EFFECT OF FEEDING METHIONINE-SUPPLEMENTED RATION TO SHEEP: 1. DIGESTIBILITY, NITROGEN AND SULFUR BALANCES, BODY WEIGHT PERFORMANCE AND WOOL CHARACTERISTICS

Ibrahim M. Saddick and Barakat M. Ahmed
Department of Animal Production , Faculty of Agriculture,
Minufiya University, Shebin El-Kom, Egypt

تأثير اضافة المثيونين الى عليقة الأغنام
١ - معاملات الهضم ، ميزانى النيتروجين والكبريت ، التغير فى وزن الجسم وصفات الصوف

ابراهيم محمد صديق و بركات محمد أحمد

ملخص البحث

أستخدمت حملان الأغنام الأوسيمى النامية عند عمر ٨ شهور ومتوسط وزن ٣٧ كجم فى مجموعتين بكل ستة حملان لدراسة تأثير اضافة المثيونين الى العليقة على معاملات الهضم ، ميزانى النيتروجين والكبريت ، التغير فى وزن الجسم وصفات الصوف . غذيت المجموعة الأولى على عليقة أساسية مكونة من علف مصنع ونخالة ودريس البرسيم ، بينما غذيت المجموعة الثانية على نفس العليقة مضافا اليها ٣,٣ جم مثيونين / كجم من العليقة الجافة ، وقد استمرت التجربة لمدة ثلاثة شهور .

وقد أظهرت النتائج أن اضافة المثيونين أدت الى خفض النسبة بين عنصرى النيتروجين والكبريت من ١٣,٢ : ١ الى ٩,٦ : ١ ، كما أدت الى زيادة معاملات هضم كل من البروتين الخام والكربوهيدرات الذائبة معنويا .. بينما زادت معاملات هضم المادة الجافة والمادة العضوية زيادة غير معنوية ، هذه الزيادة فى معاملات الهضم أدت الى ارتفاع القيمة الغذائية للعليقة نتيجة اضافة المثيونين فقد ارتفعت قيمة المواد الكلية المهضومة من ٦٥,٤ الى ٦٩,٤٪ والبروتين المهضوم من ١١,٤ الى ١٢,٤٪ والطاقة المهضومة من ٢٦٥٦ الى ٢٨٢٢ كيلو كالورى / كجم ، وقد أحتجزت الأغنام المغذاه على المثيونين مقدار أكبر من كل من النيتروجين والكبريت .

زاد متوسط النمو اليومى ـ غير معنويا ـ بمقدار ١٦,٠٨٪ نتيجة اضافة المثيونين فكانت ١٦٦ جم / يوم للمجموعة التى غذيت على عليقة مضافا اليها المثيونين مقابل ١٤٣ جم / يوم لمجموعة المقارنة · قد أدت اضافة المثيونين الى زيادة الصوف النظيف من وحدة المساحة من جلد الحيوان (١٠٠ سم٢) على طول فترة التجربة بمقدار ٧,٣٧٪ ، بينما زاد الصوف النظيف المنتج من الرأس من الأغنام فى اليوم بمقدار ٩,٥٩٪ وذلك مقارنة بمجموعة المقارنة · بلغ متوسط قطر الليفة ٣٠,٤١ ، ٣٠,٠٣ ميكرون فى صوف الأغنام المغذاه على عليقة مضافا اليها مثيونين ومجموعة المقارنة على التوالى. لوحظ نفس الاتجاه فى نسبة الألياف النخاعية · زاد طول الخصلة بمقدار ٤,٣٠٪ فقط نتيجة اضافة المثيونين ، ومع ذلك فقد كانت الفروق فى صفات الصوف غير معنوية ·

ABSTRACT

Two groups, each of 6 growing male Ossimi lambs 8-month of age and average body weight 37 kg were used in a 3-month feeding experiment to study the effect of feeding methionine-supplemented ration (MSR) on digestibility, nitrogen (N) and sulfur (S) balances, body weight performance and wool characteristics. The first group, served as control, was fed a basal ration containing co-op feed, wheat bran and clover hay. The other group was fed the same ration supplemented with 3.3 g methionine/kg DM. Wool growth over the experimental period was determined by the mid-side patch technique.

