Animal Science 1997, 65: 55-62
1357-7298/97/69920055$20·00

Effects of amount offered and chopping on intake and selection of sorghum stover by Ethiopian sheep and cattle

E. L. K. Osafo[1]†, E. Owen[1], A. N. Said[2]‡, M. Gill[3] and J. Sherington[2]§

[1]*Department of Agriculture, University of Reading, Earley Gate, PO Box 236, Reading RG6 6AT*
[2]*International Livestock Centre for Africa, PO Box 5689, Addis Ababa, Ethiopia*
[3]*Natural Resources International, Central Avenue, Chatham Maritime, Chatham ME4 4TB*

Abstract

Experiment 1, with rams (17·0 kg initial weight (M)), and experiment 2, with steers (203 kg M), involved 2 × 2 arrangements of treatments to compare the effect of doubling the amount of stover offered (25 or 50 g/kg M daily) and chopping (unchopped or chopped), upon intake, selection and live-weight change. The stover used was a non-bird-resistant, local variety (Dinkamash). The particle length distribution of the chopped stover (produced by a tractor-driven chaff cutter) was: <4·5 mm, 0·148; 4·5 to 8 mm, 0·157; 8 to 12 mm, 0·181; 12 to 20 mm, 0·269; 20 to 33 mm, 0·168; 33 to 54 mm, 0·040; 54 to 90 mm, 0·003; >90 mm, 0·034. The stover was supplemented with minerals and cottonseed cake (sheep, 0·1 kg dry matter (DM) per day; cattle, 0·76 kg DM per day). Experiment 1, over 56 days, involved 48 Menz Highland, 18-month-old, rams, with four replicate pens containing three rams. Experiment 2, over 49 days, used 32, individually penned, Friesian × zebu yearling steers. With rams, doubling the amount offered and chopping increased intake, and the effects were additive (unchopped: 0·98 v. *1·24; chopped: 1·08* v. *1·60 (s.e. 0·071) kg DM per pen per day). With steers, there was an amount × chopping interaction (*$P < 0.05$*) (unchopped: 3·7* v. *4·7 chopped: 3·6* v. *3·9 (s.e. 0·16) kg DM per day), with chopping reducing intake of stover offered at 50 g/kg M per day. Increased intakes were associated with increased growth rate. In both experiments refused stover contained less leaf-plus-sheath than offered stover but the difference was more pronounced in rams compared with steers indicating the superior selective ability of the rams. In rams offered unchopped stover, the increase in stover intake with increasing amount offered was accounted for by a proportional 1·03 unit increase in consumption of leaf-plus-sheath and a 0·06 unit reduction in intake of stem. Doubling the amount of unchopped stover offered increased intake of both rams and steers by 0·27 unit. Chopping stover was clearly beneficial for rams but not for steers. Doubling the amount of stover offered is a simple excess-feeding strategy to apply. Excess feeding also increases the proportion of stover refused from about 0·2 to 0·5, thus generating an uneaten residue available for other purposes, e.g. mulch or compost.*

Keywords: *food intake, sheep, sorghum stover, steers.*

Introduction

World production of sorghum grain was estimated to be 61 Mt in 1994 (Food and Agriculture Organization (FAO), 1995); this quantity of grain would be associated with the production of three to four times as many tonnes of crop residue, i.e. stover. This modest production compares with a global production of 601 Mt of maize grain in 1994 (FAO, 1995). However, sorghum is a drought tolerant cereal and is grown in the semi-arid tropics and sub-tropics. In these regions, sorghum grain is a staple food for humans and the stover is used as a low-quality livestock forage and a commodity for other purposes, e.g. in Ethiopia for fencing, fuel and mulch (Osafo, 1993). Sorghum production and therefore stover production are likely to increase in the future because of population growth leading to increased cultivation of marginal areas, and because of climatic

Present addresses:
† Department of Animal Science, University of Science and Technology, Kumasi, Ghana.
‡ PO Box 766, Malindi, Kenya.
§ Natural Resources Institute, Chatham Maritime, Chatham ME4 4TB.

changes (Intergovernmental Panel on Climate Change, 1990).

Sorghum stover therefore represents an increasingly large crop-residue resource which is currently underutilized as a ruminant forage because of its low nutritive value (dry matter (DM) digestibility <0·55 and crude protein (CP) <50 g/kg DM) and low intake (Alhassan *et al.*, 1987; Olayiwole and Olorunju, 1987; Kabatange and Kitalyi, 1989).

