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Cowpea (*Vigna unguiculata* L. Walp) and groundnut (*Arachys hypogea* L.) haulms as supplements to sorghum (*Sorghum bicolor* L. Moench) stover: intake, digestibility and optimum feeding levels

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Abstract

Two feeding trials were conducted to study the combined effects of (i) varying degrees of selective consumption and (ii) supplementation with cowpea (Trail 1) or groundnut haulms (Trial 2), on intake of organic matter (IOM) from sorghum stover, and total intake of digestible organic matter (IDOM). In both trials, 36 rams were allocated to 36 different treatments: six levels of feeding sorghum stover (25, 40, 60, 90, 120 and 160 g organic matter (OM) $kg^{-0.75}$ per day) combined with six levels of supplementation (0, 5, 12.5, 20, 40, and 60 g OM $kg^{-0.75}$ per day). Each diet was offered for a 21 day period; intake and digestibility were recorded during the last 9 days. Non-linear regression models were used to describe the combined effects of varying amounts of stover (x) and supplements (s) offered. All animals ate the full amount of supplement offered, but not the sorghum stover. For animals without supplement, maximum intake (m) of stover (i.e. IOM at high levels of x) was estimated at 50.7 g $kg^{-0.75}$ per day in Trial 1 and 45.7 g $kg^{-0.75}$ per day in Trial 2. In both trials, m decreased linearly with s at the rate 0.4 g g^{-1}. Also, the shape of the curve relating intake of stover to x was affected by level of supplementation. Digestibility of whole stover (0.47 in Trial 1; 0.40 in Trial 2) was much lower than that of cowpea haulms (0.70) and groundnut

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haulms (0.62), but in both trials animals selected material of higher digestibility when excess stover was offered. Thus, the negative effect of supplementation on intake of stover was partly compensated by higher digestibility of consumed stover. For rations without cowpea in Trial 1, the maintenance level of IDOM was reached by offering 61 g sorghum OM (kg$^{-0.75}$ per day) of which 47 g was consumed. With the same amount of offered sorghum 9, 18, 28, 38 and 48 g cowpea OM were needed to attain intake levels equivalent to 1.2, 1.4, 1.6, 1.8 and 2.0 times maintenance, respectively. In the trial with groundnut, maintenance was not reached with sorghum alone and larger amounts of supplement were required for the levels of intake mentioned above. Iso-production curves describing which amounts of stover and supplement gave the same IDOM, were not linear with constant slope corresponding to the comparative digestibility of whole stover and supplements, but strongly curved. Such curves can be used to derive optimum combinations of stover and higher quality feeds, depending on feed prices, desired production level and taking into account the effects of selective consumption. With prices of cowpea and groundnut haulms 4 times higher than that of stover, the results of Trial 1 indicate that least cost rations for feeding at 1.2 M (maintenance) would consist of 72 g sorghum OM (kg$^{-0.75}$ per day) combined with 7 g cowpea haulms. For feeding at 1.6 M this would be 70 + 26 g, and at 2 M, 54 + 50 g. Similarly, with the feeds used in Trial 2, optimum combinations of sorghum stover and groundnut haulms for the same levels of feeding would be 58 + 24, 51 + 47, and 11 + 78 g OM kg$^{-0.75}$ per day.

Keywords: Sorghum stover; Cowpea haulm; Groundnut haulm; Selective consumption; Supplementation; Iso-production curves; Optimum ration

1. Introduction

In sub-Saharan Africa, livestock account for about 25–35% of the agricultural domestic product (Winrock International, 1992). In the past, livestock was mainly kept in pastoral and agro-pastoral systems. As expansion of crop areas due to population growth has reduced grazing lands, pastoralists have started to grow crops. As a result, the two specialised activities (pastoralism and arable cropping) are both developing towards mixed crop–livestock systems (Winrock International, 1992; De Grandi, 1996). This leads to increased competition for forage. To alleviate feed shortage in the dry season, farmers collect crop residues and store them for later use in stall feeding (Songué, 1997). Sorghum and millet are the major cereal crops in Burkina Faso. Their stover can only cover the energy maintenance requirements of sheep and cattle, if large amounts are offered, allowing selective consumption (Kaasschieter et al., 1998). For production, higher quality supplements are needed.