Results indicated that methionine supplementation decreased the N:S ratio from 13.2:1 to 9.6:1. Digestibility of crude protein and nitrogen-free extract increased significantly due to methionine supplementation. However not significant, digestibility of DM and OM also increased. The increase in digestibility lead to an improvement in the nutritive value of MSR; TDN improved from 65.4 to 69.4%, DP from 11.4 to 12.4% and DE from 2656 to 2822 kcal/kg. Sheep fed MSR retained more N and S.

Average daily gain non-significantly increased by 16.08%; it was 166 g/d for MSR vs. 143 g/d for the control. Sheep fed MSR produced 7.37% more clean wool per unit area (100 cm^2) of the skin over the experimental period and 9.59% more clean wool per sheep per day than the control group. The averages of fiber diameter were 30.41 and 30.03 micron for MSR and control groups, respectively. Similar trend was observed for percentage of medullated fibers. Staple length increased by only 4.30% in the MSR. All results regarding wool characteristics, however, were not significant.

INTRODUCTION

Methionine is the first limiting amino acid for a variety of diets (Hutton and Annison, 1972; Armstrong and Annison, 1973; Harrison et al. (1973). Barry et al. (1973) showed that intraperitoneal injections of methionine increased voluntary intake and wool growth of sheep fed silage.

Methionine is known for its slowly degradation rate in the rumen (Bray and Till, 1975) which means that much of it would escape microbial degradation and be absorbed post-ruminally. Bird and Moir (1972) suggested that since methionine itself was relatively slowly degraded in the rumen, its inclusion in the diet at an appropriate level might stimulate wool growth.

For these reasons the effect of methionine-supplemented ration on nutrient digestibility, nitrogen and sulfur balances, feed intake, feed efficiency, body weight gain and wool characteristics of sheep was studied.

MATERIALS AND METHODS

The present study was carried out at the Animal Production Experimental Farm, Minufiya University, Shebin El-Kom, Egypt in 1987.

A prelimenary experiment was conducted to evaluate the feeding value of the ingredients used under our experimental condition. These ingredients were clover hay, wheat bran and co-op feed*. Six

* Co-op feed containing: soybean meal, 28%; wheat bran, 44%; yellow maize, 19%; rice bran, 3%; molasses, 2%; limestone, 3%; salt, 1%; production of Tanta Co. for Oil and Soap.

mature Ossimi rams were randomly assigned to three groups, 2 rams each. They were kept in individual metabolic cages. The first two rams were fed clover hay alone, while the others were fed clover hay supplemented with either wheat bran or co-op feed. Digestibility and feeding value of wheat bran and co-op feeds were determined by the indirect way. Chemical composition, digestion coefficients, feeding value and amino acid composition of these ingredients are shown in Tables 1 and 2.

Twelve non-shorn growing male Ossimi lambs, 8-month of age were divided into two groups on body weight basis with 6 lambs each. Control group was fed a ration of co-op feed, wheat bran and clover hay. The treated group was fed the same ration supplemented with methionine. Lambs were weighed at the beginning of the experiment and thereafter at two-weeks intervals till the end of the experiment. Weighing took place in the morning after an overnight holding of feed and water. The experimental period lasted for 3 months.

