A note on the chemical composition, intake and digestion of *Striga hermonthica* herbage by sheep

D E HESS & S FERNÁNDEZ-RIVERA*

*International Crop Research Institute for the Semi-Arid Tropics, BP 320, Bamako, Mali, and *International Livestock Research Institute, BP 12404, Niamey, Niger*

Received 29 March 1999
Revised version accepted 26 January 2000

Summary

Striga hermonthica causes serious crop yield losses in West Africa. Hand pulling, an effective method for the reduction of light infestations, might be encouraged if farmers could use this weed as livestock feed. This study evaluated the chemical composition and the voluntary intake and digestion of *S. hermonthica* herbage by sheep. Crude protein (g kg^{-1} dry matter (d.m.)) was 184 in the whole plant, 230 in the leaf and 87 in the stem. Ash content varied from 183 to 253 g kg $d.m.^{-1}$. The concentration of neutral and acid detergent fibre and lignin in whole pot-grown plants was 364, 278 and 127 g kg $d.m.^{-1}$ respectively. The digestibility of dry and organic (o.m.) matter was 493 and 657 g kg^{-1}, respectively, and intake of digestible o.m. was 27.1 g kg $W^{-0.75}$. The relatively high N and P levels in *S. hermonthica* warrant further evaluation in terms of its potential use as a source of protein or for compost. Its use as a feed appears to be limited by the high ash content and possibly by anti-nutritional effects on animals. These effects should be further investigated before recommending its use for this purpose.

Keywords: *Striga hermonthica*, forage quality, digestibility, intake, sheep.

Introduction

The parasitic weed *Striga hermonthica* (Del.) Benth. causes important economic losses in West African agriculture by decreasing pearl millet (*Pennisetum glaucum* (L.) R. Br.) and sorghum (*Sorghum bicolor* (L.) Moench) yields. At early stages of infestation before parasites have become numerous, weeding is an effective option to achieve control or eradication (Saunders, 1933). Infestations can be reduced and their negative effects on grain production limited by manual weeding (Ramaiah, 1985; Ransom & Odhiambo, 1994; Hess *et al.*, 1996; Hess & Dembélé, 1999). Interaction with farmers in Ghana, Tanzania and Malawi revealed that low cost is an important consideration for farmers when adopting control methodologies for *Striga* spp. (Kroschel & Sauerborn, 1996). A majority (54%, 71% and >90% of farmers in Tanzania, Malawi and Ghana respectively) considered hand pulling to be feasible in their farming systems. It is possible

Correspondence: D E Hess, ICRISAT, BP 320, Bamako, Mali. Tel: (+223) 223375; Fax: (+223) 228683; E-mail: d.e.hess@icrisatml.org

that this practice would be encouraged if the weed herbage could be promoted as a livestock feed. However, information on the feeding value of *Striga* spp. is very limited. Bebawi & El Hag (1983) reported that the herbage contained 12.6% crude protein and had a dry-matter digestibility *in vivo* of 47%. More information on the variation in concentration of nutrients, the presence of anti-nutritional factors and the consumption and digestion of herbage of *Striga* spp. by ruminants is needed for an adequate evaluation of its potential use as a feed.

The objectives of this study were to evaluate the chemical composition of *S. hermonthica* at two stages of maturity and to determine the voluntary intake and digestion of fresh herbage by sheep. Research was conducted at the ICRISAT Sahelian Centre, near Niamey, Niger.

Materials and methods

Experiment 1: chemical composition of Striga hermonthica *herbage*

Ten whole-plant *Striga hermonthica* samples were harvested from pearl millet plants growing in pots in a glasshouse. One group of pots was watered according to need (unstressed), whereas the second group was watered only after the weeds showed signs of wilting (stressed). Plants were classified according to maturity: preflowering and flowering. Five samples were collected at each stage. All samples were dried at 55 °C to determine d.m. content and then ground to pass through a 1 mm screen and analysed for o.m. content, crude protein (CP = N × 6.25), ash-free neutral (NDF) and acid (ADF) detergent fibre, and lignin (LIG). Analyses for NDF, ADF and LIG were done sequentially following the procedures described by Van Soest *et al.* (1991). Analyses for N and P were performed by acid-digesting the samples (Nelson & Sommers, 1980) and the use of an autoanalyser (Anon., 1977). For all variables, means for the two maturity stages were compared using a *t*-test.

