Wheat-straw as roughage component in finishing diets of growing lambs

T.S. Brand,* S.W.P. Cloete and F. Franck
Elsenburg Agricultural Development Institute, Private Bag, Elsenburg 7607, Republic of South Africa
G.D. van der Merwe
Outeniqua Agricultural Development Centre, P.O. Box 249, George 6530, Republic of South Africa

Received 13 August 1990; accepted 9 July 1991

Five diets were formulated on an iso-nutrient basis (approximately 12 MJ digestible energy, 16,5% crude protein, 5% non-degradeable protein, 33% neutral detergent fibre, 18% acid detergent fibre, 0,8% calcium and 0,3% phosphorus) so that lucerne hay (LH) was substituted by increasing levels of wheat-straw (WS), lupins and fish-meal. The LH content of the diets decreased from 42 to 0%, while the WS, lupin and fish-meal contents increased from 0 to 26%, 0 to 14%, and 4,0 to 6,0%, respectively. A sixth diet was composed to be similar to the diet containing 26% WS, but thermally ammoniated wheat-straw (AWS) was used instead of untreated WS. In a digestibility and N balance study with 24 SA Mutton Merino wethers, apparent digestibility coefficients and N balance were largely independent of the substitution of LH with WS. Energy and fibre digestibility on the diet containing 26% AWS were higher ($P \leq 0,05$) than on the diet containing 26% WS. The diets were evaluated according to a completely randomized design in terms of dry-matter intake (DMI), average daily gain (ADG) and feed conversion ratio (FCR), in a growth study with 6—8 SA Mutton Merino lambs per diet. Mean ($\pm$ *SD*) initial live mass of the lambs was 15,7 $\pm$ 2,1 kg. No differences in DMI, ADG or FCR were found between the diets containing either 26% WS or 26% AWS. Total DMI of lambs decreased linearly ($P \leq 0,01$) by 80,5 (SE_b = 14,0) g/d per unit substitution of LH with WS, lupins and fish-meal. This trend accounted for 99,3% of the variance between diets. Daily gain was similarly affected, with a corresponding linear ($P \leq$, 0,05) decline of 8,3 (SE_b = 3,3) g/d associated with 59,5% of the variance between diets. The substitution of LH with WS, lupins and fish-meal did not influence FCR significantly; absolute values for diets ranging between 4,5—5,1 kg diet DMI required per kg live mass-gain. Mean dressing percentage of male lambs did not differ significantly between diets and varied between 44,3% and 45,5%. Efficiency were thus largely unaffected by the substitution of LH with WS, lupins and fish-meal. These sources may therefore be used to substitute LH provided that the lower DMI, and resultant poorer growth rate, is taken into consideration. Thermal ammoniation of the roughage portion in the diet containing 26% WS had no benefit in terms of DMI, ADG or FCR.

