ILCA BULLETIN

No. 35–December 1989

This is the last issue of *ILCA Bulletin.* Beginning in April 1990, ILCA will instead publish a new internationally reviewed quarterly journal, *African Livestock Research,* whose aim is to promote communications among all scientists whose work is relevant to improving and increasing livestock production in Africa.

The need for a journal addressing an international forum and the varied disciplines of livestock research was expressed at the Fourth Biennial Meeting between ILCA and Leaders of Livestock Research, Development and Training in sub-Saharan Africa, held in 1987. The next two years witnessed many consultations within and outside ILCA, which culminated in the endorsement of *African Livestock Research* by the Fifth Biennial Meeting in October 1989.

Many papers have already been received, and these are now being reviewed. We hope that you will stay with us as authors and readers and help make *African Livestock Research* the most lively and relevant journal for livestock research in Africa. The journal will accept manuscripts on all aspects of basic and applied research applicable to livestock and mixed crop-livestock production systems in Africa, whether such research is carried out in Africa or outside the continent.

Copies of 'Notes for contributors' are available from

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ISSN 0255–0008

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Preface

In a world where population increases and food shortages are major problems, ruminants can augment the food supply by converting energy sources which people cannot use into products which they can. Most ruminants in sub-Saharan Africa rely on poor-quality roughages for most of their sustenance. This is especially true during dry seasons. These roughages are commonly deficient in protein and unable to produce high rates of weight gain.

The nutritive value of roughage can be improved by supplementing it with crude protein from forage legumes and leguminous browse. Forage legumes not only provide high-quality protein to animals, they also increase the fertility of soil by enhancing its nitrogen content. Browse from multipurpose leguminous trees can play similar roles. Both are also particularly important in areas where increasing human population has led to increased demand for cropping land, shorter fallowing periods and less communal grazing.

The full potential of many sub-Saharan African farming systems will only be achieved through exploiting the complementarity between crop and livestock production. This, together with the need to improve the quality of animal feed, has led ILCA to devote much effort over the years to promoting forage legume production and gaining better understanding of the nutritional value of leguminous feed resources.

One aspect that has received considerable attention is the study of the effects of polyphenolics in browse on feed intake, fibre digestion and animal growth. This research has shown that reasonable growth rates can be achieved by supplementing roughage-based diets with browses with low to moderate levels of insoluble polyphenolics. Although these substances limit the availability of nitrogen to the animal, this is offset by a lower excretion of nitrogen.

The Centre's forage production research has been strongest in the subhumid zone of West Africa for several reasons. For example, the zone is still fairly underutilised and its climate is suitable for a wide range of crops. And it is in this zone that the integration of pastoralists and crop farmers is most active, creating opportunities for introducing forage legumes into the existing farming systems.

Growing legumes in fodder banks is gaining acceptance among settled agropastoralists as a means of providing additional protein to animals during the dry season. Legume intercropping reduces the decline in soil fertility and bolsters the nutritional value of crop residues. Both interventions have been shown to be profitable, but while the adoption of fodder banks is already on the way, intercropping is likely to become more popular only when the number of cattle in the subhumid zone increases and agropastoralists are obliged to pay farmers for crop residues.

The third article in this issue of *ILCA Bulletin* looks at on-farm performance testing as a means of determining the performance potential of cattle and sheep under different levels of management, disease exposure and feed availability and quality. The role of networks in improving on-farm performance testing in sub-Saharan Africa through standardised testing methods and rapid data handling is also highlighted.

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The influence of polyphenolics on the nutritive value of browse: A summary of research conducted at ILCA

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SUMMARY

MANY AFRICAN *browse species contain high levels of polyphenolic compounds (including tannins) which have a large effect on protein digestibility and nitrogen metabolism in ruminants. A brief discussion of tannin chemistry and methods of tannin analysis is presented. Results from research on the nutritive value of African browse species are reviewed. The nutritive value of tanniferous browse cannot be easily predicted from chemical analyses because tannins can have both negative and positive effects on nitrogen metabolism. Examples of both types of effect are presented and the implications for feeding browse to ruminants are discussed.*

INTRODUCTION

In arid, semi-arid and subhumid areas, where cropping is impossible or unreliable, man depends on ruminants for sustenance. Ruminants produce food for human consumption by feeding on plants or plant parts that have no nutritive value for man. Trees and shrubs survive harsh climatic conditions and are an important source of browse feed in drier parts of Africa.

Because of its high content of protein, browse has been suggested as a solution to feeding tropical animals: woody species are more drought-tolerant than grasses and may be a more reliable feed resource. Browse trees benefit soils by protecting them from erosion and may increase soil fertility. They also benefit crops and animals with shade, and provide people with fuel, medicines and building materials.

