), encapsulation in material resistant to rumen fermentation (Papas et al., 1984) and inhibition of deamination capacity of rumen microbes (Chalupa, 1975).

Methionine is resistant to ruminal degradation without protection and has been shown to increase rumen methionine levels when given orally (Doyle and Bird, 1975). Ability of sheep to convert methionine to cysteine was later monitored by Pisulewski and Buttery (1985). Their results indicated as duodenal infusion of methionine increased from 0 to 5 $g \cdot d^{-1}$ cysteine plasma concentrations increased from 4.5 to 18.5% with associated increases in wool and plasma albumin cysteine concentrations. Increases of cysteine in wool and plasma albumin indicated methionine was indeed being converted to cysteine as trans-sulfuration pathways exist in muscle as well as the liver, site of plasma albumin synthesis (Radcliff and Eagan, 1978).

Ørskov and Robinson (1981) postulated a need for NRDP in diets of ewes during the last trimester of pregnancy, during early lactation and for young fast-growing lambs when microbial protein will not satisfy AA N requirements. Similarly, Hassan and Bryant (1986 a,b,c) found lambs fed fish meal or formaldehyde treated rapeseed meal in combination with sufficient energy to satisfy maintenance requirements promoted improved N retention, digestibility of acid detergent fiber and live weight gain. Non-rumen degradable protein has been shown to elicit a positive response in weight change when incorporated into ewe (Prior and Christenson, 1976; Robinson, 1983; Orr et al., 1985) and cow diets (Miner et al., 1986) during late gestation as well as during early lactation (Gonzales et al., 1979; Loerch et al., 1985; Cofey et al., 1986).

Gestation Protein and Energy Requirements

Coop (1982) defined N requirement as the total unavoidable loss of N divided by the biological value of N arising from microbial protein and undegraded dietary N entering the small intestine. A crucial factor in fulfilling N requirement is the quantity of N in a ration meeting maintenance requirements for energy that will also satisfy microbial protein synthesis requirements. Quantity of N required also depends on dietary physical and chemical composition as quantity of N exiting the reticulo-rumen does not always equal quantity of intake (Coop, 1982).

Nitrogen partitioning among maternal tissues, fetal demands, wool synthesis and lactation has led to several estimates of protein maintenance requirements for ewes. vanEs (1972) estimated protein requirements ranging from 214 to 247 $mg \cdot d^{-1} \cdot kg^{.75}$ of apparently digested N while Coop's review article (1982) estimated protein requirements at 136 to 534 $mg \cdot d^{-1} \cdot kg^{.75}$. Daily ME and protein requirement estimates for twin-bearing ewes weighing 70 kg when mated and given a diet containing 2.5 Mcal of ME/kg of dry matter and 10 g of CP/Mcal of ME are given in table 1 (Robinson, 1982). These recommendations for protein requirements were made under the premise of having adequate energy available at all stages of gestation. Sufficient energy may not always be available, imposing a restriction on microbial protein synthesis (Coop 1982).

Robinson (1982) recommended when low density energy diets are fed supplements of NRDP could be fed during early pregnancy and at higher levels than recommended (MLC, 1981) in late gestation. vanEs (1972) calculated maintenance energy requirements for mature sheep to be 1.3 to 3.3 Mcal $ME \cdot d^{-1} \cdot kg^{.75}$ with lower levels sufficient for stall-fed sheep and higher levels for ewes on pasture in harsh climates.

Table 1. Daily metabolizable energy and protein requirements for maternal and fetal needs[a]

Item	Fetal age (days)			
	60	88	116	130
Metabolizable energy, Mcal/d	2.5	2.8	3.6	4.0
Net protein requirements, g/d				
Fetuses	1.0	7.6	21.8	29.2
Placental, fluids, uterus	3.3	2.7	1.9	2.2
Wool	6.0	6.0	6.0	6.0
Udder and secretions	.3	.5	2.6	8.6
Tissue maintenance	14.0	14.0	14.0	14.0
Total net protein,	25.0	31.0	46.0	60.0
Microbial protein synthesis, g	83.0	65.0	122.0	134.0
Net protein from microbial and NRDP sources, g	35.0	40.0	51.0	56.0
Protein required in diet, g	74.0	92.0	137.0	178.0
Recommended protein intake, g/d	104.0	119.0	153.0	200.0

[a]Adapted from Robinson (1982)

More recently, Robinson (1987) compared recommended energy and protein requirements (Table 2) proposed by National Research Council (NRC, 1985) and allowances proposed by Ministry of Agriculture Fisheries and Food (MAFF, 1984), Meat and Livestock Commission (MLC, 1981) and Agricultural Research Council (ARC, 1984) for ewes weighing 75 kg with twin lambs.