Feed ingredients were mixed to keep the roughage: concentrate ratio at 50:50. Methionine was added to the tested ration at the level of 3.3 g/kg DM to increase methionine content of the basal ration from 0.16 to 0.49%. The level of 3.3 g/kg was used to obtain a nitrogen:sulfur ratio near the 10:1 as has been recommended by Moir et al. (1967) and Bray and Hemsley (1969). The unsupplemented ration served as control. Rations (Table 3) were fed in equal portions at 0800 and 1400 hr. Collection of biological samples was delayed until feed refusals were negligible for all animals. Dietary ingredients were mixed completely and fed ad lib. for a 2-week period to allow each animal to establish its own ad lib. After this time, animals were fed at 95% ad lib. to ensure the complete intake. Samples of the feedstuffs were collected and analyzed for DM to ensure that the ratio of hay: concentrate is kept at 50:50. All animals had free access to water.

Table 1: Chemical composition, digestion coefficient and feeding value of the feed ingredients used in the present study

Item*	Co-op feed	Wheat bran	Clover hay
	%		
DM	88.7	89.1	87.6
OM	81.6 (92.0)	83.2 (93.4)	80.1 (91.4)
CP	14.5 (16.4)	12.8 (14.4)	12.1 (13.8)
EE	3.1 (3.5)	2.7 (3.0)	2.4 (2.7)
NFE	53.9 (60.8)	57.4 (64.4)	40.1 (45.8)
CF	10.1 (11.4)	10.3 (11.6)	25.5 (29.1)
Ash	7.1 (8.0)	5.9 (6.6)	7.5 (8.6)
N	2.3 (2.6)	2.1 (2.3)	1.9 (2.2)
S	0.16 (0.2)	0.22 (0.3)	0.15 (0.2)
N/S	14.5 (14.5)	9.3 (9.2)	12.9 (13.0)
Digestion coefficient:			
	%		
DM	65.5	62.0	58.6
OM	71.9	66.3	65.8
CP	75.4	63.3	69.3
EE	85.3	83.0	81.9
NFE	73.0	72.0	70.5
CF	54.0	47.0	41.6
Feeding value, (on DM basis):			
TDN, %	68.4	65.8	49.5
DP, %	12.3	9.1	9.6
DE, kcal/kg	2734	2630	2016

* DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; NFE, nitrogen-free extract; CF, crude fiber; N, nitrogen; S, sulfur; TDN, total digestible nutrients; DP, digestible crude protein; DE, digestible energy (calculated).

Values between parenthesis are on DM basis.

Table 2: Amino acid composition of the feed ingredient used in the present study.

Amino acid	Co-op feed	Wheat bran	Clover hay
	-------------	%	-------------
Arginine	1.75	0.96	0.80
Histidine	0.47	0.35	0.25
Isoleucine	0.65	0.58	0.75
Leucine	1.25	0.90	0.89
Lysine	0.71	0.58	0.62
Cyst(e)ine	0.32	0.25	0.32
Methionine	0.24	0.17	0.10
Phenylalanine	0.90	0.43	0.71
Tryptophan	0.27	0.33	0.21
Threonine	0.61	0.40	0.70
Tyrosine	0.57	0.40	0.50
Valine	0.83	0.73	0.71

Table 3: Composition of the experimental rations.

Item	Rations	
	MSR[1]	Control
	g/kg	
Clover hay	509	509
Co-op feed[2]	429	429
Wheat bran	62	62
Methionine (supplement)	3.3	-
Amino acid composition:	%	
Arginine	1.22	1.22
Histidine	0.35	0.35
Isoleucine	0.70	0.70
Leucine	1.05	1.05
Lysine	0.66	0.66
Cyst(e)ine	0.32	0.32
Methionine	0.49	0.16
Phenylalanine	0.77	0.77
Tryptophan	0.24	0.24
Threonine	0.64	0.64
Tyrosine	0.52	0.52
Valine	0.76	0.76

[1] MSR, methionine-supplemented ration.

[2] Co-op feed containing: soybean meal, 28%; wheat bran, 44%; yellow maize, 19%; rice bran, 3%; molasses, 2%; limestone, 3%; salt, 1%.; production of Tanta Co. for oil and soap.