Vyf rantsoene is op 'n iso-nutriëntbasis (ongeveer 12 MJ verteerbare energie, 16,5% ruproteïen, 5% nie-degradeerbare proteïen, 33% neutraalbestande vesel, 18% suurbestande vesel, 0,8% kalsium en 0,3% fosfaat) saamgestel, sodat lusernhooi (LH) stapsgewys deur stygende peile van koringstrooi (KS), lupiene en vismeel vervang is. Die LH-inhoud van die rantsoene het afgeneem vanaf 42 tot 0%, terwyl die KS-, lupien- en vismeelinhoud onderskeidelik toegeneem het vanaf 0 tot 26%, 0 tot 14%, en 4,0 tot 6,0%. 'n Sesde rantsoen, soortgelyk aan die rantsoen wat 26% KS bevat het, is saamgestel maar termies-geammonifiseerde koringstrooi (AKS) is gebruik. Volgens 'n vertering- en N-balansstudie met 24 SA Vleismerinohamels, was skynbare verteringskoëffisiënte en N-balans grootliks onafhanklik van vervanging van LH met KS. Energie- en veselverteerbaarheid op die AKS-rantsoen was egter hoër ($P \leq 0,05$) as by die rantsoen wat 26% KS bevat het. Die ses rantsoene is vervolgens in 'n bloklose proefontwerp geëvalueer in terme van droëmateriaalinname (DMI), gemiddelde daaglikse toename (GDT) en voeromsettingsdoeltreffendheid (VOD), met 6—8 SA Vleismerinolammers per rantsoen. Die gemiddelde aanvangsmassa ($\pm$ *SA*) van die lammers was 15,7 $\pm$ 2,1 kg. Geen verskille in DMI, GDT of VOD het voorgekom tussen die rantsoene wat 26% KS teenoor 26% AKS bevat het nie. Totale DMI van lammers het reglynig afgeneem ($P \leq 0,01$) met 80,5 (SE_b = 14,0) g/d per eenheid vervanging van LH met KS, lupiene en vismeel. Die verkreë neiging het 99,3% tot die variasie as gevolg van rantsoen bygedra. Groeitoename is dienooreenkomstig benadeel ($P \leq 0,05$) en 'n ooreenstemmende reglynige afname van 8,3 (SE_b = 3,3) g/d het 59,4% van die variasie tussen rantsoene verklaar. Vervanging van LH met KS, lupiene en vismeel het VOD nie betekenisvol beïnvloed nie, met die absolute VOD-waardes vir die onderskeie rantsoene wat tussen 4,5—5,1 kg voer DMI per kg massatoename gevarieer het. Gemiddelde uitslagpersentasie van ramlammers het nie betekenisvol tussen diëte verskil nie, en het tussen 44,3% en 45,5% gevarieer. Doeltreffendheid is dus nie beïnvloed deur die verplasing van LH met KS, lupiene en vismeel nie. Dié bronne kan dus gebruik word om LH te vervang, mits die verlaging in DMI en die gepaardgaande stadiger groei in ag geneem word. Termiese ammonifisering van die ruvoergedeelte by die rantsoen wat 26% KS bevat het, het geen voordeel in terme van DMI, GDT of VOD ingehou nie.

Keywords: Lambs, finishing, wheat-straw, digestibility, N retention, ammoniation, production.

* Author to whom correspondence should be addressed.

Introduction

Lucerne hay plays an integral role as roughage component in finishing diets for growing lambs in South Africa. Lucerne hay is, however, expensive and in some years difficult to obtain. Although straw is not usually recommended for inclusion in finishing rations, straw may be the most practical and economic roughage component in some areas. Wheat-straw, as a by-product from the wheat industry, is normally available in the wheat producing areas.

The utilization of wheat-straw by farm animals is limited because of its high lignin content and low protein and mineral content (Hart *et al.*, 1975; Jackson, 1977). It is also well proved that the addition of straw to diets depresses dry matter (DM), organic matter (OM) and crude protein (CP) digestibility (Williams *et al.*, 1985), as well as voluntary intake (Rexen, 1979). In studies with cattle, decreased food intakes were observed when the amount of straw in diets exceeded 20%, while daily gain decreased with increasing amounts of straw in the diets (Forbes *et al.*, 1969a; 1969b). In general it also seems that, if dietary straw increases, more food is required per unit of live mass-gain (Forbes *et al*, 1969b; Raven *et al.*, 1969).

Positive associative effects have, however, been observed for intake (Klopfenstein & Owen, 1981; Preston & Parra, 1981), digestibility (Hunt *et al.*, 1985; Hunt *et al.*, 1988) and production (Klopfenstein & Owen, 1981), when poor quality roughages are fed in combination with good quality roughages like lucerne hay. Ammoniation improves the nutritive value of straw (Brand *et al.*, 1991; Silva *et al.*, 1989), although evidence from the literature shows that, with high intake levels of concentrates, ammoniation of low quality roughages did not affect performance (Seed *et al.*, 1985; Zhao & Cui, 1988).

Considering the availability of wheat-straw and the need of farmers in the integrated cropping small stock farming systems to use wheat-straw in diets, this study was conducted (i) to determine the degree whereto the inclusion of wheat-straw in finishing diets for lambs affected digestibility, N retention and animal performance, and (ii) to evaluate ammoniated wheat straw as roughage component in a balanced diet, containing >60% concentrates.