Browse is particularly important in areas where increasing human population has necessitated the cultivation of grazing land. The larger areas cultivated produce more crop residues whose nutritive value can then be enhanced by nitrogen supplementation in the form of browse. Although tree leaves have a high protein content, tannins and other secondary compounds may bind this protein, thus rendering it unavailable to the animal. Tannins and related polyphenolics may have negative effects on palatability and digestibility, and many are also poisonous.

One research priority for the study of browse is to determine the effect of tannins on protein availability and other aspects of digestion. This is a complex problem because the term 'tannin' refers to a heterogeneous group of phenolic compounds which precipitate protein to varying degrees, depending on the type of phenolic and protein present as well as the chemical environment. The nutritional effects of these compounds must be fully understood before the

economic value of browse as a component of an animal management system can be realistically determined.

Scientists in ILCA's Nutrition Unit have attempted to determine the effects of tannins in woody species on feed intake and the growth, digestion and nitrogen metabolism of ruminants. The research was conducted in Ethiopia using local browse species, mainly *Acacia,* which are widely distributed in Africa. This paper summarises ILCA's findings over several years of research. Nitrogen metabolism in ruminants and tannin chemistry are briefly discussed to give background information on the work reported.

NITROGEN METABOLISM

In ruminants, feed is mainly digested in the rumen, which causes the growth of a microbial population, which, in turn, is digested in the lower tract, thereby benefiting the host animal. Nitrogen metabolism in ruminants has been reviewed by Ørskov (1982), Van Soest (1982) and NRC (1985), and is briefly described below.

The primary source of nitrogen for rumen microbes is either protein or non-protein nitrogen from feed. Most of this is converted to ammonia and then incorporated into microbial cells (Ørskov, 1982). The ability of rumen organisms to use ammonia depends on an adequate supply of energy. The energy must be available at the same time as the ammonia, otherwise the ammonia will not be effectively utilised. Excess ammonia in the rumen is absorbed into the blood and converted to urea by the liver.

A secondary source of nitrogen for the rumen microbes is urea recycled from the blood directly through the rumen wall or in saliva (Kennedy and Milligan, 1980). Urea diffuses from blood to rumen, while rumen ammonia diffuses in the reverse direction (Houpt, 1970). The amount of urea recycled is fairly constant and independent of dietary nitrogen (Van Soest, 1982). Recycled urea is more important for animals on low nitrogen intake, because recycling prevents the loss of endogenous nitrogen to excretion in urine and allows its use by nitrogen-deficient rumen microbes.

The rumen microorganisms convert nitrogen into microbial cells, irrespective of whether the nitrogen originated as protein or as non-protein nitrogen unusable by the host. The conversion of feed nitrogen into microbial cells is obviously an advantage to the animal in the case of non-protein nitrogen. However, it is detrimental if the nitrogen source is high-quality protein because most nitrogen in bacterial cell walls is indigestible (Ørskov, 1982), resulting in a net loss of N available to the host.

Available microbial protein does not vary in amino-acid composition in response to diet (Storm, 1981). A comparison of the amino-acid composition of microbes and animal tissue shows that microbial protein may be deficient in some amino acids necessary for wool production but not in those required for growth and milk production (Ørskov, 1982; Van Soest, 1982).

Some protein escapes ruminal digestion to undergo peptic digestion in the abomasum. The rate of protein escape is increased by high rates of passage, low protein solubility, small particle size and high level of intake (Van Soest, 1982). Efforts have been made to encourage protein to escape from the rumen by chemical or physical treatment which alters protein solubility or degradability. These methods need to protect protein from ruminal but not peptic digestion.

Previous research suggests that treating protein with tannins may increase protein escape (Driedger and Hatfield, 1972). Some tannins may bind proteins in the neutral pH of the rumen and release them in the acidic abomasum (Barry and Forss, 1983). This seems to occur with feeds treated with hydrolysable tannins (Driedger and Hatfield, 1972) because they contain ester linkages (Haslam, 1966) which hydrolyse in gastric acid, thus releasing the protein. However, it is unlikely that proanthocyanidins will have the same effect (Zelter et al, 1970) because they have an acid-resistant biphenyl structure (Haslam, 1966). Most naturally occurring forage tannins are proanthocyanidins (McLeod, 1974).

Microbial and escape protein from the rumen may be digested in the lower tract and absorbed by the host. Protein bound in plant cell walls or in chemical complexes is not absorbed. The unabsorbed protein, as well as endogenous nitrogen from the digestive tract and recycled urea, may be available to microorganisms in the large intestine (Visek, 1968; Beever et al, 1974; Nolan, 1975). The incorporation of nitrogen into microorganisms in the lower tract depends on the energy source which escapes absorption (Beever et al, 1974; Van Soest, 1982).