At the end of the experimental period, three animals of each group were randomly chosen and placed in the metabolic cages as described by Maynard et al. (1979), allowing separate collection of urine and feces. Animals were adapted to the cages for 14 days followed by 6-day collection period. During the collection period, urine was collected daily and a 10% aliquot was composited and refrigerated. Total N was determined as described in A.O.A.C. (1980). Feces were collected daily and dried for 24 hr in a forced air oven at a maximum temperature of 70°C. Daily collection from each animal were composited in cans and allowed to air-equilibrate. Composites were weighed and sampled for subsequent analysis. All feed and fecal samples were ground through a 1 mm screen and mixed before analysis. The complete chemical analysis was carried out according to A.O.A.C. (1980).

Mid-side patch technique was applied in this experiment for the determination of wool growth.

An area of 10 x 10 cm, centered over the last rib on the right side of each sheep and midway along the dorso-ventral curvature, was clipped and delineated at the beginning of the experiment. Wool growth per unit area over the experimental period was determined by clipping the wool from these measured areas at the end of the experiment. The wool was scoured after Ryder and Stephenson (1968) to estimate clean wool weight per unit area over the experimental period. Samples from this scoured wool were used to study the following wool characteristics: staple length, fiber diameter and percentage of medullated fibers. Staple length was measured against a ruler. Fiber diameter was measured microscopically according to Nicolaev (1962). Number of medullated fibers was recorded while examining the fiber diameter. For further study on carcass, all animals were slaughtered. After complete bleeding, the pelt was removed. The pelt was placed on a flat table and the total surface area of each sheep was measured as a product of length and width of the pelt. This enable a calculation of clean wool production per sheep.

Data were statistically analyzed according to Gill (1978).

RESULTS AND DISCUSSION

Data summarized in Table (4) represent the chemical composition, digestion coefficients and feeding value of the experimental rations. There were no significant differences between both rations regarding the chemical composition either calculated on as fed- or on DM-basis except that of sulfur (S) which was higher in the methionine-supplemented ration (MSR) than the control one. This was expected due to the methionine (as a sulfur-containing amino acid). The increase in S content led to a decrease in the N:S ratio from 13.2:1 to 9.58:1. A ratio near 10:1 was obtained by Moir et al. (1967) and Ahmed and Saddick (1987) for sheep and associated with the best sheep performance.

Digestion coefficients of CP and NFE increased significantly due to methionine supplementation. Digestibility of DM and OM also increased, however, differences were not significant. The increase in digestibility could be attributed to the narrow N:S ratio rather than to methionine itself. Bray and Hemsley (1969) using a simple oat hull, urea and mineral diet with sheep found DM digestion increased from 46.6 to 51.9% by increasing S intake to narrow the N:S ratio from 24 to 9.7:1. Even with green forage, Ahmed and Saddick (1987) reported an increase in digestibility of all nutrients when N:S ratio was near 10:1. Sulfur deficiency was found to restrict DMD both in vivo and in vitro (Bray and Till, 1975).

Table 4: Chemical composition, digestion coefficient and feeding value of the experimental rations.

Item	MSR[1]		Control	
	as fed	DM basis	as fed	DM basis
Chemical composition	----------------	%	----------------	
DM	88.20	100	88.16	100
OM	80.80	91.61	80.93	91.80
CP	13.77	15.61	13.18	14.95
EE	2.70	3.06	2.70	3.06
NFE	46.43	52.64	47.09	53.41
CF	17.90	20.29	17.96	20.37
Ash	7.40	8.39	7.23	8.20
N	2.20	2.49	2.11	2.39
S	0.23[a]	0.26[a]	0.16[b]	0.18[b]
N/S	9.58[a]	9.58[a]	13.19[b]	13.28[b]
Digestion coefficient(on DM basis)				
DM		70.02		67.33
OM		71.72		68.10
CP		79.22[a]		76.32[b]
EE		65.50		64.52
NFE		81.69[a]		74.79[b]
CF		52.60		51.99
Feeding value (on DM basis)				
TDN		69.44[a]		65.36[b]
DP		12.37[a]		11.41[b]
DE, kcal/kg DM (calculated)		2822[a]		2656[b]
NR, 1:		4.61		4.73

[1] MSR, methionine-supplemented ration.