Experimental procedure

Five experimental diets (Table 1) in which lucerne hay (LH) was substituted by wheat-straw (WS), lupins (*Lupinus albus* cv. Kiev) and fish-meal, were formulated (as-fed basis) to be approximately iso-nutritious with regard to digestible energy (DE ± 12 MJ), crude protein (± 16,5%), undegradeable protein (UDP, ± 5,0%), acid detergent fibre (ADF, ± 18,0%), neutral detergent fibre (NDE ± 33,0%) and required calcium and phosphorus contents (0,8 and 0,3%). An additional diet was formulated similar to the diet with the highest WS content (Table 1), but thermally ammoniated wheat straw was used. The wheat-straw was ammoniated in a commercial An-Stra-Verter® oven at a level of 30 g NH_3/kg straw dry matter (DM) for 24 h at 90 °C (Brand & Cloete, 1988). Thermal ammoniation was preferred, as previous results indicated a marked advantage in voluntary DM intake when compared to other methods of ammoniation (Brand & Cloete, 1988). All ingredients were hammermilled through a 12-mm screen and mixed together in the required proportions.

Table 1 Composition of experimental diets on an air-dry basis[a]

	Experimental diets					
Ingredient (%)	0 WS	6,5 WS	13 WS	19,5 WS	26 WS	26 AWS[b]
Barley grain	51,0	51,0	51,0	51,0	51,0	51,0
Lucerne hay	42,0	31,5	21,0	10,5	–	–
Wheat-straw	–	6,5	13,0	19,5	26,0	26,0
Lupins	–	3,5	7,0	10,5	14,0	14,0
Fish-meal	4,0	4,5	5,0	5,5	6,0	6,0
Molasses powder	1,5	1,5	1,5	1,5	1,5	1,5
Feed lime	0,5	0,5	0,5	0,5	0,5	0,5
Salt	0,5	0,5	0,5	0,5	0,5	0,5
Ammonium chloride	0,5	0,5	0,5	0,5	0,5	0,5

[a] All diets contained 100 g/t Tylan 100 and 250 g/t Salocin.

[b] Contains thermally ammoniated wheat-straw (AWS) instead of untreated wheat-straw (WS).

Digestion trial

Twenty-four South African Mutton Merino (SAMM) wethers with a mean live mass of 42 kg were used as experimental animals. The wethers were randomly allocated to the six different diets and subjected to a 31-day trial period, consisting of a 21-day adaptation period, and a 10-day collection period during which faeces and urine were collected. During the collection period, the experimental animals were fed at a level of 85% of *ad libitum* intake in two equal portions at 8h00 and 13h00. They had free access to water at all times. Representative feed, faeces and urine samples were taken daily and pooled for analyses. Dry matter, organic matter (OM) and crude protein (CP) contents of feed and faeces samples as well as the nitrogen (N) content of urine samples were determined (AOAC, 1984). Lignin, acid detergent fibre (ADF), neutral detergent fibre (NDF), cellulose and hemicellulose contents were determined as described by Van Soest (1963) and Van Soest & Wine (1967). Apparent digestibility coefficients were subsequently calculated for DM, OM, CP, ADF, NDF, cellulose and hemicellulose, while apparent N retention results were also obtained.

Growth trial

The growth trial was carried out with 48 SAMM lambs, approximately 69 days of age and with a mean live mass (± *SD*) of 15,7 ± 2,5 kg. They were individually housed in indoor pens equipped with feed and water trays. The lambs were blocked on live mass and randomly allocated to the experimental diets within blocks. The experimental diets were fed *ad libitum* to eight lambs per diet. Three lambs (two on the diet containing 6,5% WS and one on the diet containing 19,5% WS) refused to eat and had to be excluded from the study. The trial ended when the ram lambs were slaughtered at a mean live mass (± *SD*) of 35,5 ± 5,0 kg and at approximately 154 days of age. Feed intake and live mass were measured every four days. The allometric autoregressive model for description of growth as proposed by Roux (1976) and described by Siebrits (1986), was used to calculate individual figures regarding voluntary dry-matter intake (DMI), live mass-gain

(ADG) and feed convertion ratio (FCR) for individual lambs for the growth interval 15—35 kg live mass. Initial μ values were estimated from results published by Meissner (1977).