Suitable supplements are residues of legume crops, and industrial by-products. Use of cultivated forages by smallholders is limited, due to shortage of land and high costs of inputs (Williams et al., 1997). Use of agro-industrial by-products is also low, as they are often exported or not accessible to farmers due to poor infrastructure and marketing, and high prices (Compaoré, 1991). Cowpea (*Vigna unguiculata* L. Walp) and groundnut (*Arachis hypogaea* L.) are important crops in sub-Saharan Africa (Ehlers and Hall, 1997; Mortimore et al., 1997; Stalker, 1997). They are grown either as monoculture or intercropped with cereals. The use of their residues as a supplement to cereal straws in animal production has been described by several authors (Stares et al., 1992; N'Jai, 1998; Kaasschieter et al., 1998). Kaasschieter et al. (1998) combined various levels of supplementation with cowpea haulms and cotton seed cake with varying degrees of selection in basal feed (millet stover and rice straw) fed to cattle. The present study aimed at determining the effects of different levels of supplementation with cowpea and groundnut haulms on voluntary intake and digestibility of sorghum (*Sorghum bicolor* L. Moench) stover under varying degrees of selective consumption by sheep. The experiments served as a basis for determination of optimum combinations of stover and supplements.

2. Materials and methods

2.1. Forages

Cowpea haulms, groundnut haulms and sorghum stover were used. The cowpea and groundnut haulms included all parts of the plant remaining after the pods had been removed (roots, stems and leaves). All forages originated from farmers' fields in the North Soudanian zone of Burkina Faso, characterised by a single rainy season with 600–800 mm rainfall in the period May–October. After threshing, the crop residues were collected and sun-dried. Sorghum stover was cut in pieces of about 60 cm to match the length of the feeding through.

2.2. Experimental design

Forty adult Djallonké rams, weighing 20–25 kg were purchased in a local market. During the first 4 weeks (preparation period), animals grazed natural pasture 5 h per day and received each 500 g cotton seed cake per day. Animals were vaccinated against Pasteurellosis and PPR, and treated for intestinal parasites in this period. Separate trials of similar design were conducted using cowpea (Trial 1) or groundnut (Trial 2) haulms as supplements. Because only 12 individual feeding places were available, both experiments consisted of three periods of 21 days each, comprising 12 days of adaptation and 9 days of measurement. For the first period 12 animals were randomly selected from the 40 available, for the second period 12 animals from the remaining 28, and for the third period 12 from the then remaining 16. The animals had free access to water and a mineral block, and were equipped with faeces collection bags. In both trials, six levels of feeding sorghum stover (25, 40, 60, 90, 120, and 160 g OM $kg^{-0.75}$ per day) were combined with six levels of supplementation (0, 5, 12.5, 20, 40, and 60 g OM $kg^{-0.75}$ per day). The 36 treatments were divided among periods as shown in Table 1.

2.3. Data collection and analysis

Intake of feed was estimated from the amounts offered on days 1–7 and refusals weighed on days 2–8. Also, the amount of faeces produced during this 7-day period was recorded. The forage was stored in bundles of about 4 kg. Each second day, one bundle of

Table 1
Experimental design

Amount of supplement offered (g OM $kg^{-0.75}$ per day)	Amount of sorghum stover offered (g OM $kg^{-0.75}$ per day)					
	25	40	60	90	120	160
0	1[a]	2	3	1	2	3
5	2	3	1	2	3	1
12.5	3	1	2	3	1	2
20	1	2	3	1	2	3
40	2	3	1	2	3	1
60	3	1	2	3	1	2

[a] Period.

each forage was sampled to determine its morphological composition: proportion (dry weight basis) of stems, leaf sheaths, leaf blades and leaf nerves for sorghum; roots, stems, and leaves for cowpea and groundnut. Also every second day, the morphological composition of the combined refusals of that day and the preceding day was determined. From these data, amounts of different components ingested were estimated. Samples of faeces, and morphological components of offered feed and refusals, were analysed for dry matter (DM) by drying to constant weight at 105°C in a forced air drying oven. Ash and crude protein (CP) were estimated by AOAC (1984) procedures. In vitro digestibility of morphological components of offered feed was estimated according to Tilley and Terry (1963). In vivo digestibility of consumed feeds was estimated by regression analysis as described below.