[a,b] Values not sharing the same superscript within each row are significantly different ($P \angle 0.05$).

The increase in digestibility led to an improvement in the nutritive value. Table (4) showed that the TDN improved from 65.36 to 69.44%, DP from 11.41 to 12.37% and DE from 2656 to 2822 kcal as the control diet was supplemented with methionine. Nutritive ratios were almost similar.

Table (5) presents the N and S balances. Both balances were positive in the experimental groups. However, sheep fed MSR retained more N and S than the control group. Starks et al. (1953) reported that the addition of S caused a significant increase in the retention of N and S. Moir et al. (1967) and Ahmed and Saddick (1987) reported that maximum N balance was achieved with dietary N:S ratio near 10:1. Bray and Hemsley (1969) found a highly significant linear relationship between N balance and S balance which showed an approximately 10:1 ratio between these parameters.

Loosli and Harris (1945) improved a basal diet for growth in lambs by raising the CP level from 6.55 to 10.28% with urea or a supplement of urea and sodium sulfate, or urea and methionine or with linseed meal. The urea with 1.11% methionine greatly enhanced the percentage of dietary nitrogen retained. Lofgreen et al. (1947) significantly increased N retention when 0.2% methionine was added to a 10% CP basal ration. McLaren et al. (1965) and Ustinova (1968) improved N retention and wool production, respectively with sheep receiving diets supplemented with methionine or methionine and cystine.

Table (6) shows the average initial and final body weights, total gain and daily gain (ADG) for MSR and control groups. Methionine supplementation increased the ADG of sheep by 16.08% compared to the control group. However, difference was short of significance. Dietary methionine or methionine analogue supplementation have given increases in ADG of sheep (Bray and Till, 1975) and for dairy cattle

Table 5: Nitrogen (N) and sulfur (S) balances as affected by feeding methionine-supplemented ration (MSR).

Item	MSR	Control
	N-balance, g/d	
N intake	32.26	29.76
N in feces	6.70	7.05
N in urine	18.92	16.99
Total N excretion	25.62	24.04
N retained	6.64	5.72
	S-balance, g/d	
S intake	3.75[a]	2.61[b]
S in feces	0.79	0.62
S in urine	2.29[a]	1.56[b]
Total S excretion	3.08[a]	2.18[b]
S retained	0.67[a]	0.43[b]
Dietary N:S ratio	9.91:1	13.30:1

[a,b]Values not sharing the same superscript within each row are significantly different ($P < 0.05$).

Table 6: Effect of feeding methionine-supplemented ration (MSR) to sheep on their average daily gain (ADG), feed intake and feed efficiency (mean ± SE).

Item	MSR	Control
No of animals	6	6
Avg. initial body weight, kg	37.58±2.20	37.50±4.11
Avg. final body weight, kg	52.50±1.72	50.33±3.74
Avg. total gain, kg	14.92±0.97	12.83±1.05
ADG, g	166 ± 11	143 ± 12
Feed intake		
DM, kg/head/d	1.44	1.44
TDN, kg/head/d	1.13	1.07
DE, Mcal/head/d	4.06	3.82
DP, g/head/d	201.6	186.0
Feed efficiency		
kg DM/kg gain	8.67	10.07
kg TDN/kg gain	6.81	7.48
kg DP/kg gain	1.21	1.30
PER*	0.82	0.77

*PER, protein efficiency ratio, kg gain/kg protein consumed.

(Lundquist et al., 1983). Data of ADG confirm those of N and S balances (Table 5). Hume and Bird (1970) found a significant increase in the amount of protein synthesized in the rumen with either sulfate or S-amino acid additions; this would make more protein available for the host animals.