Four additional whole-plant samples of flowering *S. hermonthica* were taken during a digestion and intake study (expt 2). This material had been harvested from infested pearl millet in a farmer's field at Sadoré, Niger. Sub-samples were taken and separated into leaf, stem and inflorescence. Samples of the three plant parts as well as of entire plants were dried at 55 °C to determine d.m. and ground to pass through a 1 mm sieve. These samples were analysed for o.m., CP and phosphorus (P). Neutral detergent insoluble ash (NDIA) and acid detergent insoluble ash (ADIA) were determined by incinerating the NDF and direct-ADF (i.e. with no neutral detergent pretreatment) residues at 525 °C, according to Van Soest *et al.* (1991). ADIA was also treated with HBr (concentration 48%) to test for the presence of silica (Van Soest, 1982).

Fibre fractions (NDF, ADF and LIG) were determined using the double sequential procedure (i.e. using the sequences NDF-ADF-LIG-ash and ADF-NDF-LIG-ash) described by Van Soest *et al.* (1991). Neutral detergent fibre is considered to represent the cell wall and is inversely related to feed intake, whereas acid detergent fibre, determined sequentially after NDF, includes mostly ligno-cellulose and is inversely related to forage digestibility (Van Soest, 1982). Lignin remains essentially undigested. Because of the large differences in LIG values obtained with the two sequences, two colorimetric tests for the presence of tannins were performed on the four feed samples collected during the feeding experiment. These tests were the vanillin-HCl reaction (Broadhurst & Jones, 1978), which is specific for proanthocyanidins (Reed, 1995) and the Folin-Ciocalteu reaction (Julkunen-Tiitto, 1985), which is specific for total free phenolic hydroxyl groups (Reed, 1995). For all variables, the means and mean standard errors were estimated.

Experiment 2: consumption and digestion of Striga hermonthica *by sheep*

Six sheep weighing 48.6 ± 3.1 kg were fed fresh *S. hermonthica* herbage as their sole source of organic nutrients for 23 days, the last eight days being used for data collection. The weed herbage was collected daily between 7:00 and 9:00 h and fed twice daily at 10:00 and 16:00 h. At the time the fresh feed was being weighed to feed the animals, feed samples were taken and frozen immediately. During the experiment the animals were fed *ad libitum*. The actual level of daily feed excess was 191 ± 30 g d.m. per animal. The sheep had free access to water and a locally made mineral block consisting mostly of common salt.

Daily excretion of urine was collected in 25 mL 0.1 N sulphuric acid to prevent volatilization of ammonia. Samples of feed, faeces, refusals and urine were taken daily and frozen until completion of the trial. Feed, refusals and faeces were processed as in expt 1. The samples of feed offered were analysed as indicated above and feed refusals and faeces were analysed for d.m., o.m., N and NDF. Urine was analysed for N. Digestibility of dry (d.m.d.) and organic (o.m.d.) matter, intake of d.m., o.m., and digestible o.m. and nitrogen balance were determined. For each variable the mean and standard deviation were estimated.

Results and discussion

The chemical composition of three common feeds in the Sahel (cowpea (*Vigna unguiculata* (L.) Walp.)) hay, groundnut (*Arachis hypogaea* L.) haulms and millet stover), as well as their digestibility and voluntary intake by sheep, is presented in Table 1. This information (unpublished data), obtained during two different studies at the ICRISAT Sahelian Centre, is presented to provide a reference for comparing the feed potential of *Striga* spp.