Supplements offered were fully ingested. The NLREG program of Sherrod (1994) was used to study the relation of intake of organic matter from sorghum stover (IOM) and total intake of digestible organic matter (IDOM) with the amounts of stover (x) and supplements (s) offered. The model of Zemmelink (1980) was used for intake of non-supplemented stover:

$$y = m\left(1 - \exp\left\{-\left(\frac{px}{m}\right)^h\right\}\right)^{1/h} \tag{1}$$

in which y is the intake of stover, m the upper limit (asymptote) for y, p the edible fraction of the stover, and h a shape parameter, such that $y = m(1-\exp(-1))^{1/h}$ at the critical level of feeding ($x = m/p$); y and x are both expressed in g OM $kg^{-0.75}$ per day. To account for the effect of supplementation on intake of stover, m and h were replaced by a function of s (also in g OM $kg^{-0.75}$ per day). Preliminary analysis of the data indicated that maximum intake of stover decreased linearly with s. Therefore, parameter m in Eq. (1) was rewritten according to the equation:

$$m = a_m - b_m s \tag{2}$$

where a_m and b_m are regression constants. For h, an exponential function was used:

$$h = b_h \exp(-c_h s) \tag{3}$$

where b_h and c_h are regression constants. Least-squares estimates of total IDOM as a function of the amounts of stover and supplement offered, were derived by expanding from the basic equation:

$$\mathrm{IDOM} = sd_{\mathrm{su}} + yd_{\mathrm{st}} \tag{4a}$$

in which d_{su} and d_{st} are digestibility (g g^{-1}) of the supplement (s) and of the consumed stover (y), respectively. To allow for the possibility that digestibility of stover varies due to varying degrees of selective consumption, d_{st} was expressed as a function of the fraction of stover refused:

$$d_{\mathrm{st}} = a_d + b_d \frac{x - y}{x} \tag{4b}$$

where a_d represents digestibility of whole stover (no selection) and b_d the increase of digestibility due to selective consumption at higher levels of refusal. Model (4a,b) was fitted in two ways: (A) using actual intake of stover by individual animals and (B) using IOM values predicted from x by Eq. (1). With the latter method, IDOM is effectively estimated from amounts of supplement (s) and stover offered (x).

2.4. Determination of optimum combinations of feeds

The relationship of IDOM with x and s was used to derive iso-production curves, showing which combinations of x and s give the same IDOM. The least cost criterion was used to determine the optimum combinations of supplements and basal feed for selected production targets.

3. Results

3.1. Morphological and chemical composition of forages

Sorghum stover used in Trial 1 contained 64.3% stems, 20.3% leaf sheaths, 10.8% leaf blades, and 4.6% leaf nerves (Table 2). CP content of these morphological fractions varied from 1.8% for stems to 5.4% for leaf blades, with intermediate values for leaf sheaths (2.9%) and leaf nerves (3.0%), and 3.3% for the whole stover. Similarly, in vitro organic matter digestibility (IVOMD) varied from 40.0% (leaf nerves) to 58.4% (leaf blades). The quality of stover used in Trial 2 was slightly lower (higher proportion of stem, lower CP and IVOMD). Cowpea haulm was composed of 18.4% roots, 45.3% stems and 36.3% leaves (Table 3). CP content of roots (7.7%) and stems (7.8%) was much lower than that of leaves (14.6%). Whole haulm contained 91.1% OM and 10.0% CP, and IVOMD was 67.5%. Digestibility varied from 63.9% (stems) to 72.0% (leaves). Groundnut haulms contained more leaves (48.1%) than cowpea. However, CP content and digestibility of leaves and stems were lower. The whole groundnut haulm contained 8.2% CP with 61.2% IVOMD.