Ram lambs (four per treatment) were slaughtered at the end of the growth trial and weighed directly thereafter for the calculation of dressing percentage.

Statistical analysis

Two sets of analyses were completed. Standard one-way analysis of variance procedures (Snedecor & Cochran, 1980) were used to compare apparent digestibility coefficients, N balance and growth traits on the diets containing 26% untreated or ammoniated WS. The substitution of LH by WS was also assessed by one-way analysis of variance. In the analysis on lamb growth traits, the degrees of freedom for diets were partitioned into orthogonal polynomials, depicting linear and quadratic trends caused by the substitution of LH by WS. Chemical composition, mean apparent digestibility and mean apparent N retention results were related to WS content in the diet by linear regression.

Results and Discussion

The chemical composition of the iso-nutrient diets is presented in Table 2. The CP contents of the diets accorded with the values calculated initially, and differred little between diets. The contents of ADF (R^2 = 41,5%) and NDF (R^2 = 87,8; $P \leq$ 0,05) tended to increase with increased levels of WS, although the diets were theoretically composed to be equal. The same tendency was observed regarding cellulose (R^2 = 68,9%) and hemicellulose (R^2 = 80,7; $P \leq$ 0,05) contents, whereas lignin content tended to decline (R^2 = 61,8%) with increased levels of WS. The chemical composition of the total diet was unaffected by thermal ammoniation in the diet containing 26% WS (Table 2).

Table 2 Chemical composition of experimental diets (DM basis)

	Diet					
Item (%)	0 WS	6,5 WS	13 WS	19,5 WS	26 WS	26 AWS[a]
DM content	90,3	90,5	90,9	90,9	90,8	90,8
OM content	92,1	92,5	93,6	94,3	94,2	95,1
CP content	18,9	18,5	18,0	17,2	18,3	18,7
ADF content	16,5	19,9	21,4	19,6	20,4	19,1
NDF content	32,6	35,5	38,7	37,7	40,8	42,0
Cellulose	11,7	13,7	16,0	14,9	15,7	15,9
Hemicellulose	16,1	15,0	17,2	18,1	20,4	22,9
Lignin content	4,0	4,6	4,1	3,6	3,1	2,8

[a] Contains thermally ammoniated wheat-straw (AWS) instead of untreated wheat-straw (WS).

Metabolism trial

The digestibility of the five iso-nutrient diets, where LH (42—0%) was substituted by WS (0—26%), lupins (0—14%), and fish-meal (4—6%), is presented in Table 3. No significant differences were observed in apparent digestibility coefficients between the diets. OM digestibility varied between 71,1 and 75,2%, with an overall mean of 73,3 (DE content of 13,6 MJ), which was in correspondence with the DE content calculated initially (13,3 MJ on a DM basis). The substitution of LH by WS in combination with lupins and fish-meal, had no significant influence on the apparent digestibility of DM, OM, CP or the fibre fractions, while NDF digestibility tended to decrease linearly (R^2 = 53%) with increasing levels of LH in the diet. No significant differences in apparent N-retention were detected between diets, although it tended (R^2 = 93,4%, $P \leq$ 0,01) to decrease with increased levels of WS.

Table 3 Effect of substitution of lucerne hay with wheat-straw (WS), lupins and fish-meal on apparent digestibility coefficients and apparent N retention (means based on four replicates)

	Diet					
	0 WS	6,5 WS	13 WS	19,5 WS	26 WS	SE_m
DM digestibility (%)	72,7	71,2	72,5	73,6	70,2	2,31
OM digestibility (%)	74,4	71,6	73,7	75,2	71,1	2,68
ADF digestibility (%)	30,4	34,5	40,6	41,2	32,9	5,67
NDF digestibility (%)	43,1	42,8	48,4	51,5	47,2	6,13
Cellulose digestibility (%)	38,1	34,8	42,2	46,4	36,7	6,25
Hemicellulose digestibility (%)	58,1	53,8	58,1	62,6	60,7	7,95
CP digestibility (%)	81,2	79,5	78,8	81,3	86,2	2,63
Apparent N retention[a] (g/d)	14,9	13,0	9,5	9,8	6,5	7,1

[a] [N intake – (faecal N + urinary N)].