Faecal nitrogen is composed of undegraded feed nitrogen, microbial nitrogen from the rumen and large intestine, and endogenous nitrogen from the digestive tract (Mason, 1969). The size of these fractions depends on the content of protein and energy in the diet, rate of passage, and the nutritional status of the host (Mason, 1979). Faecal material originating from microbial and endogenous sources can be separated from other faecal material by its solubility in neutral detergent (Mason, 1969).

TANNINS

Chemistry of tannins

Tannins are a subset of plant polyphenols found in leaves, twigs, flowers, fruit and tree bark. Long after Fischer's (1919) work on the chemistry of the so-called 'vegetable tannins', the subject remained "one of the untidy corners of organic chemistry" (Gupta and Haslam, 1980), and even at present, the chemical classification of some phenolic compounds may prove difficult.

The original definition of tannin as 'a compound able to convert hide to leather' was unclear, because while all tannins contain phenolic groups, not all phenolics can cross-link collagen fibres in animal hides to form leather. Nevertheless, the ability of tannins to precipitate proteins is one of their most important biological properties.

Precipitation can be the result of hydrogen bonding (Loomis and Battaile, 1966), covalent bonding (Swain, 1979), ionic bonding (Gustavson, 1956) or hydrophilic bonding (Oh et al, 1980). The ability of tannins to precipitate proteins depends on their molecular weight, water solubility, conformation and other factors. A definition with enough generality to include all tannins was given by Horvath (1981):

Tannins are any phenolic compound of sufficiently high molecular weight and containing sufficient phenolic hydroxyls and other suitable groups (i.e. carboxyls) to form effectively strong complexes with protein and other macro-molecules under the particular environmental conditions being studied.

This definition allows for the fact that tannins may form complexes with starch and cellulose, as well as protein. It also underscores the difficulty in precisely defining the chemistry of tannins.

Tannins are usually subdivided into two major groups: hydrolysable and condensed tannins. Hydrolysable tannins split into sugars and phenolic carboxylic acids in acid and alkaline conditions (White, 1957). They are further classified according to the products of hydrolysis into gallo-tannins (gallic acid and glucose) and ellagi-tannins (ellagic acid and glucose) (McLeod, 1974). Two other categories, tara-gallo-tannins (gallic and quinic acid plus glucose) and caffe-tannins (caffeic acid arid quinic acid plus glucose) have also been suggested (Haslam, 1966).

The condensed tannins are often referred to as proanthocyanidins because they produce red anthocyanidins when heated in acid (Haslam, 1982). Proanthocyanidins are phenylpropanoid polyphenols and are categorised by the type of monomer they contain - either flavan-3-ols or flavan-3, 4-diols - into catechins or leucoanthocyanidins (Horvath, 1981).

The term leucoanthocyanidin was originally used to name the whole group of condensed tannins (Haslam, 1982); the literature must, therefore, be read carefully to avoid misinterpretation. Furthermore, since condensation is a reaction which hydrolysable tannins can also undergo, the term 'proanthocyanidin' is preferred to 'condensed tannin'.

Besides hydrolysable tannins and proanthocyanidins, a group called the beta-tannins can be added (Swain, 1979; Horvath, 1981). Beta-tannins are protein-precipitating compounds which are insoluble in water. They form very stable bonds with protein, and they can have lower molecular weight than other tannins and still be effective.

However, as more is learned about tannin chemistry in relation to animal nutrition, the less useful this classification system is likely to be because there are some compounds, such as catechin gallates, which have properties of both the hydrolysable and condensed tannins. Catechin gallates are important nutritionally because they are toxic to some rumen bacteria (Mueller-Harvey et al, 1988).

The interaction between tannins and proteins is very specific (Hagerman and Butler, 1981) and depends on the characteristics of both tannin and protein, such as molecular weight, tertiary structure, isoelectric point and compatibility of binding sites. It also depends on the properties of the solvent, especially its pH. Proanthocyanidins seem to be more important than hydrolysable tannins in forming complexes in feed (Reed et al, 1985).

Tannin assays

Using fresh samples to determine tannin content is best, but if storage is necessary, freezing is preferred. In some situations, drying is the only means of preserving material. However, at low drying temperatures (<40° C), enzymes may still function, thereby leading to oxidation. At temperatures above 60° C, heat damage (Van Soest, 1965) and polymerisation (Haslam, 1966) may occur.