Table 2
Morphological and chemical composition of sorghum stover

	Stem		Leaf sheath		Leaf blade		Leaf nerve		Whole straw	
	Mean	S.E.[a]	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Trial 1										
Proportion (percentage of total DM[b])	64.3	4.27	20.3	0.92	10.8	1.25	4.6	0.49	100	–
Chemical composition										
DM (%)	92.3	1.11	93.2	0.84	93.4	0.87	93.5	0.48	93.1	0.39
OM (%DM)	92.4	0.48	91.1	0.27	90.9	0.37	93.9	0.19	92.3	0.48
CP (%DM)	1.8	0.32	2.9	0.22	5.4	0.32	3.0	0.08	3.3	0.42
IVOMD (%)[c]	51.3	5.79	42.1	3.41	58.4	4.06	40.0	2.96	49.7	3.25
Trial 2										
Proportion (percentage of total DM)	71.2	0.51	17.8	0.06	7.6	0.01	3.4	0.44	100	–
Chemical composition										
DM (%)	93.2	0.24	92.4	0.14	94.3	1.02	93.4	0.67	93.3	0.33
OM (%DM)	93.3	0.81	91.7	0.76	86.4	0.38	93.4	0.16	91.2	0.89
CP (%DM)	1.7	0.12	1.7	0.18	5.6	0.36	2.7	0.29	2.7	1.15
IVOMD (%)	43.6	3.53	38.5	3.08	54.5	2.09	32.2	3.73	43.1	2.95

[a] Standard error.
[b] Dry matter.
[c] In vitro organic matter digestibility.

Table 3
Morphological and chemical composition of cowpea and groundnut haulm

	Root		Stem		Leaf		Whole haulm	
	Mean	S.E.[a]	Mean	S.E.	Mean	S.E.	Mean	S.E.
Cowpea haulm								
Proportion (percentage of total DM[b])	18.4	1.67	45.3	3.74	36.3	4.73	100	–
Chemical composition								
DM (%)	91.5	1.97	93.4	1.33	93.2	0.75	92.7	0.78
OM (%DM)	92.7	0.36	91.9	1.18	88.5	0.29	91.1	0.75
CP (%DM)	7.7	1.03	7.8	1.07	14.6	1.31	10.0	1.28
IVOMD (%)[c]	67.3	1.80	63.9	1.15	72.0	1.81	67.5	1.78
Groundnut haulm								
Proportion (percentage of total DM)	21.7	1.11	30.2	0.65	48.1	1.18	100	–
Chemical composition								
DM (%)	93.1	0.50	92.5	0.14	93.4	0.09	93.0	0.20
OM (%DM)	91.9	0.24	92.6	0.22	87.2	0.32	90.5	0.86
CP (%DM)	8.1	0.35	5.9	0.60	10.7	0.36	8.2	0.74
IVOMD (%)	60.5	1.83	58.4	1.84	64.4	2.67	61.2	1.91

[a] Standard error.
[b] Dry matter.
[c] In vitro organic matter digestibility.

3.2. Intake

Supplements offered were completely ingested. The same was true for leave blades of sorghum. Animals on the higher levels of feeding sorghum ate slightly less than 100% of the leaf sheaths and leaf nerves, but only a small proportion of the offered stems (Fig. 1). In Trial 1, maximum intake of stover (m) without cowpea was estimated at 50.7 g OM $kg^{-0.75}$ per day (Table 4). It decreased linearly with level of supplementation, at the rate of 0.424 g g^{-1} of cowpea haulm offered ($P < 0.01$). Within the range of supplement given, maximum total IOM was 85 g $kg^{-0.75}$ per day, consisting of 60 g OM $kg^{-0.75}$ per day cowpea haulm and 25 g OM $kg^{-0.75}$ per day stover. In Trial 2, maximum intake of stover without groundnut was estimated at 45.7 g OM $kg^{-0.75}$ per day; also in this case m decreased linearly with s, at the rate of 0.413 g g^{-1} groundnut haulm offered. The shape parameter (h) of the intake curves without supplementation was estimated at 2.735 and 4.365 in Trials 1 and 2, respectively. With supplementation, the