No significant differences.

The effect of ammoniation of wheat straw on digestibility and N balance is presented in Table 4. Ammoniation of wheat-straw in the 26 WS diet generally improved ($P \leq$ 0,01) the apparent digestibility of the diet. Apparent digestibility coefficients for DM and OM were improved by 5,2 and 5,8 percentage units, respectively. Apparent digestibility of the fibre fractions was also significantly ($P \leq$ 0,05) improved by 45,3% in the case of ADF, 33,6% in the case of NDF, 54,8% in the case of cellulose, and by 24,9% in the case of hemicellulose.

Table 4 Effect of ammoniation of wheat straw on digestibility and N balance (means based on four replicates)

	Diet		
	26 WS	26 AWS	SE_m
DM digestibility (%)	70,2	75,4[a]	2,01
OM digestibility (%)	71,1	76,9[b]	1,77
ADF digestibility (%)	32,9	47,8[a]	6,29
NDF digestibility (%)	47,2	63,1[b]	3,22
Cellulose digestibility (%)	36,7	56,8[b]	5,27
Hemicellulose digestibility (%)	60,7	75,8[b]	2,32
CP digestibility (%)	80,2	79,5	2,15
Apparent N retention[1] (g/d)	6,5	7,0	4,21

[a] Denote significant ($P \leq$ 0,05) dffferences in rows.

[b] Denote significant ($P \leq$ 0,01) differences in rows.

[1] [N intake – (faecal N + urinary N)].

This improvement in apparent digestibility of the diet was expected, as it is generally known that ammoniation improves the digestibility of wheat-straw (Cloete *et al.*, 1983; Cloete & Kritzinger, 1984; Brand & Cloete, 1988). Zorrilla-Rios *et al.* (1989) also reported an increase in OM digestibility when ammoniated and untreated WS were fed to sheep in combination with concentrates. They found no increase in NDF digestibility, while N digestibility was significantly ($P \leq 0,01$) decreased. Nitrogen metabolism was unaffected by the ammoniation of WS in the experimental diets.

Growth trial

The average DMI, ADG and FCR values of the lambs fed the respective diets, as obtained from the allometric autoregressive model, are presented in Table 5. DMI was reduced ($P \leq 0,01$) by increasing levels of WS in combination with lupins and fish-meal. The response was linear; DMI decreased by 80,5 (SE_b = 14,0) g/d ($P \leq 0,01$) with every increment of WS inclusion. This trend accounted for 99,3% of the variance introduced by diets. These results accord with those of Hunt *et al.* (1988), who also found that DM intake increased linearly when WS was replaced by LH in a 100% wheat-straw diet. They attributed this linear response to a lack of associative action between wheat-straw and lucerne hay. A review from the literature (O'Donovan, 1983) suggested that severe depression in feed consumption may be observed at higher straw inclusion levels, perhaps over 30%. Although not directly comparable, it should be noted that the substitution of LH by urea-ammoniated WS resulted in a marked reduction of 164 ± 22 g/d in diets containing 60% roughage in a foregoing study (Brand *et al.*, 1990). This decrease was attributed to the high fibre content and/or poor palatability of urea-ammoniated WS in comparison with LH. In our study, the diets were formulated on an approximate iso-fibre basis, and the reduced DMI appeared to be mainly the result of the poorer palatability of wheat-straw.