Dry matter intake (Table 6) was essentially similar in both groups. However, intakes presented as TDN, DE or DP were higher for those fed MSR than those fed the control diet. This was due to the increase in digestibility. As digestibility influences intake (Blaxter et al., 1961) favourable N:S ratio, in affecting digestibility, will greatly increase DE intake and as more total protein is synthesized by the rumen microorganisms under such condition, protein balance as well as energy balance is improved leading to more body weight gain.

Sheep fed MSR utilized their feed more efficiently than the control group. Differences, however, were not statistically significant (Table 6).

Mean values of different wool characteristics are presented in Table (7). Over the experimental period, sheep on treatment produced 7.37% more clean wool per unit area of skin than those on control. This difference was not significant.

The relationship between unit area of the skin and total surface area for each sheep was estimated to convert the weight of clean wool per unit area to total clean wool weight on the whole animal. Did so, the treated sheep produced 9.59% more clean wool per day than those in the control group. This difference, however, did not reach a significant level. It is worthy to note that the response in the average animal's daily gain (16.08%) to methionine supplementation is relatively more than the response in wool growth (9.59%) compared to the control group. Starks et al. (1953) found that lambs

Table 7: Wool growth rate, staple length, fiber diameter and percentage of medullated fibers of Ossimi sheep fed methionine-supplemented ration (MSR). Mean ± SE.

Item	MSR	Control
Clean wool weight (g/100 cm^2 of the skin)	5.83 ± 0.70	5.43 ± 0.51
Clean wool weight (g/100 cm^2 of the skin/d)	0.065±0.008	0.060±0.006
Clean wool weight (g/d)	5.94 ± 0.59	5.42 ± 0.49
Staple length (cm)	4.61 ± 0.20	4.42 ± 0.26
Fiber diameter (micron)	30.41 ± 0.62	30.03 ± 0.65
Medullated fibers, %	3.83 ± 0.85	3.75 ± 0.88

could utilize S, and that they retained more N than lambs receiving no additions of S. The S and N contents of the wool, however, remained the same.

Regarding the staple length, the small increase produced by methionine supplementation (4.30%) did not attain significant. Similarly no significant difference was detected neither in fiber diameter nor in the percentage of medullated fibers between the treated and control groups.

Data available in the literature show some confliction with respect to the effect of methionine supplementation on wool characteristics. In this respect, Doyle and Bird (1975) and Doyle and Moir (1979) found a relatively small responses in wool growth to methionine supplementation, which comes in agreement with the results obtained in the present study. On the other hand, many experiments have shown stimulation of wool growth by Cyst(e)ine and/or methionine (Reis and Schinckel, 1963 and Reis, 1979). In contrast, Reis (1979) reported that excessive amounts of methionine are inhibitory. Also, Feeding methionine hydroxyanalogue has increased wool growth in some experiments (Wright, 1971 and Langlands, 1972) but in others it has been ineffective (Carrico et al., 1970; Reis, 1970 and Wickham, 1970). Reis and Tunks (1982) have shown that ethionine, an analogue of methionine, is an inhibitor of wool growth and may cause shedding of the fleece.

Such confliction in the response of wool characteristics to methionine supplementation could be attributed to different diets applied in this concept and to the genetic potential for wool growth. Methionine supplementation caused significant increase in wool growth rate and a small-non-significant increase in fiber diameter with sheep fed hay or silage, but had no effect on either wool growth rate or fiber diameter with the diet of fresh pasture (Barry, 1976).

On the other hand, methionine when given to sheep receiving a diet of wheat grain only depressed wool growth with a reduction in fiber diameter (Reis and Tunks, 1974). The extent of the response is, however, affected by the genetic potential for wool growth (Williams et al., 1972). Osman and El-Husseiny (1978) found that the addition of S alone to the basal diet had a pronounced benificial effect on wool production of Merino and Ossimi breeds, while for Rahmani breed had no appreciable effect on wool production, and they added that N and S content of the basal diet were appropriate for Rahmani breed. Furthermore, Reis (1979) stated that while the supply of S-amino acids plays a major role in regulating the growth and composition of wool, the balanced mixture of essential amino acids is required for high rates of wool growth.