Experiment 1: chemical composition of Striga hermonthica *herbage*

The herbage collected in the farmers' fields was made up of 24.2 ± 3.7% leaf, 43.6 ± 3.0% stem and 32.1 ± 2.6% inflorescence. In the glasshouse samples, no differences were observed in chemical composition according to maturity stage (Table 2). *Striga hermonthica* grown either under glasshouse or field conditions (Tables 2 and 3) had a concentration of ash much higher than that observed in feeds commonly available in the Sahel (Table 1). It is unlikely that this high mineral content was due to soil contamination. The solubility of ash in neutral detergent was

Table 1 Chemical composition (g kg d.m.$^{-1}$), digestibility (g kg^{-1}) and voluntary intake (g kg W$^{-0.75}$) by sheep of crop residues and legume hays commonly available in the Sahel; unpublished data from two different studies at the ICRISAT Sahelian Centre

Feed	o.m.	CP	NDF	ADF	LIG	P	o.m.d.	d.m.i.	d.o.m.i.
Cowpea hay	902.3	176.0	425.5	252.9	54.8	1.6	675.0	95.3	59.3
Cowpea hay	926.9	157.4	450.1	269.6	54.7	1.8	673.2	95.0	60.7
Groundnut hay	862.2	107.8	423.6	336.6	79.6	2.8	637.1	77.2	45.2
Groundnut hay	878.9	107.2	469.3	377.7	80.0	2.4	558.3	71.6	35.3
Millet stover	928.1	46.5	734.3	405.1	51.7	0.6	493.3	52.1	22.8
Millet stover	916.2	47.7	715.0	430.5	50.4	0.7	445.7	54.2	22.2

o.m. = organic matter; CP = crude protein; NDF = ash-free neutral detergent fibre; ADF = ash-free acid detergent fibre; LIG = lignin; P = phosphorus; o.m.d. = organic-matter digestibility; d.m.i. = dry-matter intake; d.o.m.i. = digestible organic-matter intake.

Table 2 Chemical composition of *S. hermonthica* herbage grown in the glasshouse and harvested at two maturity stages (g kg d.m.$^{-1}$)

Item	Pre-flowering	Flowering	SE
Organic matter	756	747	17.6
Crude protein	251	222	26.1
Neutral detergent fibre*	363	365	21.2
Acid detergent fibre*	271	285	22.0
Lignin*	123	131	14.3

*Ash-free.

Table 3 Ash, protein and phosphorus concentration in *S. hermonthica* herbage harvested from farmers' fields at flowering (g kg d.m.$^{-1}$)

Item	Whole plant	Leaf	Stem	Inflorescence	SE
Total ash	182.8	253.4	117.5	196.6	19.24
NDIA	117.5	93.8	27.1	87.5	19.03
ADIA	130.4	156.1	28.4	92.8	28.02
AD-HBrIA	132.5	157.1	30.3	94.7	29.94
Phosphorus	6.3	6.2	5.2	7.8	0.26
Crude protein	183.6	230.4	86.9	210.6	18.89

NDIA = neutral detergent-insoluble ash; ADIA = acid detergent-insoluble ash; AD – HBrIA = acid detergent- and HBr-insoluble ash.

higher than in acid detergent (Table 3). Biogenic silica is known to be soluble in neutral detergent but not in acid detergent (Van Soest *et al.*, 1991). Therefore the difference between NDIA and ADIA can be interpreted as a quantitative estimate of biogenic silica. ADIA was essentially insoluble in HBr (Table 3), which suggests the presence of SiO_2 (Van Soest, 1982). Silica, found mainly in many grasses but also in some other plants, lowers the digestion of feeds in the rumen and promotes the formation of stones in the kidney (Van Soest, 1982).

The concentration of protein in *S. hermonthica* (Tables 2 and 3) was higher than that found by Bebawi & El Hag (1983) and is similar to that typically found in forage legumes (Table 1). This suggests that this herbage could play a role as a protein source for livestock. In *S. hermonthica* plants collected in farmers' fields (Table 3), the leaf was the part with the highest levels of CP (230 g kg d.m.$^{-1}$) and lowest values of o.m. (747 g kg d.m.$^{-1}$), followed by the inflorescence (211 g CP kg d.m.$^{-1}$, 803 g o.m., kg d.m.$^{-1}$). The stem had the lowest CP (87 g kg d.m.$^{-1}$) and the highest o.m. (882 g kg d.m.$^{-1}$) values. Samples grown under soil moisture stress (data not shown) had higher levels of CP than samples grown under normal soil moisture conditions (298 $\pm$ 22 vs. 182 $\pm$ 19 g kg d.m.$^{-1}$). Low soil moisture stress is known to increase the feed quality in other forages (Van Soest *et al.*, 1978).