Table 5 Means for voluntary dry-matter intake (DMI), average daily gain (ADG) and feed conversion ratio (FCR) calculated for the growth interval 15—35 kg live mass of lambs fed five iso-nutrient diets in which lucerne hay was gradually replaced by increasing amounts of wheat-straw (WS), lupins and fish-meal

		Measurement		
Diet	Number of replicates	DMI (g/d)	ADG (g/d)	FCR (kg DMI/kg gain)
0 WS	8	1521	303	5,06
		(100)[a]	(100)	(100)
6,5 WS	6	1426	285	5,02
		(94)	(94)	(99)
13 WS	8	1339	305	4,45
		(88)	(101)	(88)
19,5 WS	7	1263	271	4,67
		(83)	(89)	(92)
26 WS	8	1201	269	4,57
		(79)	(89)	(90)
SE_m		122	29,3	0,71

[a] Figures in parentheses are expressed as percentages of the diet containing 0% WS.

Lambs receiving the diets containing 26,0 and 19,5% WS, grew slower ($P \leq 0,05$) than those on the 0 and 13,0% WS diets (Table 5). Daily gain decreased by 8,4 (SE_b = 3,3) g/d with every increment of WS inclusion. This trend accounted for 59,4% of the variance introduced by diets. The lower ADG values on the diets containing elevated WS levels, corresponded with the observed lower DMI levels. The growth performance could none the less be regarded as acceptable. These results confirmed evidence from the literature that acceptable growth performance can be obtained from diets containing low (10—20%) levels of straw inclusion (O'Donovan, 1983). A decreased ADG was only observed when fattening lambs were fed 30% coarsely chopped WS (O'Donovan & Ghadaki, 1973), or straw levels of 30—35% (Al-Khazraji *et al.*, 1981).

No significant differences in FCR were found between diets. There was, however, a trend for FCR to improve with increasing levels of WS in the diets. This trend ammounted to 0,13 (SE_b = 0,08) kg DMI/kg live mass-gain for every increment WS inclusion, accounting for 59,3% of the variance introduced by diets (P = 0,12). This was in contrast with evidence from the literature which, in general, indicated that more feed is required per unit live mass-gain as dietary straw increases (O'Donovan, 1983). The inclusion levels of straw in our diets were notably under the levels where FCR could be depressed. Feeding period significantly ($P \leq 0,01$) increased as the levels of WS in the diets increased, corresponding to the lower DMI, and resultant lower live mass-gains observed on the diets containing higher levels of WS. The dressing percentages of the ram lambs are presented in Table 7. No significant differences occurred between treatments (variation between 44,3 and 45,5%) and no specific tendency was observed.

The average DMI, ADG and FCR values of the lambs, receiving 26% untreated or ammoniated WS as roughage, are presented in Table 6. Ammoniation had no influence on DMI of the total diet. This was unexpected, because ammoniation of straw generally results in increased DMI (Silva *et al.*, 1989; Brand *et al.*, 1991). Seed *et al.* (1985) also found no significant increase in DMI with high concentrate levels and untreated or

Table 6 Means for voluntary dry-matter intake (DMI), average daily gain (ADG) and feed conversion ratio (FCR) calculated for the growth interval 15—35 kg live mass of lambs (n = 8) fed two concentrate diets with respectively 26% wheat-straw (WS) or ammoniated wheat-straw (AWS)

		Experimental diet	
Measurement	SE_m	26 WS	26 AWS
Number of replicates		8	8
DMI (g/DM/d)	134	1201	1152
		(100)[a]	(96)
ADG (g/d)	44,1	269	265
		(100)	(99)
FCR (kg feed/kg gain)	1,02	4,57	4,44
		(100)	(97)

Differences not significant.

[a] Figures in parentheses are expressed as percentages of the diet containing 26% WS.