The small response observed in wool characteristics in the present work could indicate that: first: on basal diet the quantity of S-containing amino acids supplied by its digestion was in the requirement for optimum wool production. Second: the N:S ratio of the basal diet (13:1) was satisfactory for Egyptian Ossimi breed of carpet wool type.

REFERENCES

Ahmed, P.M. and I.M. Saddick (1987). Effect of feeding berseem-tyfon mixture on digestibility, nutritive value, nitrogen and sulfur balances, microbial activity and wool characteristics of Ossimi sheep. Minufiya J. Agric. Res.Vol.12 No.1:155-175.

A.O.A.C. (1980). Association of Official Agricultural Chemists. Official methods of analysis. Washington, DC.

Armstrong, D.G. and E.F. Annison (1973). Proc. Nutr. Soc. 32, 107. Cited in Gill, M. and M.J. Ulyatt. 1979. The metabolism of methionine in silage-fed sheep. Br. J. Nutr. 41:605.

Barry, T.N. (1976). Effects of intraperitoneal injections of DL-methionine on the voluntary intake and wool growth of sheep fed sole diets of hay, silage and pasture differing in digestibility. J. Agric. Sci. Camb., 86: 141-149.

Barry, T.N.; P.F. Fennessy and S.J. Duncan (1973). N.Z. J. Agric. Res. 16,64. Cited in Gill, M. and M.J. Ulyatt. 1979. The metabolism of methionine in silage-fed sheep. Br. J. Nutr. 41, 605.

Bird, P.R. and R.J. Moir (1972). Sulphur metabolism and excretion studies in ruminants. VIII. Methionine degradation and utilization in sheep when infused into the rumen or abomasum. Aust. J. Biol. Sci. 25: 835-48.

Blaxter, K.L.; F.W. Wainman and R.S. Wilson (1961). The regulation of food intake by sheep. Anim. Prod. 3: 51-61.

Bray, A.C. and J.A. Hemsley (1969). Sulphur metabolism in sheep. IV. The effect of a varied dietary sulphur content on some body fluid sulphate levels and on the utilization of a urea-supplemented roughage by sheep. Aust. J. Agric. Res. 20: 759-773.

Bray, A.C. and A.R. Till (1975). Metabolism of sulphur in the gastro-intestinal tract. Proc. IV. Internat. Symp. Ruminant Physiol. Digestion and metabolism in the ruminant. Aust. 1975.

Carrico, R.G.; F.R.M. Cockrem; D.D. Haden and G.A. Wickham (1970). Wool growth and plasma amino acid responses of N.Z. Romney sheep to formalin-treated casein and methionine supplements. N.Z. J. Agric. Res. 13: 631-40.

Doyel, P.T. and P.R. Bird (1975). The influence of dietary supplements of DL-methionine on the growth rate of wool. Aust. J. Agric. Res. 26: 337-42.

Doyel, P.T. and R.J. Moir (1979). Sulphur and methionine metabolism in sheep. III. Excretion and retention of dietary and supplemented sulphur, and production responses to intraruminal infusions of DL-methionine. Aust. J. Agric. Res. 30: 1185-96.

Gill, J.L. (1978). Design and analysis of experiments in the animal and medical sciences. The Iowa State Univ. Press. Ames.,Iowa, USA.

Harrison, D.G.; D.E. Beever; D.J. Thomson and D.F. Osbourn (1973). J. Agric. Sci. Camb. 81, 391. Cited in Gill, M. and M.J. Ulyatt. 1979. The metabolism of methionine in silage-fed sheep. Br. J. Nutr. 41, 605.

Hume, I.D. and P.R. Bird (1970). Synthesis of microbial proteins in the rumen. IV. The influence of level and form of dietary sulphur. Aust. J. Agric. Res. 21: 315-22.