Ruminant production in sorghum-growing areas could be improved if there were means of improving the low nutritive value of stover. Methods of upgrading crop residues as food have received much research and development attention since the mid 1970s (Owen and Jayasuriya, 1989). Treatment with urea to generate ammonia (Schiere and Ibrahim, 1989) has received particular emphasis in the tropics and sub-tropics, for crop residues such as rice straw. However, urea treatment is unlikely to be applied widely to sorghum stover as the crop is grown on small-holder farms where water and capital are limited and the improvement in animal productivity does not justify the expense (Saadullah and Siriwardene, 1993; Singh *et al.*, 1993). The present study was concerned with improving intake of stover using chopping or 'excess feeding' to allow animals to exercise selective eating. These two low-technology approaches are considered more applicable alternatives to treatment with urea.

Chopping of sorghum and maize stovers is often practised, but there is little published information on whether this is worthwhile (Fernández-González, 1981; Walker, 1984). In an informal survey in Ethiopia (Osafo, 1993), farmers argued for chopping sorghum stover because it was easier to feed in chopped form and the amount wasted was reduced.

Wahed *et al.* (1990) found that straw intake by small ruminants increased when generous amounts were offered allowing much higher refusal-rates than the conventional 0·15 to 0·20 of the amount offered in *ad libitum* feeding (Blaxter *et al.*, 1961). In the study of Wahed *et al.* (1990), intake of straw digestible organic matter by sheep increased from 6·6 to 10·5 and 12·7 g/kg live weight (M) daily respectively, as the amount of barley straw offered was increased from 18 to 54 and 90 g DM per kg M per day. However, increasing the amount offered resulted in increasing rates of straw refused (208, 647 and 751 g/kg offered). It was hypothesized that the increased intake was due to animals selecting for the more rumen-degradable (Bhargava *et al.*, 1988; Flachowsky *et al.*, 1991) leaf and sheath components. Furthermore, work in Ethiopia (Aboud *et al.*, 1993) showed that goats and sheep increased their intake of chopped stover when the amount offered was increased from 25 to 50 g/kg M per day but there was little further intake when the amount offered was increased to 75 g/kg M per day.

The objective of the present study was to quantify the effects of chopping or increasing the *ad libitum* amount of stover offered upon intake, selection and live-weight gain, using (a) sheep (experiment 1) and (b) cattle (experiment 2). It was hypothesized that increasing the amount of stover offered would increase intake and selection but that the effect was likely to be mediated by chopping, the effect being larger in sheep than in cattle because of the anatomical differences in the mouth parts of the two species. In both experiments the stover was supplemented with cottonseed cake and minerals.

Material and methods

Experiment 1: sheep

Forty-eight Menz Highland rams which had been reared at the International Livestock Centre for Africa's (ILCA) Debre Berhan Station were moved to ILCA Debre Zeit Station and treated for gastro-intestinal parasites prior to the commencement of experiment 1. The rams ranged from 15 to 20 months of age and from 13 to 20 kg live weight. Experiment 1 involved a 2 × 2 factorial arrangement of treatments with four replicate, unbedded pens, each containing three rams per treatment. The factors were, amount of sorghum stover offered (25 or 50 g/kg M per day) and physical form (unchopped or chopped sorghum stover). Rams were blocked according to initial live weight. Cottonseed cake (952 g DM per kg; 453 g CP per kg DM) was offered at 340 g per pen daily and the supplement was designed to meet requirements for rumen-degradable protein (Agricultural Research Council (ARC), 1980 and 1984). The experiment was deemed to start on the day rams were first offered stover. This aimed to mimic husbandry methods used in Ethiopia involving abrupt change from one forage to another (Osafo, 1993). The experiment lasted 56 days. Prior to the commencement of the experiment, rams were given teff (*Eragrostis tef*) straw for 10 days.

The stover used was from a non-bird-resistant cultivar, Dinkamash, which was grown at Melkassa, 70 km south east of Debre Zeit. Following grain harvesting by hand, the standing stover was left in the field for 2 months before being handcut and transported to Debre Zeit, where it was stored in a barn for a further 5 months. At commencement of the experiment and on days 20 and 40, a portion of the stover was chopped using an Alvan Blanch, 'Maxi' chaff cutter mounted on a power take-off (PTO) set to rotate at 2200 r.p.m. The particle length distribution of a composite sample of the chopped stovers (experiments 1 and 2) was measured using the method of Gale and O'Dogherty (1982). The proportion by weight in each length category was as follows: <4·5 mm, 0·148; 4·5 to 8 mm, 0·157; 8 to 12 mm, 0·181; 12 to 20 mm, 0·269; 20 to 33 mm, 0·168; 33 to 54 mm, 0·040; 54 to 90 mm, 0·003; >90 mm, 0·034. Unchopped stover was offered to sheep in long form, with no processing. Stover stem lengths were approximately 120 cm.