Although *S. hermonthica* was found to have a relatively small NDF fraction (Tables 2 and 4), it appeared to be more lignified than other feeds common in the Sahel (Table 1). The two sequential methods used to determine lignin described by Van Soest *et al.* (1991) yielded quite different results (Table 4). The difference in the lignin values determined by both methods indicates the presence of tannins (Van Soest *et al.*, 1991), which are known to depress microbial activity in the rumen (Reed, 1995). The presence of relatively low levels of total free phenolic hydroxyl groups was confirmed by the absorbency at 500 nm (A_{500}) observed in the Vanillin-HCl reaction ($A_{500} = 0.012 \pm 0.002$ per 0.1 g d.m.), whereas moderate levels of proanthocyanidins were suggested by the absorbency at 675 nm (A_{675}) measured in the Folin–Ciocalteu reaction ($A_{675} = 0.299 \pm 0.055$ per 0.1 g d.m.).

Table 4 Double sequential fractionation of *S. hermonthica* fibre harvested from farmers' fields at flowering (g kg d.m.$^{-1}$)

Fibre fraction	Whole plant	Leaf	Stem	Inflorescence	SE
NDF*	510.1	385.6	641.5	478.7	11.91
ADF*	445.9	359.0	569.4	419.8	15.25
LIG*	216.4	205.5	162.3	271.7	1.66
ADF†	388.2	269.0	458.2	362.5	19.14
NDF†	319.6	195.7	419.3	297.7	17.64
LIG†	139.4	89.3	121.1	184.4	2.80

* Sequence NDF-ADF-H_2SO_4 lignin-ash.
† Sequence ADF-NDF-H_2SO_4 lignin-ash.
NDF = ash-free neutral detergent fibre; ADF = ash-free acid detergent fibre; LIG = ash-free lignin.

Experiment 2: consumption and digestion of Striga hermonthica *by sheep*

During the first two days of the *in vivo* trial, *S. hermonthica* vegetation was mostly uneaten. However, consumption increased substantially after three to four days, and one week later the sheep ate it readily. The d.m.d. was 493 ± 20 g kg^{-1} (Table 5), which is close to the value of 47% determined by Bebawi & El Hag (1983). However, the o.m.d. was relatively high (657 ± 28 g kg^{-1}). These results suggest that, when evaluating the digestibility of *Striga* spp., both o.m.d. and the concentration of o.m. in the d.m. should be reported. Although o.m.d. is relatively high, the energy value is greatly diluted by the high concentration of inorganic elements. In the present study, the concentration of digestible o.m. in the d.m. was 523 ± 22 g kg^{-1}, which is somewhat higher than that observed in cereal residues, but lower than that observed in legume forages (Table 1). The difference between d.m.d. and o.m.d. is explained by the almost complete recovery of the *S. hermonthica* inorganic matter in the faeces.

The voluntary intake of d.m. and o.m. was 51.1 ± 7.8 and 41.1 ± 6.4 g kg W$^{-0.75}$, respectively, whereas the consumption of digestible o.m. (d.o.m.i.) was 27.1 ± 5.0 g kg W$^{-0.75}$. These levels of consumption are comparable with or slightly higher than those observed for pearl millet stover, but much lower than those obtained with legume forages available in semi-arid West Africa (Table 1). The metabolizable energy (ME) value of the digestible o.m. is 15 MJ kg^{-1} (Anon., 1984). Thus the ME value of *S. hermonthica* herbage would be 7.8 MJ kg^{-1}. With the levels of consumption observed in the present study, this would provide 6.46 MJ day^{-1} when consumed by a 40 kg sheep, which is similar to the estimated ME requirements for maintenance (6.4 MJ day^{-1}) (Anon., 1984). These results suggest that, if no toxic or anti-nutritional compounds

Table 5 Digestibility and intake by sheep of *S. hermonthica* herbage harvested from farmers' fields at flowering

Variable	Mean	SD
Digestibility, g kg^{-1}		
d.m.	492.5	20.21
o.m.	657.4	27.61
o.m./d.m.	523.0	21.97
NDF	583.4	62.41
Daily intake per animal		
g d.m.	939.9	153.93
g o.m.	756.5	124.42
g d.m. kg W^{-1}	19.4	3.04
g d.m. kg W$^{-0.75}$	51.1	7.98
g digestible o.m. kg W$^{-0.75}$	27.1	4.97

d.m. = dry matter; o.m. = organic matter; NDF = ash-free neutral detergent fibre; W = body mass, kg.