Table 7 Mean dressing percentages (± *SD*) of ram lambs (four per treatment) fed five different iso-nutrient diets in which lucerne hay was gradually replaced by increasing amounts of wheat-straw (WS), lupins and fish-meal

Diet	Dressing percentage (%)
0 WS	44,9 ± 0,4
6,5 WS	44,3 ± 2,0
13 WS	45,2 ± 2,2
19,5 WS	45,5 ± 0,2
26 WS	45,4 ± 1,0

ammoniated maize residue as roughage component. Live mass-gain as well as FCR were unaffected by ammoniation. These findings accord with results of Zhao & Cui (1988) and Seed *et al.* (1985), who found that ammoniation of low quality roughages did not affect performance when fed in combination with high levels of concentrate. Similar results were published by Garrett *et al.* (1979), who showed that the growth response to alkali treatment may be undetectably small when included in concentrate diets of growing lambs at a level of 36%. Dressing percentages of the two different diets were respectively 45,4 ± 0,4% and 43,9 ± 0,8% and did not differ significantly.

Conclusions

It was evident that the replacement of LH by WS as roughage adversely affected DMI and ADG. This result could possibly be attributed to the lower inherent palatability of WS in comparison with LH, and partly to the higher fibre content of the diet with a high WS content. Performance on the diets containing WS as main or sole roughage source could, however, be regarded as satisfactory. The inclusion of WS as roughage in lamb growth diets could thus be recommended if the slightly lower ADG and resultant longer feeding period are not regarded as prohibitive. Evidence from the literature suggests that 30% WS should be regarded as a maximum inclusion level in lamb growth diets (O'Donovan, 1983). No advantage owing to thermal ammoniation of WS could be demonstrated at the inclusion levels studied presently. This finding is in accordance with those involving other crop residues and livestock species (Garrett *et al.*, 1979; Williams *et al.*, 1985; Seed *et al.*, 1985; Zhao & Cui, 1988).

Acknowledgements

The authors thank Miss D. Young for technical assistance with the growth trial and the personnel of the Elsenburg Animal Production Laboratory for chemical analyses of the samples.

References

AL-KHAZRAJI, A.K., AL-KHOJA, M.N., AL-KHASHAB, A.H. & MOMEN, S., 1981. The effect of straw : concenterate ratios on the performance of growing Barbary lambs. *Technical Report* FAO-DGRAE Acc. 301/81 Agricultural Research Centre, Tripoli. p. 16.

AOAC, 1984. Official methods of analysis (13th edn.) Association of Official Analytical Chemists, Washington DC.

BRAND, A.A. & CLOETE, S.W.P., 1988. Die benutting van ureum-aangevulde en verskillende tipes geammoniseerde garsstrooi by skape. *S. Afr. J. Anim. Sci.* 18, 118.

BRAND, A.A., CLOETE, S.W.P. & FRANCK, F., 1990. Substitution of lucerne hay by ammoniated wheat straw in growth diets for lambs. *S. Afr. J. Anim. Sci.* 20, 78.

BRAND, A.A., CLOETE, S.W.P. & FRANCK, F., 1991. The effect of supplementing untreated, urea-supplemented and urea-ammoniated wheat-straw with maize-meal and/or fish-meal in sheep. *S. Afr. J. Anim. Sci.*, 21, 48.

CLOETE, S.W.P., DE VILLIERS, T.T. & KRITZINGER, N.M., 1983. The effect of ammoniation by urea on the nutritive value of wheat straw for sheep. *S. Afr. J. Anim. Sci.* 13, 143.

CLOETE, S.W.P. & KRITZINGER, N.M., 1984. Urea ammoniation compared to urea supplementation as a method of improving the nutritive value of wheat straw for sheep. *S. Afr. J. Anim. Sci.* 14, 59.

FORBES, T.J., IRWIN, J.H.D. & RAVEN, A.M., 1969a. The use of coarsely chopped barley straw in high concentrate diets for beef cattle. *J. Agric. Sci., Camb.* 73, 347.

FORBES, T.J., RAVEN, A.M. & IRWIN, J.H.D., 1969b. The use of coarsely milled barley straw in finishing diets for young beef cattle. *J. Agric. Sci., Camb.* 73, 365.

GARRETT, W.N., WALKER, H.G., KOHLER, G.O. & HART, M.R., 1979. Response of ruminants to diets containing sodium hydroxide or ammonia-treated rice straw. *J. Anim. Sci.* 48, 92.