These estimates of energy and crude protein allowances demonstrate a wide range of recommendations for protein and energy requirements. National Research Council (1985) energy requirements are similar compared to ARC (1984), MLC (1981) and MAFF (1984) allowances. Ministry of Agriculture Fisheries and Food (1984) recommend lower energy allowances throughout gestation compared to NRC (1985), ARC (1984) and MLC (1981). Energy requirements proposed by NRC (1985) are increased at an earlier stage of gestation compared to other recommendations. Protein requirements for maintenance and throughout gestation for NRC (1985) are higher than other allowances (table 2). These differences in energy and protein allowances or requirements may explain why some investigators have noted significant differences in embryonic mortality when level of nutrition is increased or decreased during early and mid-gestation.

Table 2. Recommended energy and protein allowances for housed sheep[a]

	Recommendation source			
Item	NRC[b]	ARC[c]	MLC[c]	MAFF[c]
Energy, Mcal/d				
Maintenance	2.5	2.5	2.4	1.9
Gestation, week				
0	2.9	2.5	2.4	1.9
4	2.9	2.5	1.9	1.9
8	2.9	2.4	1.9	1.9
12	2.9	2.6	1.9	1.9
16	4.5	3.3	3.5	2.5
20	4.5	4.5	4.5	3.8
Protein, g/d				
Maintenance	120.0	70.0	100.0	***
Gestation, week				
0	140.0	70.0	100.0	
4	140.0	70.0	70.0	
8	140.0	70.0	70.0	
12	140.0	80.0	70.0	
16	225.0	105.0	220.0	
20	225.0	160.0	260.0	

[a]Taken from Robinson (1987)
[b]Energy and protein requirements
[c]Energy and protein allowances
***Requirements for protein not provided in review

Embryonic Mortality

Pre-natal mortality includes all types of ova loss occurring at mating through parturition. Generally it is assumed most losses occur during the first 30 to 40 days of gestation (Edey, 1976; Robinson 1977, 1982). Ova losses originate from two sources 1) basal losses independent of environmental factors and 2) induced losses influenced by numerous environmental factors. Management strategies may decrease induced losses, i.e., nutritional treatment, if causative effects of such losses can be identified. Pre- and post-mating low nutritional studies by Edey (1976) have resulted in either no effect or increased induced losses. However, Doney and Gunn (1981) found long periods of chronic but non-severe levels of undernutrition in pregnancy had no effect on total viable ova and fetuses. They also showed rapid changes in ewe nutrition post-mating may induce greater losses than an intermediate plane of nutrition held constant during gestation.

Developing embryos reach the uterus by day three (day 0 = estrus) and at day 21 most fetal organs are present. During the first 30 days of gestation uterine fluids provide necessary nutrients for embryonic growth and development. From day 35 until parturition cellular differentiation has ceased and hypertrophy occurs. Embryonic mortalities occurring before day 12 of pregnancy, prior to implantation, results in a return to estrus. Embryo death after day 12 results in ewes failing to exhibit estrus during the next cycle (Robinson, 1982). If only one embryo dies after day 12 alterations in distribution among remaining viable embryos between uterine horns may result in smaller, lighter than average lambs for their litter size

(Rhind et al., 1980).

Robinson (1977, 1982) reviewed influences of maternal nutrition on fetal growth and concluded when ewes are in good body condition at mating minimal embryonic mortality occurs. Increased embryonic mortality was demonstrated when energy intake was 15% of maintenance requirements (ARC, 1984) for seven days. He suggested embryonic mortality due to low nutrition in flock feeding situations seldom affects more than 15% of ewes. Ewes most susceptible to nutritional embryonic mortality include young ewes, those in poor condition and ewes with twin or greater conceptions. Dingwall et al. (1987) reduced dietary intake at day 30 of gestation to 75% of maintenance (MLC, 1981) resulting in a live weight decrease of 3.2 kg compared to control ewes which gained 2.4 kg when fed <u>ad libitum</u>. Changes in condition scores were not reported in their study. Differences in ewe live weight change were not correlated to viable fetal numbers. Rhind et al. (1980) observed abrupt reductions in feed intake (Meat and Livestock Commission, 1981) after one month of pregnancy resulted in late embryo and early fetal mortality. These discrepancies (Dingwall et al., 1987 compared to Rhind et al., 1980) may be due to Dingwall et al. (1987) slaughtering ewes during first 34 days of gestation before embryonic mortality occurred. Rattray (1977) has suggested plane of nutrition during mid- and late gestation has a greater influence on fetal development rather than fetal mortality. Rattray's results (1977) support those of Rhind et al. (1980).