Item	Mean	SD
Dry matter, g kg^{-1}	403.2	21.34
Organic matter, g kg d.m.$^{-1}$	542.8	27.39
NDF, g kg d.m.$^{-1}$	365.9	49.95
Nitrogen, g kg d.m.$^{-1}$	19.3	1.30
Phosphorus, g kg d.m.$^{-1}$	13.0	1.07

Table 6 Composition of faeces excreted by sheep fed on *S. hermonthica* herbage

are present and, if given as the sole source of organic nutrients, *S. hermonthica* herbage would be sufficient to maintain the weight of sheep.

The faeces of animals fed *S. hermonthica* plants were bluish, coarser and larger than those from animals fed conventional feeds. Faecal o.m. was only 543 ± 27 g kg d.m.$^{-1}$ (Table 6). Analysis of the effect on nutrient excretion in faeces suggests that feeding *S. hermonthica* to sheep for prolonged periods may result in substantial nutrient losses. The amount of neutral detergent solubles excreted in faeces (y, g day^{-1}) as a function of the amount of *S. hermonthica* consumed per day (x, g day^{-1}) was predicted by the equation $y = 48.6(\pm 28.3) + 0.27(\pm 0.08)x$; ($r^2 = 0.73$). For each additional 100 g d.m. consumed there was a loss of 27 g of faecal solubles. This loss, which is of endogenous origin, appeared to be about twice as much as the endogenous loss observed across forages with a large range of feed qualities (Van Soest, 1982) and could be due to the abrasive effect of the undigested weed residues on the digestive tract. Mature plants of *Striga* spp. are stiff and covered with short, rigid hairs (Raynal-Roques, 1987). Endogenous losses include not only organic, but also inorganic nutrients. The amount of inorganic matter (y, g day^{-1}) excreted in faeces as a function of the amount of inorganic matter from *S. hermonthica* consumed per day (x, g day^{-1}) was predicted by the equation $y = -5.3(\pm 21.0) + 1.22(\pm 0.31)x$; ($r^2 = 0.80$). Thus, 1.22 g of minerals would be excreted through faeces per g of inorganic matter consumed in the weed vegetation. These results suggest that the effect of *S. hermonthica* on nutrient excretion should be further investigated before recommending its use as an animal feed. The farmers in the region appear to be aware of this effect on faecal consistence as, in northern Nigeria, the weed is fed to treat diarrhoea in ruminants (B R Ntare, pers. comm.).

Daily urine excretion was 2973 mL (SD 1198) animal^{-1}. This level of excretion was higher than that observed at this location for sheep fed on low-quality mature forages (Schlecht *et al.*, 1998). The high urinary excretion may be explained, at least in part, by the need to eliminate excess urea resulting from the ammonia absorbed in the rumen. The consumption of *S. hermonthica* nitrogen by sheep was 26.3 ± 3.7 g day^{-1}, of which 3.6 ± 2.9 g day^{-1} were apparently retained in the animal's own tissues. Faecal excretion of nitrogen was 9.2 ± 1.6 g day^{-1}, whereas urinary excretion was 13.6 ± 1.9 g day^{-1}. Nitrogen excreted through urine was 52.4 ± 9.2% of the nitrogen consumed and this loss equalled 59.8 ± 4.4% of the total nitrogen losses. The high levels of excretion of urinary nitrogen suggest that the weed protein is highly degraded in the rumen, which coincides with the high levels of ammonia in the rumen fluid observed by Bebawi & El Hag (1983).