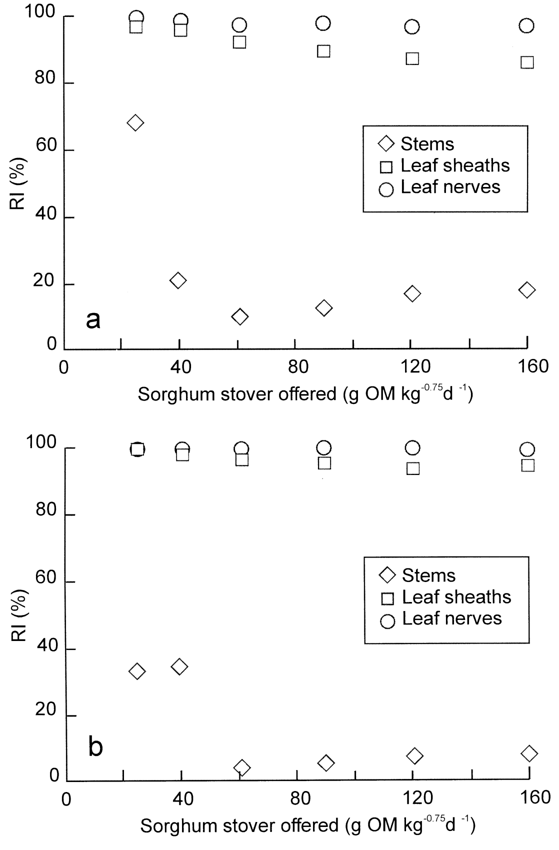

Fig. 1. Effect of amount of sorghum stover offered on the relative intake (RI) of different morphological components (RI: intake of component as proportion of the amount of that component offered): (a) Trial 1; (b) Trial 2.

Table 4
Least-squares estimates of parameters in models describing IOM from sorghum stover (y) and total IDOM for sorghum/cowpea rations (Trial 1) and sorghum/groundnut rations (Trial 2); (±S.E.)

Parameters	Trial 1		Trial 2	
	Predicted[a]	Actual[b]	Predicted[a]	Actual[b]
y (g kg$^{-0.75}$ per day)[c]				
a_m	50.7±1.66		45.7±1.85	
b_m	0.424±0.076		0.413±0.082	
b_h	2.735±0.665		4.365±2.226	
c_h	0.0235±0.0065		0.0319±0.0116	
RSD	4.08		5.21	
R^2	0.897		0.817	
P	<0.01		<0.01	
IDOM (g kg$^{-0.75}$ per day)[d]				
d_{su}	0.699±0.021	0.698±0.014	0.621±0.023	0.621±0.010
a_d	0.465±0.036	0.475±0.020	0.398±0.038	0.422±0.013
b_d	0.198±0.070	0.184±0.039	0.167±0.071	0.127±0.025
RSD	3.21	2.10	3.42	1.41
R^2	0.937	0.974	0.884	0.983
P	<0.01	<0.01	<0.01	<0.01

[a] Estimates when predicted IOM and related predicted refusal were used in the IDOM models.
[b] Estimates when actual IOM and actual refusal were used in the IDOM models.
[c] $y = m(1 - \exp\{-(px/m)^h\})^{1/h}$ (Model 1 in text), in which p is the edible fraction of stover (for stovers used in present study = 1), $m = a_m - b_m s$ (Model 2), $h = b_h \exp(-c_h s)$ (Model 3).
[d] $\text{IDOM} = sd_{su} + y(a_d + b_d(x - y)/x)$ (Model 4a,b).

value of h decreased. This implies that for higher s, not only maximum intake of stover (m) decreased, but also intake expressed as a fraction of m (y/m) at $x = m$. This can be interpreted as animals becoming more selective when they receive supplement.

3.3. Digestibility

Estimated digestibility of cowpea and whole stover in Trial 1 (when using predicted IOM values) were similar to those obtained by in vitro analysis: 0.699 and 0.465, respectively, compared to 0.675 and 0.497 (Table 4). Refusals of stover increased with level of feeding stover, as well as level of supplementation, and varied from 0 to 58% of the amount offered. This had a significant ($P < 0.01$) effect on digestibility of ingested stover, which increased by 0.198%-unit per %-unit increase in the proportion of stover refused. In Trial 2, digestibility of groundnut haulms and stover were estimated at 0.621 and 0.398, respectively. Also here, stover digestibility increased with level of refusal (0.167%-unit per %-unit). For both trials, using actual intakes and refusals of stover instead of predicted values, gave similar results.

3.4. Iso-production curves and optimum rations

The iso-production curves from Trial 1 (Fig. 2a) indicate that maintenance (assumed requirements 24 g digestible organic matter kg$^{-0.75}$ per day) could be reached with