Hutton, K. and E.F. Annison (1972). Proc. Nutr. Soc. 31, 151. Cited in Gill, M. and M.J. Ulyatt. 1979. The metabolism of methionine in silage-fed sheep. Br. J. Nutr. 41, 605.

Langlands, J.P. (1972). Methionine hydroxy analogue as a dietary supplement for sheep. Proc. Aust. Soc. Anim. Prod. 9:321-5.

Lofgreen, G.P.; J.K. Loosli and L.A. Maynard (1947). The influence of protein source upon nitrogen retention by sheep. J. Anim. Sci. 6: 343-347.

Loosli, J.K. and L.E. Harris (1945). Methionine increases the value of urea for lambs. J. Anim. Sci. 4: 435-437.
Lundquist, R.G.; J.G. Linn and D.E. Otterby (1983). Influence of dietary energy and protein on yield and composition of milk from cows fed methionine hydroxy analog. J. Dairy Sci. 66: 475-491.
Maynard, L.A.; J.K. Loosli; H.S. Hintz and R.G. Warner (1979). Animal Nutrition. McGraw-Hill Book Co. Inc. NY.
McLaren, G.A.; G.C. Anderson and K.M. Barth (1965). Influence of methionine and tryptophan on nitrogen utilization by lambs fed high levels of nonprotein nitrogen. J. Anim. Sci. 24: 231-234.
Moir, R.J.; M. Somers and A.C. Bray (1967). Utilization of dietary sulphur and nitrogen by ruminants. Sulphur Inst. J. 3:15.
Nicolaev, A.I. (1962). Wool Technology. Moscow-Union Center Press.
Osman, M.A. and O. El-Husseiny (1978). Effect of sulphur and nitrogen supplements on wool growth and composition. Annals of Agric. Sci. Moshtohor. 9: 249-258.
Reis, P.J. (1970). The influence of abomasal supplements of some amino acids and sulphur-containing compounds on wool growth rate. Aust. J. Biol. Sci. 23: 441-6.
Reis, P.J. (1979). Effects of amino acids on growth and properties of wool. In Physiological and Environmental Limitations to wool growth (ed. J.L. Black and P.J. Reis). pp. 223-242. Armidale: Univ. New England Publishing Unit.
Reis, P.J. and P.G. Schinkel (1963). Some effects of sulphur-containing amino acids on the growth and composition of wool. Aust. J. Agric. Res. 16: 218-230.
Reis, P.J. and D.A. Tunks (1974). The influence of abomasal supplements of methionine on wool growth of wheat-fed sheep. Aust. J. Agric. Res. 25: 919-29.
Reis, P.J. and D.A. Tunks (1982). Inhibitory effects of ethionine, an analogue of methionine, on wool growth. Aust. J. Biol. Sci. 35: 49-62.
Ryder, M.L. and S.K. Stephenson (1968). Wool Growth. London Academic Press.
Starks, P.R.; W.H. Hale; U.S. Garrigus and R.M. Forbes (1953). The utilization of feed nitrogen by lambs as affected by elemental sulfur. J. Anim. Sci. 12: 480-492.
Ustinova, M.P. (1968). Effect of synthetic methionine on wool production of Sheep. Zivotnovodstvo 6, 85-89, (Russian); Nutr. Abstr. Rev. 39, 265.
Wickham, G.A. (1970). Wool growth in relation to sulphur-containing amino acid administration to sheep. Proc. N.Z. Soc. Anim. Prod. 30: 209-15.
Williams, A.J.; G.E. Robards and D.G. Saville (1972). Metabolism of cystine by Merino sheep genetically different in wool production. II. The responses in wool growth to abomasal infusions of L-cystine or DL-methionine. Aust. J. Biol. Sci. 25: 1269-76.
Wright, P.L. (1971). Body weight gain and wool growth response to formaldehyde treated casein and sulphur amino acids. J. Anim. Sci. 33: 137-41.