The high level of nitrogen in *S. hermonthica* warrants a further evaluation as a protein source, especially if the sun-dried weed could be preserved for use during the dry season as a component of a feed mix. However, the results from this study suggest that the potential value of the weed as a basal feed for ruminants would be limited by its high concentration of ash which would lead to a low consumption of digestible organic matter. In addition, livestock might not consume the plants if they have other choices, which would be likely given that this weed would be available during the rainy season. The amount of herbage of *S. hermonthica* that could be collected from a field would depend on the number of emerged weed plants, but in most cases it would probably be insufficient to constitute the basis of the diet of animals and thus it could be considered only as a complementary feed ingredient. However, during the crop-growing season in the Sahel, feed availability is a constraint because of restricted access to feed resources. As during this time animals are often tethered to prevent crop damage due to grazing, pulling and carrying weeds (including *Striga* spp.) for animal feeding is commonly practised. Some weeds (and on occasion *Striga* spp.) are indeed sold as feeds in the markets of larger cities. Because of their relatively high protein content, weeds can make significant contributions to animal feeding (Schlecht *et al.*, 1995).

An area of concern is the presence and potential effects of anti-nutritional factors. Although no signs of toxicity were observed in this study nor in that reported by Bebawi & El Hag (1983), it is possible that the duration of both studies was insufficient for any ill-effects to appear. This aspect should be further investigated before making recommendations on feeding *S. hermonthica* herbage to livestock. Hand pulling the weed before flowering would have the greatest impact on soil seedbank reduction. This is also the growth stage at which the weed's protein content is higher. Feeding mature *S. hermonthica* plants to ruminants might also promote the spread of its seeds, as the capacity to germinate was not completely lost when seeds were incubated in nylon bags in the rumen (Bebawi & El Hag, 1983).

The progressive intensification of farming systems in the savannahs of western and central Africa requires improved techniques of soil fertility management. Organic residues can, through composting in the vicinity of the field, play an important role in organic restitution in these regions (Berger, 1996). Farmers are aware of the improvements to soil fertility brought about by composting and returning organic matter to the soil (Ganry & Badiane, 1998). In Burkina Faso, Mali and Senegal, the production and use of manure and compost are being developed and implemented (Berger *et al.*, 1987; Ly *et al.*, 1997; Sanogo, 1997). The high concentration of nitrogen and phosphorus in *S. hermonthica* herbage suggests that it could be added to other plant/crop residues used for composting. The high temperatures generated during the composting process would have the advantage of reducing the viability of any pathogens present (e.g. seeds of *Striga* spp.; oospores of the downy mildew pathogen *Sclerospora graminicola* (Sacc.) Schroet.; sclerotia of the sorghum pathogen *Colletotrichum graminicola* (Cesati) G.W. Wilson). The potential use of *Striga* spp. for composting is an area of research that merits further investigation.

Acknowledgements

The authors are most grateful to MM Harouna Garba, Mamoudou Issa and Bakabé Tessaou (ILRI-Niger), and M Idrissa Abdou (ICRISAT-Niger) for their assistance in the experiments.

References

Anonymous (1977) Determination of nitrogen in BS digests. *Technicon Industrial Method* 334–74WB. Technicon Industrial Systems, Tarrytown, NY, USA.

Anonymous (1984) *Energy Allowances and Feeding Systems for Ruminants*. Reference Book 433, Ministry of Agriculture Fisheries and Food. Her Majesty's Stationery Office, London, UK.

Bebawi FF & El Hag GA (1983) Nutritive value of the parasitic weed *Striga hermonthica*. *Tropical Agriculture (Trinidad)* **60,** 44–47.

Berger M, Belem PC, Dakouo D & Hien V (1987) Le maintien de la fertilité des sols dans l'Ouest du Burkina-Faso et la nécessité de l'association agriculture–élevage. *Coton et Fibres Tropicales* **42,** 201–207.

Berger M (1996) L'amélioration de la fumure organique en Afrique soudano-sahélienne. *Agriculture et Développement* Numéro hors-série, 1–8.

Broadhurst RB & Jones WTJ (1978) Analysis of condensed tannins using acidified vanillin. *Journal of the Science of Food and Agriculture* **29**, 788–794.

Ganry F & Badiane A (1998) La valorisation agricole des fumiers et des composts en Afrique soudano-sahélienne: diagnostique et perspectives. *Agriculture et Développement* **18**, 73–80.