Stover was offered each day, at 08.00 and 14.00 h, in mangers (one per pen) of 3·0 m length, 0·45 m width and 0·30 m depth. The amount of stover offered to each pen was based on total initial live weight per pen, and was adjusted upwards, weekly in relation to increasing live weight. No adjustment was made if pen live weight decreased. Cottonseed cake was offered 30 min before offering stover. Each pen was provided with water and a mineral block. Refused stover was collected and weighed daily at 07.30 h. Samples (300 g) of refusals per pen were taken daily and pooled over each week. At the end of the experiment the weekly pooled samples were further pooled to yield a composite sample of refusal for each pen. Stover offered was sampled daily and 2-week bulked samples prepared to yield four samples each of chopped or unchopped stover offered. Samples of offered and refused stover were halved to provide 0·5-kg samples for each of subsequent chemical and botanical analyses. Samples for botanical analysis were hand-separated into leaf-plus-sheath and stem and the fractions subsequently dried. Offered and refused stover samples were analysed for DM, ash and nitrogen content (Association of Official Analytical Chemists, 1984) and neutral-detergent fibre (NDF) content (Goering and Van Soest, 1970).

Unfasted live weight of rams was recorded on 2 days consecutively at the beginning of the experiment and on 1 day, each week, thereafter.

For data on intake, weight gains and chemical and botanical composition of refusals, an analysis of variance for a 2 × 2 factorial design was carried out using the general linear model procedure (GLM) of the Statistical Analysis Systems Institute (SAS, 1987). For offered stover, comparisons between chopped and unchopped were done using a paired t test, with sampling periods used for pairing. For comparing the chemical and botanical composition of offered stover with refusals, the data values of the relevant offered stover were subtracted from the values for the refusals to give the change in composition. A one sample t test was used to test whether this change was different from zero.

Experiment 2: cattle

Experiment 2 had the same design as experiment 1 except for a different source of stover and use of cattle, and involved 32 individually fed Friesian × zebu steers of 200 kg initial live weight and 15 months of age, with eight steers per treatment. The experiment lasted 56 days but intake data for days 50 to 56 were discarded because heavy rains caused a problem of sampling refusals.

Unlike experiment 1, the stover (cultivar, Dinkamash) was hand cut immediately after grain harvesting and stored in a barn for 28 days before the commencement of feeding. All other methods regarding stover production and processing were as in experiment 1.

The steers were individually tethered and provided with a feeding manger (1·1 m long, 1·0 m wide and 0·9 m deep), water bowl and mineral block. Feeding management was as in experiment 1, except that cottonseed cake supplement was fed at 760 g DM per steer daily. Sampling and analysis of offered and refused stover were similar to experiment 1. Samples (300 g) of refusal per steer were taken daily and pooled over the experiment to yield a composite sample for each steer. Stover offered was sampled daily and pooled over each week to yield a total of eight samples (one per week) of each of chopped and unchopped forms. For chemical analysis offered samples were further bulked to provide two samples of chopped or unchopped stover (weeks 1 to 4, 5 to 8). The frequency of weighing animals was as in experiment 1. Statistical analysis of the data was as in experiment 1.

Results

Experiment 1: sheep

Although there was no significant difference ($P > 0·05$) in chemical composition between stover offered in the unchopped or chopped form, chopping appeared to increase content of leaf-plus-sheath ($P < 0·01$) (Table 1). Irrespective of treatment, refused stover, compared with offered stover, contained more NDF ($P < 0·01$), less leaf-plus-sheath ($P < 0·001$) and more stem ($P < 0·001$). Refusals from rams offered 50 g/kg M per day contained more leaf-plus-sheath ($P < 0·001$) and less stem ($P < 0·001$) than refusals from rams offered 25 g/kg M per day (Table 1).

Rams consumed all the cottonseed cake supplement offered. The proportion of stover refused (kg DM refused per kg offered; Table 2) was much higher at the 50 compared with the 25 g/kg M per day offer rate. Stover DM intake was significantly increased by chopping and by doubling the amount offered; there was no interaction between chopping and amount

Table 1 *Chemical and botanical composition of sorghum stover offered or refused in experiments 1 and 2*

	Offered			Refused							
Form of stover (F)	Unchopped	Chopped		Unchopped		Chopped			Significance of refused		
Amount offered (A)(g/kg M per day)			s.e.	25	50	25	50	s.e.	F	A	F×A
Experiment 1: sheep											
Dry matter (DM) (g/kg)	925	926	3·2	902	890	923	914	9·7			
Ash (g/kg DM)	100	105	4·5	123	106	74	78	4·7			
Crude protein (g/kg DM)	24	28	1·5	22	20	24	23	1·0			
Neutral-detergent fibre (g/kg DM)	735	734	8·6	796	801	806	811	5·0			
Leaf + sheath (g DM per kg DM)	237	308	13·2	7	16	9	18	1·6		***	
Stem (g DM per kg DM)	763	692	13·2	993	984	991	982	1·6		***	
Experiment 2: cattle											
DM (g/kg)	904	895	6·3	908	904	902	903	1·5			
Ash (g/kg DM)	118	147	14·4	144	131	134	139	4·1			
Crude protein (g/kg DM)	49	70	9·5	45	48	56	57	1·9			
Neutral-detergent fibre (g/kg DM)	730	637	24·2	751	738	711	703	6·9	***		
Leaf (g DM per kg DM)	33	94	9·4	23	33	46	61	6·5	***		
Sheath (g DM per kg DM)	263	211	49·8	112	153	91	121	5·4	***	***	
Stem (g DM per kg DM)	704	695	49·2	865	814	863	818	8·9		***	