Undernutrition alters gestating ewe endocrine status which may adversely affect fetal growth and development. Lawson (1977) found during the first two weeks of pregnancy embryo growth is influenced by endocrine factors, especially maternal plasma progesterone concentrations, which appear to alter uterine fluid AA balance (Menezo and Wintenberger-Torres, 1976). During the first 14 days of gestation embryo development is dependent upon uterine fluids for nutrient supply. Increases in plasma progesterone during early pregnancy caused by undernutrition have been reported by Cumming et al. (1971). Caton et al. (1974) demonstrated increased progesterone levels reduced uterine blood flow and oxygen consumption in early gestation. Similarly, Dancis et al. (1968) noted decreasing maternal plasma AA concentrations may be mediated through changes in circulating estrogen, progesterone, cortisol and insulin. However, whether hormonal concentrations are influenced by undernutrition as a direct effect or a nutritional stress causing additional adrenal activity has yet to be elucidated.

Fetal Development

Robinson and Forbes (1968) investigated effects of various quantities of CP and/or ME intakes on lamb birth weights and ewe live weight changes in mature 68 kg Border Leicestser X Scottish Blackface ewes bearing twins from week 4 of gestation through week 3 of lactation. Both quantity of ME and CP had a greater influence on maternal than fetal weight change. This was later interpreted to show ability of ewes to sustain fetal growth and development at expense of maternal body tissues and reserves. As reported earlier, Dingwall et al. (1987) found significant differences in ewe weight did not correspond to a difference in 55 day fetal weights.

Wenham (1977) radiographed fetuses ranging in age from 50 to 145 days to identify primary and secondary ossification centers occurring in skeletons. Ossification centers increased linearly with age up to 100 days at which time ossification rate increased and continued throughout gestation. This is supported by findings of McDonald et al. (1979) who demonstrated fetal calcium content increased significantly from week 10 of gestation through parturition. These findings suggest during the first month of pregnancy absolute fetal growth rates are small but specific growth is of considerable magnitude.

Nutritional inadequacies incurred during month 1 of gestation which alter fetal growth rates may later influence fetal viability, growth and development. Robinson et al. (1977) treated Finnish Landrace X Dorset Horn ewes as described previously in Dingwall et al. (1987) but during months 4 and 5 ewes were fed according to fetal numbers instead of maintenance allowances. Dingwall et al. (1987) found fetal weights during the first 2 months of gestation declined by a factor of .89 for each additional fetus compared to ewes gestating singles. Although late gestation accounts for two-thirds of fetal growth and development, Robinson's et al. (1977) mathematical model implied initial fetal weight differences occurred during early to mid-gestation, with resulting weight differences present throughout gestation until parturition. Curet (1973) observed underfeeding protein during early pregnancy had an adverse effect on 90 day fetal weights. Robinson (1977) suggested decreases in absolute fetal growth rates during the first 90 days were related to insufficient maternal nutrition per se or insufficient fetal nutrient accretion due to altered ewe endocrine status as a result of inadequate maternal nutrition.

Sykes and Field (1972b) reported ewes receiving a low protein diet (6% CP) from weeks 6 through 21 of gestation lost 364 g more tissue protein than ewes receiving a high protein diet (11.8%). Correspondingly, at parturition, lambs from low protein ewes had reduced body protein and birth weights of 199 and 809 g, respectively. Robinson et al. (1977) reported ewes on a high plane of nutrition during late gestation (270 g CP and 3.8 $Mcal{\cdot}ME^{-1}{\cdot}d^{-1}$) had lambs weighing 4 % heavier than those fed at a low nutritional plane (205 g CP and 2.9 $Mcal{\cdot}ME^{-1}{\cdot}d^{-1}$).

Conversely, prior findings of Robinson et al. (1977) and Foote et al. (1959) showed significant absolute weight differences did not exist during day 25 to 40 of gestation for single and individual twin lambs. Differences in fetal weights were more discernable during the last trimester of gestation. Ewes fed a diet reducing body weight by 25 % during the first 90 days of gestation, followed by a high level of nutrition in late gestation resulted in no effect on lamb birth weight (Bennett et al., 1964).