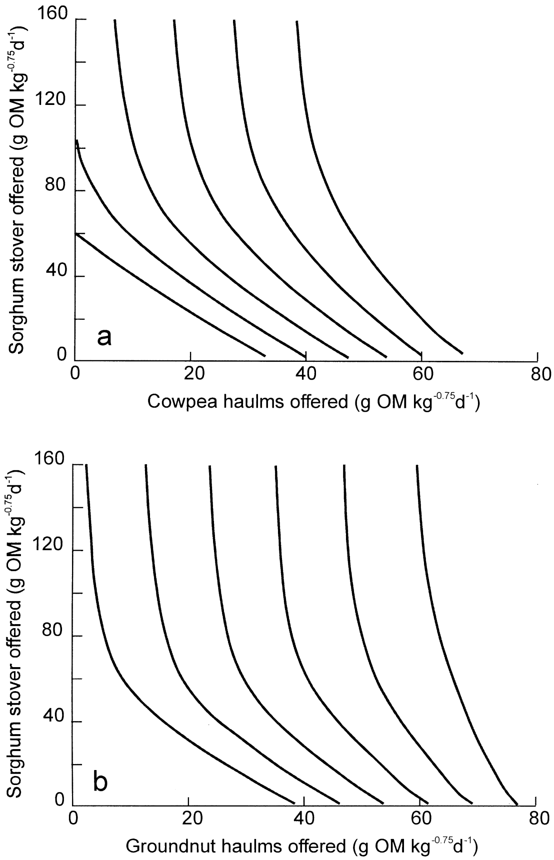

Fig. 2. Iso-production curves for sorghum stover/cowpea rations (a) and sorghum stover/groundnut rations (b). From left to right: IDOM corresponding to 1, 1.2, 1.4, 1.6, 1.8 and 2 times maintenance, respectively.

61 g OM $kg^{-0.75}$ per day sorghum offered, without cowpea. With this amount of offered sorghum 9, 18, 28, 38 and 48 g cowpea were needed to reach 1.2, 1.4, 1.6, 1.8 and 2.0 times maintenance, respectively. To reach maintenance with stover alone, this had to be offered in excess, so that animals could select 47 out of the 61 g stover OM $kg^{-0.75}$ per day offered. To reach IDOM equal to 1.2–2.0 times maintenance with the amounts of supplement above indicated, even stronger selection of stover was required: up to 58% refusal to reach 2 times maintenance with 48 g OM $kg^{-0.75}$ per day cowpea. To avoid such large refusals of stover, the amount of cowpea in the diet had to be increased. Due to the lower digestibility of feeds used in Trial 2, more supplement (groundnut haulm), and/or higher refusal rates of stover were required to reach the same IDOM levels (Fig. 2b).

In Burkina Faso, prices of cowpea and groundnut haulms are about 4 times higher (0.4 FF kg^{-1}) than of sorghum stover (0.1 FF). The results of Trial 1 indicate that, if the least cost criterion is used and animals are fed at 1.2 times maintenance, 72 g sorghum OM (per kilogram metabolic weight per day) should be combined with 7 g cowpea haulms. For feeding at 1.6 times maintenance this would be $70+26$ g, and for 2 times maintenance $54+50$ g. Similarly, optimum combinations (g OM $kg^{-0.75}$ per day) of sorghum stover and groundnut haulms for the same levels of IDOM would be $58+24$, $51+47$, and $11+78$.

4. Discussion

The forages used in this study had lower CP and digestibility than those used by Savadogo et al. (2000). Such variation in quality of crop residues may be due to many factors, i.e. genetic characteristics (Badve et al., 1994; Singh and Schiere, 1995; Subba Rao et al., 1994), environmental factors (soil characteristics, rainfall) and crop management (level of fertilisation, plant density, stage of maturity at harvest, methods of harvesting, and storage) (Harika and Sharma, 1994; Walli et al., 1994). Camara (1996) and Kaasschieter et al. (1998) reported CP values ranging from 7.8 to 21.7% for cowpea and from 5.6 to 29.2% for groundnut. FAO (1981) reported 3.7–4.3, 14.4, and 9.9% CP for sorghum stover, cowpea and groundnut haulms, respectively. Manyuchi et al. (1997) reported intermediate values for groundnut haulms (13.1% CP, 65% digestibility). Under practical farming conditions the nutritive value is often low, because cowpea and groundnut are grown primarily for grains. Thus, in practice, residues have often a lower proportion of leaves and lower CP content than those from research stations. The material in the present study was similar to that often found in practice.