HART, M.R., GRAHAM, R.P., HANNI, P.F., ROCKWELL, W.C., WALKER, H.G., KOHLER, G.O., WAISS, A.C. & GARRET, W.N., 1975. Processing methods to improve the feed value of rice straw. *Feedstuffs* 47(39), 22.

HUNT, C.W., KLOPFENSTEIN, T.J. & BRITTON, R.A., 1988. Effect of alfalfa quality and wheat straw ammoniation on intake and digestibility of alfalfa-wheat straw combination diets fed to sheep. *Nutr. Rep. Int.* 37, 675.

HUNT, C.W., PATERSON, J.A. & WILLIAMS, J.E., 1985. Intake and digestibility of alfalfa-tall fescue combination diets fed to lambs. *J. Anim. Sci.* 60, 301.

JACKSON, M.G., 1977. The alkali treatment of straws. *Anim. Fd. Sci. Techn.* 2, 105.

KLOPFENSTEIN, T.J. & OWEN, F.G., 1981. Value and potential use of crop residues and by-products in dairy rations. *J. Dairy Sci.* 64, 1250.

MEISSNER, H.H., 1977. An evaluation of the Roux mathematical model for the functional description of growth. Ph.D dissertation, UPE.

O'DONOVAN, P.B., 1983. Untreated straw as a livestock feed. *Nutr. Abstr. Rev.* 53, 442.

O'DONOVAN, P.B. & GHADAKI, M.B., 1973. Effect of diets containing different levels of wheat straw on lamb performance, feed intake and digestibility. *Anim. Prod.* 16, 77.

PRESTON, T.R. & PARRA, R., 1981. Utilization of crop residues and agroindustrial by-products in animal nutrition: constraints and perspectives. PAO/ILCA workshop held in Dakar. 21—25 Sept. 1981.

RAVEN, A.M., FORBES, T.J. & IRWIN, J.H.D., 1969. The utilization by beef cattle of concentrate diets containing different levels of milled barley straw and of protein. *J. Agric. Sci., Camb.* 73, 355.

REXEN, F.P., 1979. Low quality forages improve with alkali treatment. *Feedstuffs* 51(42), 33.

ROUX, C.Z., 1976. A model for the description and regulation of growth and production. *Agroanimalia* 8, 83.

SEED, E.W., HOFMEYR, H.S. & MORGAN, P.J.K., 1985. The use of ammoniated maize residue to replace maize meal in fattening diets for lambs. *S. Afr. J. Anim. Sci.* 15, 27.

SIEBRITS, F.K., 1986. Application of the allometric autoregressive growth description in studies of growth and body composition. *Pig News and Information* 7, 413.

SILVA, A.T., GREENHALGH, J.F.D. & ØRSKOV, E.R., 1989. Influence of ammonia treatment and supplementation on the intake, digestibility and weight gain of sheep and cattle on barley straw diets. *Anim. Prod.* 48, 99.

SNEDECOR, G.W. & COCHRAN, W.G., 1980. Statistical methods (7th edn.). The Iowa State University Press, Ames, Iowa, USA.

VAN SOEST, P.J., 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method of determination of fibre and lignin. *J. Assoc. Off. Agric. Chem.* 46, 82.

VAN SOEST, P.J. & WINE, R.H., 1967. Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell wall consituents. *J. Assoc. Off. Agric. Chem.* 50, 50.

WILLIAMS, P.E.V., INNES, G.M., BREWER, A. & MAGADI, J.P., 1985. The effects on growth, food intake and rumen volume of including untreated or ammonia-treated barley straw in complete diets for weaning calves. *Anim. Prod.* 41, 63.

ZHAO, Z.B. & CUI, W.X., 1988. Efficiency of ammoniated straw as a feed to sheep. *Ningxia Agr. For. Sci. Techn.* 1, 42 (in Chinese).

ZORRILLA-RIOS, J., HORN, G.W. & McNEW, R.W., 1989. Effect of ammoniation and energy supplementation on the utilization of wheat straw by sheep. *Anim. Fd. Sci. Techn.* 22, 305.