Experiment 1: no. = 4 for chemical analysis and botanical composition. Experiment 2: no. = 2 for chemical analysis, no. = 8 for botanical composition.

offered ($P > 0·05$). The estimated intake of leaf-plus-sheath was increased more by amount offered than by chopping (Table 2). Estimated stem intake was not increased by either chopping or amount of stover offered.

Both chopping and doubling the amount of stover offered, resulted in a marked and significant increase in rate of live-weight gain (Table 2).

Experiment 2: cattle
There was no significant difference ($P > 0·05$) in chemical composition between stover offered in the unchopped or chopped form but chopping appeared to increase the content of leaf ($P < 0·001$) and reduce ($P > 0·05$) the sheath (Table 1). This may have reflected analytical errors of distinguishing between leaf and sheath after chopping. Except for higher NDF content of refused chopped stover ($P < 0·01$), there was no difference in chemical composition between refused and offered stovers ($P > 0·05$). For both amounts offered, there was less leaf ($P < 0·05$), less sheath ($P < 0·05$) and more stem ($P < 0·01$) in refused chopped stover compared with offered chopped stover. For unchopped stover offered at 25 g/kg M per day, there was less sheath ($P < 0·05$) and more stem ($P < 0·05$) in refused compared with offered stover; there was no difference in botanical composition between offered and refused stover for unchopped material offered at 50 g/kg M per day. There was more stem ($P < 0·001$) and less sheath ($P < 0·001$) in refusals from steers offered stover at 25 g/kg M per day rather than at 50 g/kg M per day (Table 1).

All steers consumed their cottonseed cake allowance. The proportion of stover refused doubled as the stover offer rate increased from 25 to 50 g/kg M per day (Table 2). For intake of stover, there was significant interaction ($P < 0·05$) between amount offered and chopping (Table 2). Doubling the amount offered resulted in a large increase in intake of unchopped stover ($P < 0·001$) but a smaller increase in the intake of chopped stover ($P < 0·01$). Chopping reduced intake ($P < 0·01$), particularly at the 50 g/kg M per day offer rate. There was a significant interaction between the amount of stover offered and chopping for the intakes of both leaf and stem. Leaf intake was increased much more by doubling the amount offered when the stover was unchopped. Doubling the amount of stover offered increased stem intake when the stover was unchopped but decreased stem intake when chopped.

Doubling the amount of stover offered resulted in a significant improvement in rate of live-weight gain but chopping gave only a small response ($P > 0·05$).

Table 2 *Effects of amount of stover offered and chopping on live-weight gain, stover intake and intake of leaf-plus-sheath and stem in sheep and cattle*

Form of stover (F)	Unchopped		Chopped		Significance			
Amount offered (A) (g/kg M per day)	25	50	25	50	s.e.	F	A	F×A
Experiment 1: sheep								
Rams per pen	3	3	3	3				
Initial weight (M) (kg per pen)	51·8	51·0	50·4	51·2	3·09			
Gain (g per ram per day)	30·5	56·0	45·8	70·5	3·44			
Stover offered† (kg DM per pen per day)	1·25	2·56	1·23	2·60				
Stover offered (g DM per kg M per day)	23·0	46·0	22·7	45·5				
Stover refused† (kg DM per kg DM offered)	0·21	0·52	0·11	0·38				
Stover intake† (kg DM per pen per day)	0·98	1·24	1·08	1·60				
Intake of NDF of stover (kg per pen per day)	0·71	0·82	0·78	1·10				
Stover intake (g DM per kg M per day)	18·9	24·3	21·4	31·3				
Intake of stover leaf + sheath (kg DM per pen per day)	0·29	0·59	0·38	0·78	0·009			
Intake of stover stem (kg DM per pen per day)	0·69	0·65	0·71	0·82	0·048			
Experiment 2: cattle								
No. of animals	8	8	7	8				
Initial weight (M)(kg)	204·0	204·1	200·1	202·9				
Gain (kg/day)	0·25	0·43	0·36	0·44	0·059			
Stover offered (kg DM per day)	4·9	9·5	5·1	9·9				
Stover offered (g DM per kg M per day)	23·3	44·3	23·4	46·3				
Stover refused (kg DM per kg DM offered)	0·24	0·51	0·29	0·62				
Stover intake (kg DM per day)	3·7	4·7	3·6	3·9	0·16	**	***	*
Intake of NDF of stover (kg/day)	2·7	3·4	2·3	2·1	0·16	**		**
Stover intake (g DM per kg M per day)	18·1	23·0	18·0	19·2				
Intake of stover leaf (kg DM per day)	0·5	0·8	0·5	0·6	0·07	***	***	
Intake of stover sheath (kg DM per day)	0·9	1·2	0·9	1·3	0·03	***	***	
Stover stem intake (kg DM per day)	2·4	2·8	2·2	1·9	0·12	***		**