In this study, supplementation with cowpea or groundnut haulm did not lead to increased intake of sorghum stover. At the lowest levels of supplementation, stover was substituted by supplement in both trials. The substitution rate was close to 0.4 units of stover per unit supplement. This is consistent with results of Umunna et al. (1995) who used *Lablab purpureum* as supplement to oats hay and observed a substitution rate of 0.37. In an experiment where chopped sorghum stover was the basal feed, Bosma and Bicaba (1997) measured a substitution rate of 0.20 g g^{-1} for sheep and 0.12 g g^{-1} for goats when the proportion of *Leucaena leucocephala* leaves in the diet was increased from 10 to 30%. Chriyaa et al. (1997) observed substitution rates of 0.26–0.65 when supplementing wheat straw with shrub foliage containing 10.8–13.7% CP. However, when the protein content of the supplement was high (>20%), it tended to stimulate basal roughage intake (Masama et al., 1997; N'Jai, 1998).

Although supplementation suppressed intake of sorghum stover in our trials, total IOM increased. Also, ration digestibility increased, because sorghum was replaced by higher quality supplements. In addition, higher levels of supplementation led to increased digestibility of ingested stover due to increased selection for leaves. The overall effect was doubling of total IDOM at the highest level of supplementation, compared to feeding stover only. Allowing selective consumption of sorghum stover requires that it is offered in excess of what animals eat. Such a feeding system requires additional labour for transportation and more storage space (Onwuka et al., 1997). However, when sorghum stover is fed alone, animals can only maintain their weight when they are allowed to select. Moreover, allowing selective consumption reduces the amounts supplements needed to reach levels of intake that support production. For example, in Trial 2, IDOM equivalent to 1.4 times maintenance required 54 g OM $kg^{-0.75}$ per day from groundnut haulms, when animals ingested 90% of the sorghum stover, but only 29 g $kg^{-0.75}$ per day when they were allowed to select much sharper and reject 50% of the stover. Other suggested possibilities to increase intake of low quality crop residues are physical treatment (chopping, grinding, pelleting), chemical treatment (with sodium hydroxide, urea/ammonia, sodium carbonate), and biological treatment (Singh and Schiere, 1995; Williams et al., 1997). However, in sub-Saharan Africa, these techniques are not economically viable, because of the high costs and low availability of urea and other suitable chemical products, and the variable and often disappointing effects on animal production (Williams et al., 1997). Therefore, animal production should be optimised by optimum utilisation of available products, in combination with exploiting the selective eating behaviour of animals. The refusals can be used for bedding (animal comfort and absorption of urine) and/or for soil conservation (Pieri, 1986; Bationo and Mokwunye, 1991). In this way, efficient utilisation of crop residues for animal production does not compete with maintaining soil fertility. As in this system animals eat mainly leaves, harvesting and storage techniques are required that prevent losses of leaves. Grain legumes tend to shed their leaves early, even before grain maturity. Introduction of dual-purpose legumes may reduce these losses (Ehlers and Hall, 1997; Stalker, 1997), which improves their value as ruminant feed.

The models describing the combined effects of supplementation and selective consumption include many parameters; this reflects the complexity of animal intake behaviour in response to feed heterogeneity. For instance, if at a given supplementation level, intake of stover is low because small amounts were offered (low refusal rate), digestibility is also low. If at a given level of feeding, stover intake is low because more supplement has been given (high refusals of stover), digestibility of ingested stover is higher.

The basic exponential model for the relationship between feed intake and amount offered for single feeds (Eq. (1)) can easily be expanded to include the effect of supplementation on intake of straw. In the present study, maximum intake of straw (m), i.e. intake at high levels of excess feed, decreased linearly with the amount of supplement given (s), while the shape parameter of the model (h) was best described by an exponential function of s. However, other models to describe the relationship of m and h with s can also be fitted easily.

The iso-production curves that were derived from these models give all possible combinations of amounts of sorghum stover and cowpea or groundnut haulms on offer for selected values of IDOM. The curves can be used to select optimum combinations depending on criteria such as objectives of feeding, desired production level, availability of different forages and their prices.

5. Conclusion

The results of this study indicate that excess feeding of heterogeneous basal feeds, allowing selective consumption of these materials, combined with supplementation, can be an appropriate strategy for maximising benefits from feeding crop residues.

Experiments in which diverse amounts of both basal feed (e.g. sorghum straw) and supplements (e.g. cowpea or groundnut haulms) are offered can be used to derive iso-production curves. Combined with information about prices of basal feeds and supplements, these curves can be used to derive optimum rations for defined levels of production.

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