Hess DE & Dembélé B (1999) Cultural management of *Striga* on cereals. In: *Report on the ICRISAT Sector Review for Striga Control in Sorghum and Millet* (eds DE Hess & JM Lenné), 23–32. International Crops Research Institute for the Semi-Arid Tropics, Bamako, Mali.

Hess DE, Obilana AB & Grard P (1996) *Striga* research at ICRISAT. In: *Advances in Parasitic Plants Research* (eds MT Moreno, JI Cubero, D Berner, D Joel, LJ Musselman & C Parker), 828–834. Dirección General de Investigación Agraria, Sevilla, Spain.

Julkunen-Tiitto R (1985) Phenolic constituents in the leaves of northern willows: methods for the analysis of certain phenolics. *Journal of Agricultural Food Chemistry* **33**, 213–217.

Kroschel J & Sauerborn J (1996) Farming systems and the problems of applying *Striga* control methods – a comparison of case studies from Northern Ghana, Tanzania and Malawi. In: *Advances in Parasitic Plant Research* (eds MT Moreno, JI Cubero, D Berner, D Joel, LJ Musselman & C Parker), 844–853. Dirección General de Investigación Agraria, Sevilla, Spain.

Ly C, Diaw A & Faye A (1997) Etables fumières et production laitière au Sénégal. *Cahiers Agricultures* **6**, 651–659.

Nelson DW & Sommers LE (1980) Total nitrogen analysis of soil and plant tissues. *Journal of the Association of Official Analytical Chemists* **63**, 770–778.

Ramaiah KV (1985) Hand pulling of *Striga hermonthica* in pearl millet. *Tropical Pest Management* **31**, 326–327.

Ransom JK & Odhiambo GD (1994) Long-term effects of fertility and hand-weeding on *Striga* in maize. In: *Biology and Management of Orobanche* (eds AH Pieterse, JAC Verkleij & SJ ter Borg), 513–519. Royal Tropical Institute, Amsterdam, The Netherlands.

Raynal-Roques A (1987) The genus *Striga* (Scrophulariaceae) in Western and Central Africa. In: *Parasitic Flowering Plants* (eds H Chr Weber & W Forstreuter), 367–375. Philipps-Universität Marburg, Marburg, Germany.

Reed JD (1995) Nutritional toxicology of tannins and related polyphenols in forage legumes. *Journal of Animal Science* **73**, 1516–1528.

Sanogo ZJL (1997) *Maîtrise de l'azote dans un système cotonnier-sorgho: Prévision de la fumure organique et azotée en zone Mali-Sud.* Thèse de doctorat, ENSA, Montpellier, France.

Saunders AR (1933) Studies in phanerogamic parasitism with particular reference to *Striga lutea* Lour. *South Africa Department of Agriculture Science Bulletin* **128**, 1–56.

Schlecht E, Bürkert A, Lamers J, Sangaré M & Becker K (1995) Nutrient supply of natural pasture and weeds for cattle in agro-pastoral systems of the West African Sahel. In: *Proceedings of an International Symposium on Wild and Domestic Ruminants in Extensive Land Use Systems* (eds RR Hofmann & HJ Schwartz), 158–164. Ökologische Hefte der Landwirtschaftlich-Gärtnerischen Fakultät. Heft 2. Humboldt Universität, Berlin, Germany.

Schlecht E, Fernández-Rivera S & Hiernaux P (1998) Timing, size and nitrogen concentration of faecal and urinary excretions in cattle, sheep and goats: Can they be exploited for better nutrient management?. In: *Soil Fertility Management in West African Land Use Systems* (eds G Renard, A Neef, K Becker & M von Oppen), 361–367. Margraf-Verlag, Weikersheim, Germany.

Van Soest PJ (1982) *Nutritional Ecology of the Ruminant.* O and B Books, Corvallis, Oregon, USA.

Van Soest PJ, Mertens DR & Deinum B (1978) Preharvest factors influencing quality of conserved forages. *Journal of Animal Science* **47**, 712–720.

Van Soest PJ, Robertson JB & Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* **74**, 3583–3597.