† Based on three rams per pen.

Discussion

Experiment 1, with sheep, and experiment 2, with cattle, differed only in the animal species used, source of sorghum stover and group *versus* individual feeding. The leaf-plus-sheath contents of the stovers used were at the lower end of the range (0·41 : 1 to 1·18 : 1) for 15 varieties of sorghum stovers measured at harvesting in Ethiopia (Osafo, 1993). The botanical composition of the sorghum stovers used in the two experiments were slightly different; in experiment 1, the leaf-plus-sheath : stem ratio of offered, unchopped stover (0·38 : 1) was slightly lower than that in experiment 2 (0·42 : 1). The difference was probably due to the 8-week, post-grain-harvest, standing-in-the-field period for stover in experiment 1. This would have resulted in greater loss of leaf, both in the field and during transportation and handling, compared with the stover in experiment 2, which was removed from the field immediately after grain harvesting. Osafo (1993) showed that content of leaf and sheath decreased in both field-stored and barn-stored sorghum stover during a 16-week period following grain harvesting.

The small differences between stovers used in experiments 1 and 2 notwithstanding, the results of the two experiments confirmed the hypothesis that doubling the amount of stover offered would increase intake in both sheep and cattle but that the intake response to chopping was likely to be larger in sheep than in cattle. Relative intakes (Table 3) showed that chopping and doubling the amount offered were additive in sheep, thus increasing intake proportionately by 0·63. In contrast, chopping stover decreased intake in cattle, whereas doubling the amount offered increased intake proportionately by 0·27, if the stover was unchopped. In both experiments, the increases in stover intakes which occurred, were largely made up of greater consumption of leaf and sheath (Table 2). It is notable that increased intake, in both experiments, was associated with increased growth rate and this would be expected bearing in mind that intake

Table 3 *Effect of amount of stover offered and chopping on relative intake by sheep (experiment 1) and cattle (experiment 2)*

Form of stover	Amount of stover offered (g/kg M per day)	Stover intake		Leaf + sheath intake	Stem intak	
		Sheep	Cattle		Sheep	Cattle
Chopped	50	163	105		119	79
Unchopped	50	127	127		94	117
Chopped	25	110	97		103	92
Unchopped	25	100	100		100	100

response was made up of more nutritious leaf and sheath rather than stem. The live-weight gains observed in the present experiments are within the range (44 to 63 g/day) reported for sheep in Ethiopia offered sorghum stover (Aboud, 1991) and maize stover (Osuji *et al.*, 1993).

It is likely that the intake of stover would have increased further if the amount offered had been more, as was shown by Aboud *et al.* (1991), when offering 75 g/kg M per day of stover, chopped as in the present experiments, to sheep and goats. The obvious practical disadvantage of very high stover offer-rates is the large amount of material refused. Even at the 50 g/kg M per day offer-rate in the present experiments, the proportion of stover refused ranged from 0·38 to 0·62. Improved intake by sheep due to increased offer rate has also been reported for barley straw (Wahed *et al.*, 1990), sorghum stover (Aboud *et al.*, 1991) and millet stover leaves (Fernandez-Rivera *et al.*, 1994).