Placental Development

Previous research (Wallace, 1948; Alexander, 1964) indicated placental weight plateaus around day 90 of gestation. During the remainder of gestation cotyledonary weight declines while membrane weight continues to increase, which is supported by later results of

Robinson (1977). Thus, a greater change in structural magnitude occurs compared to uterine weight change. Placenta fluid, both amniotic and allantoic, increases rapidly in weight during early pregnancy, stabilizes in mid-gestation and increases again in late gestation. Whereas placental weight does not seem to increase with increasing fetal numbers, ratio of fluid weight to number of fetuses does increase. Throughout early gestation it appears little variation in fetal, placenta, placental fluids and uterine weight exists between ewes carrying single vs multiple fetuses. McDonald et al. (1979) investigated protein and mineral accretion relationships of multiple fetuses and found CP of fetus, placenta and fetal fluids increased as gestation progressed with uterine CP content remaining fairly constant. This is not surprising since uterine tissue weight increases to a lesser degree during gestation compared to fluids and placental membranes (Robinson et al., 1977). Placental concentrations of CP and fat increased up to day 100 of gestation with little change occurring after that time. Results from a series of experiments (Robinson et al., 1977; McDonald et al., 1977; Wenham, 1977; Robinson et al., 1978; McDonald et al., 1979; Robinson et al., 1980; McDonald et al., 1981; Robinson et al., 1985 and Dingwall et al., 1987) indicated it is unclear when maximal fetal accretion rates of nutrients occur.

Fetal Amino Acids

Maternal dietary protein is a major source of fetal amino acids when maternal nutritional intake and absorption are adequate (Cockburn and Giles, 1977). In states of maternal protein malnutrition, fetal amino acid supplies are maintained via maternal metabolic protein obtained at expense of maternal tissue catabolism (Cockburn and Giles, 1977). Since fetal protein accretion increases throughout gestation, Robinson et al. (1985) investigated specific AA concentrations found in fetuses and their accretion rates. They found glycine, cystine, arginine, proline and hydroxyproline concentrations increased with fetal age while aspartate, phenylalanine, histidine and lysine decreased during mid to late gestation (day 90 to 145). During mid-gestation demand for hydroxyproline increased due to rapid collagen synthesis of fetal skeleton, skin and muscle. Robinson (1983) showed in pregnant ewes fed at maintenance that microbial protein met ewe requirements but may not be adequate to satisfy AA requirements for fetal growth and development. However, even if sufficient energy is present to ensure AA synthesis, synthesized AA may not be transferred from placenta to fetus. Lemons et al. (1976) found certain amino acids, such as glutamate and aspartate, appear to be synthesized by the fetus rather than via placental uptake. As discussed earlier, a limiting AA for fetal birthcoat growth and development may be cystine. Cystine fetal requirements cannot be met by microbial protein, with the main location of cystine being fetal birthcoat; hence, undernutrition impairs birthcoat development (Everitt, 1967). Ewes which have sufficient ME intake to meet fetal growth requirements may be able to alleviate cystine deficiencies by converting surplus methionine to cystine.

Assessing Efficacy of Supplementation

Conventional Methods

Changes in magnitude of body weight and condition have been used to assess effects of protein and energy supplementation (Preston, 1961; Bull et al., 1984; Russel, 1984). In general, a positive change has been observed in body weight, condition and wool growth when ewes and lambs were supplemented with NRDP (Reis and Schinckel, 1964; Ferguson, 1975; Leng et al., 1984; Loerch et al., 1985; and Hassan and Bryant, 1986 a,b,c). However, changes due to dietary treatments may be slow to elicit a quantifiable response in terms of weight, condition or wool growth (Russel, 1984).

Blood Metabolites

Serum metabolites have been shown (Lindsay, 1978; Lynch et al., 1979, 1981; Russel, 1984; and Bull et al., 1984) to be valuable indicators in identifying immediate responses to metabolic changes as well as explaining physiological changes noted in subsequent production. Whereas changes in body weight and condition may be slow to show a response, serum metabolites are sensitive to dietary NRDP level (Sykes and Field, 1973; Miner et al., 1986). Serum metabolites also reflect diurnal variations and stress incurred during collection periods. Thus, care must be taken to ensure standardized collection times and to minimize stress during collections (Lindsay, 1978). Correct interpretation of blood metabolite data necessitates knowledge of acceptable ranges for species of interest (table 3).