As indicated earlier, the response in stover intake due to chopping was different for cattle and sheep, chopping being beneficial in sheep and detrimental in cattle at the higher offer level. This presumably reflects the greater ability of sheep to select stover of higher nutritive value even when chop length is short. The intake response of sheep to chopping in experiment 1 contrasts with the study by Wahed (1987) who reported no intake improvement when chopping (Atlas chaff cutter, R. Hunt and Co. Ltd, Colchester) barley straw for sheep. Compared with the chopped stover in the present study, the chopped barley straw in Wahed's study contained a higher proportion by weight of longer particles (<4·5 mm, 0·007; 4·5 to 8 mm, 0·028; 8 to 12 mm, 0·05; 12 to 20 mm, 0·196; 20 to 33 mm, 0·382; 33 to 54 mm, 0·196; 54 to 90 mm, 0·105; >90 mm, 0·038), which may have accounted for the lack of response to chopping. However, it is known that the effects of chopping (as opposed to grinding) on intake of temperate forages is inconsistent and generally small (Campling and Milne, 1972; Owen, 1978; Walker, 1984). Campling and Milne (1972) pointed to the difficulty of interpreting the literature on the effects of mechanical processing of roughages because of the variation in particle size reduction achieved (even after ginding roughage through a given screen size) and the failure of many authors to define particle size. There is no published evidence in the literature to show the effects of chopping on sorghum stover intake. The Alvan Blanch chaff cutter and tractor PTO r.p.m. used in the present experiments produced chopped stover with a high proportion of short-length particles (<7·0 mm, 0·25; <12·4 mm, 0·50). The fact that chopping improved intake in sheep and not in cattle is likely to be due to the greater sensitivity of sheep to diet particle size compared with cattle (Greenhalgh and Wainman, 1972; ARC, 1980) on account of the smaller reticulo-omasal orifice in sheep. Additionally, the large decrease in intake due to chopping in cattle offered stover at 50 g/kg M per day was probably due to their being less able than sheep to select for leaf and sheath in the chopped form. As indicated earlier, Osafo (1993) found that Ethiopian farmers practised handchopping (i.e. using a machete) of sorghum stover to facilitate feeding and reduce the amount wasted. Kitalyi (1993) also reported similar practice by farmers feeding cattle in central Tanzania. There is need for further research on the benefits, or otherwise, of chopping sorghum stover.

Prior to commencing both experiments 1 and 2, the animals were not subjected to an adaptation period, the object being to mimic the practice on Ethiopian farms of abruptly changing forages offered to ruminants and donkeys. It is interesting that rams and steers, in both experiments, consumed stover readily at the first time of offer. This was probably because the animals had been previously exposed to teff (*Eragrostis tef*) straw and possibly sorghum stover, and thus had been conditioned to eating such forages (Odoi and Owen, 1993).

The amount of cottonseed cake supplement offered was minimal (0·15 to 0·26 of total DM) and designed to meet requirements for rumen-degradable protein (ARC, 1980 and 1984). Although the extent to which higher growth rates would occur with higher supplementation merits further investigation, it is likely that greater supplementation would lead to a reduction in stover intake (Hossain and Owen, 1992).

As noted earlier, the stovers used contained relatively little leaf and sheath. The intake response to doubling the amount offered would be higher if stovers contained more leaf and sheath. The stovers used in experiments 1 and 2 were from a non-bird-resistant variety (Dinkamash). Reed *et al.* (1987), measuring digestibility *in vitro*, and Aboud *et al.* (1991) measuring digestibility in sheep, showed lower DM and NDF digestibility values in stovers from bird-resistant compared with non-bird-resistant sorghum. Therefore, for stovers of comparable leaf-plus-sheath content, it is conceivable that the intakes would be lower, and the response to doubling the offer-rate larger, in bird-resistant compared to non-bird-resistant varieties.

A common feature of both experiments 1 and 2 was the large proportion of the offered stover that was refused (0·38 to 0·62), when the offer rate increased to 50 g/kg M per day. Such refusals could be mixed with excreta to generate compost (Tanner *et al.*, 1995), or refusals *per se* used as mulch (Bationo *et al.*, 1995), fuel (Osafo, 1993) or forage for less-valuable animals e.g. donkeys (Aboud, 1991).

The present experiments demonstrate that the 'excess feeding' strategy of doubling the amount of stover offered from 25 to 50 g/kg M per day is an effective and simple way of increasing the intake and hence live-weight gain of sheep and cattle offered sorghum stover *ad libitum* together with restricted quantities of cottonseed cake. Furthermore, chopping stover as in the present study is a further method of increasing intake in sheep, but not in cattle. There is need for further research on the benefits or otherwise of chopping sorghum stover for cattle and sheep.

Acknowledgements

The authors acknowledge financial sponsorship from the ODA's Livestock Production Programme (LPP) and the International Livestock Centre for Africa. The helpful advice of the Institute of Agricultural Research (Melkassa) in Ethiopia is also acknowledged. The authors are grateful to Mrs S. J. Dimmock of Silsoe Research Institute, Bedford for assessing the length distribution of chopped stover.

References

Aboud, A. A. O. 1991. Strategies for utilization of sorghum stover as feed for cattle, sheep and goats. *Ph.D. thesis, The University of Reading.*

Aboud, A. A. O., Owen, E., Reed, J. D., Said, A. N. and McAllan, A. B. 1991. Feeding sorghum stover to Ethiopian goats and sheep: effect of amount offered on growth, intake and selection. *Animal Production* **52:** 607 (abstr.).

Aboud, A. A. O., Owen, E., Said, A. N., Gill, M. and McAllan, A. B. 1993. Feeding sorghum stover to Ethiopian goats and sheep: effect of amount offered on intake, selection and performance. In *Animal production in developing countries* (ed. M. Gill, E. Owen, G. E. Pollott and T. L. J. Lawrence), *British Society of Animal Production occasional publication no. 16*, pp. 202-203.

Agricultural Research Council. 1980. *The nutritional requirements of ruminant livestock.* Commonwealth Agricultural Bureaux, Slough.

Agricultural Research Council. 1984. *The nutritional requirements of ruminant livestock. Supplement no. 1.* Commonwealth Agricultural Bureaux, Slough.

Alhassan, W. S., Obilana, A. B. and Beko, S. A. 1987. Yield and potential feeding value of straws of grain sorghum cultivars developed in Nigeria. *Animal Feed Science and Technology* **17:** 285-293.

Association of Official Analytical Chemists. 1984. *Official methods of analysis. 14th ed.* Association of Official Analytical Chemists, Washington, DC.

Bationo, A., Buekert, A., Sedogo, M. P., Christianson, B. C. and Mokwunye, A. U. 1995. A critical review of crop-residue use as soil amendment in West African semi-arid tropics. In *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa* (ed. J. M. Powell, S. Fernandez-Rivera, T. O. Williams and C. Renard), *proceedings of an international conference held in Addis Ababa, Ethiopia, 22-26 November 1993*, pp. 305-322. ILCA (International Livestock Centre for Africa), Addis Ababa.

Bhargava, P. K., Ørskov, E. R. and Walli, T. K. 1988. Rumen degradation of straw. 4. Selection and degradation of morphological components of barley straw by sheep. *Animal Production* **47:** 105-110.

Blaxter, K. L., Wainman, F. W. and Wilson, R. S. 1961. The regulation of food intake by sheep. *Animal Production* **3:** 51-62.

Campling, R. C. and Milne, J. A. 1972. The nutritive value of processed roughages for milking cattle. *Proceedings of the British Society of Animal Production*, pp. 53-60.

Fernández-Gonzáles, E. 1981. Effects of treatment with NaOH on digestibility and intake by lambs of barley straw chopped to different lengths and treated for different lengths of time. 2: *Nutrition Abstracts and Reviews, Series B* **51:** 420 (abstr.).

Fernandez-Rivera, S., Midou, A. and Marichatou, H. 1994. Effect of food allowance on diet selectivity and intake of pearl millet (*Pennisetum glaucum*) stover leaves by sheep. *Animal Production* **58:** 249-256.

Flachowsky, G., Tiroke, K. and Schein, G. 1991. Botanical fractions of straw of 51 cereal varieties and *in sacco* degradation of various fractions. *Animal Feed Science and Technology* **34:** 279-289.

Food and Agriculture Organization. 1995. *Production yearbook 1994.* FAO Statistics Series 125, vol. 48, pp. 84-85. Food and Agriculture Organization of the United Nations, Rome.

Gale, G. E. and O'Dogherty, M. J. 1982. An apparatus for the assessment of the length distribution of chopped forage. *Journal of Agricultural Engineering and Research* **27:** 35-43.

Goering, H. K. and Van Soest, P. J. 1970. Forage fibre analysis (apparatus, reagents, procedures and some applications). *Agriculture handbook, US Department of Agriculture, no. 379.*

Greenhalgh, J. F. D. and Wainman, F. W. 1972. The nutritive value of processed roughages for fattening sheep and cattle. *Proceedings of the British Society of Animal Production,* pp. 61-72.

Hossain, M. M. and Owen, E. 1992. Concentrate-substitution effect on straw intake in goats. In *Recent advances in goat production. Proceedings of and papers presented at the fifth international conference on goats held in New Delhi* (ed. R. R. Lokeshwar), pp. 847-849. Fifth International Conference on Goats, New Delhi.

Intergovernmental Panel on Climate Change. 1990. *Formulation of response strategies.* Report prepared for Intergovernmental Panel on Climate Change (IPCC) by working group III. WMO and UNEP, Geneva.

Kabatange, M. A. and Kitalyi, A. J. 1989. Livestock feeding in the semi-arid areas of central Tanzania; potentials, constraints and possible improvements. In *Overcoming constraints to the efficient utilization of agricultural by-products as animal feed* (ed. A. N. Said and D. H. Dzowela), *Proceedings of the fourth annual workshop of the African Research Network for Agricultural By-products (ARNAB), 20-27 October, 1987,* pp. 232-238. ARNAB, Addis Ababa.

Kitalyi, A. J. 1993. Sorghum stover and lablab bean haulm for dry-season feeding of lactating cattle in semi-arid central Tanzania. *Ph.D. thesis, The University of Reading.*

Odoi, F. N. A. and Owen, E. 1993. Encouraging store lambs to eat barley straw at housing: influence upon intake of pen to pen visibility and number of lambs per pen. *Animal Production* **56:** 455 (abstr.).

Olayiwole, M. B. and Olorunju, S. A. 1987. Feedlot performance of yearling steers previously maintained on different crop residues/supplementation regimes. In *Utilization of agricultural by-products as livestock feed in Africa* (ed. D. A. Little and A. N. Said), *proceedings of a workshop held at Blantyre, Malawi, September 1986,* pp. 72-82. ILCA (International Livestock Centre for Africa), Addis Ababa.

Osafo, E. L. K. 1993. Sorghum stover as a forage: cultivar effects on yield and effects of chopping, amount offered, supplementation and variety on intake, selection and live-weight gain in Ethiopian sheep and cattle. *Ph.D. thesis, The University of Reading.*

Osuji, P. O., Sibanda, S. and Nsahlai, I. V. 1993. Supplementation of maize stover for Ethiopian Menz sheep: effects of cottonseed, noug (*Guizotia abyssinica*) or sunflower cake with or without maize on the intake, growth, apparent digestibility, nitrogen balance and excretion of purine derivatives. *Animal Production* **57:** 429-436.

Owen, E. 1978. Processing of roughages. In *Recent advances in animal nutrition — 1978* (ed. W. Haresign and D. Lewis), pp. 127-148. Butterworths, London.

Owen, E. and Jayasuriya, M. C. N. 1989. Recent developments in chemical treatment of roughages and their relevance to animal production in developing countries. In *Feeding strategies for improving productivity of ruminant livestock in developing countries,* pp. 205-230. International Atomic Energy Agency, Vienna.

Reed, J. D., Tedla, A. and Kebede, Y. 1987. Phenolics, fibre and fibre digestibility in the crop residue from bird resistant and non-bird resistant sorghum varieties. *Journal of the Science of Food and Agriculture* **39:** 113-121.

Saadullah, M. and Siriwardene, J. A. de S. 1993. Reasons for success and failure of straw treatment and straw feeding in Bangladesh and Sri Lanka. In *Feeding of ruminants on fibrous crop residues. Aspects of treatment, feeding, nutrient evaluation, research and extension* (ed. K. Singh and J. B. Schiere), *proceedings of an international workshop held at the National Dairy Research Institute, Karnal (Haryana — India), February 4-8, 1991,* pp. 277-288. Indo-Dutch project on bioconversion of crop residues. Agricultural University, Wageningen.

Schiere, J. B. and Ibrahim, M. N. M. 1989. *Feeding of urea-ammonia treated rice straw. A compilation of miscellaneous reports produced by the straw utilization project (Sri Lanka).* Pudoc, Wageningen.

Singh, M., Kumar, M. N. A., Rai, S. N. and Pradan, P. K. 1993. Urea-ammonia treatment of straw under village conditions. Reasons for success and failure. In *Feeding of ruminants on fibrous crop residues. Aspects of treatment, feeding, nutrient evaluation, research and extension* (ed. K. Singh and J. B. Schiere), *proceedings of an international workshop held at the National Dairy Research Institute, Karnal (Haryana — India), February 4-8, 1991,* pp. 289-296. Indo-Dutch project on bioconversion of crop residues. Agricultural University, Wageningen.

Statistical Analysis Systems Institute. 1987. *Procedures guide for personal computers, version 6 edition.* SAS Institute Inc., Cary, NC.

Tanner, J. C., Holden, S. J., Winugroho, M., Owen, E. and Gill, M. 1995. Feeding livestock for compost production; a strategy for sustainable upland agriculture on Java. In *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Volume II: technical papers* (ed. J. M. Powell, S. Fernandez-Rivera, T. O. Williams and C. Renard), *proceedings of an international conference held in Addis Ababa, Ethiopia, 22-26 November 1993,* pp. 115-128. ILCA (International Livestock Centre for Africa), Addis Ababa.

Wahed, R. A. 1987. Stall-feeding barley straw to goats: the effect of refusal-rate allowance on voluntary intake and selection. *Ph.D. thesis, The University of Reading.*

Wahed, R. A., Owen, E., Naate, M. and Hosking, B. J. 1990. Feeding straw to small ruminants: effect of amount offered on intake and selection of barley straw by goats and sheep. *Animal Production* **51:** 283-289.

Walker, H. G. 1984. Physical treatment. In *Straw and other fibrous by-products as feed* (ed. F. Sundstøl and E. Owen), pp. 79-105. Elsevier, Amsterdam.

(*Received* 1 *August* 1996—*Accepted* 4 *February* 1997)