There is no definitive assay for tannins because they are heterogeneous compounds, but there are many methods for assaying tannins, each with its own specificity, which have been reviewed in literature (e.g. Swain and Hillis, 1959; Maxson and Rooney, 1972; Horvath, 1981). The International Livestock Centre for Africa (ILCA) developed two assays, one to quantify

insoluble proanthocyanidins and one for soluble phenolics, including proanthocyanidins and other phenolics which may be nutritionally important by having effects other than precipitating protein. These methods are briefly described below.

Insoluble proanthocyanidins. These are determined by heating a sample of neutral-detergent fibre in a solution of n-butanol and concentrated hydrochloric acid. The solution turns red as proanthocyanidins are converted to anthocyanidins. Absorbance is read at 550 nm (Bate-Smith, 1973; Reed et al, 1982).

Initial treatment of the sample by extraction with aqueous acetone and by neutral detergent removes soluble phenolic compounds that may polymerise under acidic conditions, thus avoiding the exaggeration of the content of insoluble proanthocyanidins. Results are presented as absorbance per gram of neutral-detergent fibre. One problem with this procedure is that not all of the proanthocyanidins dissolve, as evidenced by the red colour remaining in the fibre after the analysis.

Soluble phenolics. Total polyphenolics soluble in acetone are determined in a gravimetric assay, by precipitating them from solution with trivalent ytterbium (Reed et al, 1985). The major advantage of the assay is that, unlike in colorimetric assays, standards are not required. Precipitated phenolics may be recovered for qualitative analysis, enzymatic assay, and for assays of protein precipitation and effects on in vitro digestibility. Therefore, potential anti-nutritional effects can be related to the amount of soluble phenolics.

The two assays described give general indications of the size of different phenolic fractions in a feed. The complex tannin chemistry makes it necessary to identify the individual compounds present in the fractions before the effects of each one can be determined. High-performance liquid chromatography and thin-layer chromatography, which separate compounds according to their differential solubility in appropriate solvents, are suitable methods for separating individual phenolic compounds in browse.

Chromatography has been applied by ILCA in the study of phenolic compounds in African browses (Mueller-Harvey et al, 1987; Rittner. 1987; Tanner, 1988). It is hoped that in time, it will be possible to attribute nutritional effects to specific compounds, and then develop simpler assays for the effective compounds.

EFFECT OF BROWSE ON ANIMALS

Below is a synthesis of studies conducted at ILCA in recent years to investigate the behavioural and physiological effects of browse on small ruminants. Most of these studies compared the performance and/or physiological parameters of animals fed browse with the performance and physiological parameters of animals fed standard, non-tanniferous high-protein feeds. Browses and other high-protein feeds were each fed in combination with a low-protein roughage. Both browse and traditional feeds were fed at isonitrogenous levels designed to achieve a pre-determined performance goal. The contents of soluble phenolics and insoluble proanthocyanidins of the browse species included in these studies are shown in Table 1.

Table 1. *Contents of soluble phenolics and insoluble proanthocyanidins of eight browse species used in ILCA studies.*

Browse[1]	Soluble phenolics (% DM)	Insoluble proanthocyanidins (A_{550})	Source
Acacia brevispica (1)	23.9	0.37	Woodward and Reed (in press)
Acacia cyanophylla (1)	38.9	0.45	Reed et al (in press)
Acacia sieberiana (f)	41.8	0.12	Reed et al (in press)
	40.6	0.37	Tanner (1988)
Acacia seyal (1)	40.0	0.14	Reed et al (in press)
	30.0	0.55	ILCA (1988b)
	29.5	0.40	Rittner (1987)
Sesbania sesban (1)	17.9	0.06	Reed et al (in press)
	18.0	0.01	Woodward and Reed (in press)
	16.0	0.06	ILCA (1988b)
	15.7	0.11	Ritmer (1987)
Acacia nilotica (1)	34.0	0.15	ILCA (1988b)
	33.8	0.21	Ritmer (1987)
Acacia nilotica (f)	43.6	0.89	Tanner (1988)
Acacia tortilis (f)	37.3	0.31	Tanner (1988)
Acacia albida (f)	36.5	0.27	Tanner (1988)

[1] The plant parts used were leaves (1) and fruit (f).

Intake

Tannins may reduce intake and palatability of feeds by causing an astringent (Bate-Smith, 1973) or dry feeling in the mouth (Goldstein and Swain, 1963), or by negatively affecting digestion. ILCA data both support and contradict the hypothesis that polyphenolics have a negative effect on feed intake (Table 2).

Table 2. *Browse and roughage intakes and growth rate recorded in three experiments with sheep.*

Browse	Intake (g/d)				
	Browse	Roughage	Total	Growth	Source
Acacia cyanophylla (1)	170	318*	488*	–11*	Reed et al (in press)
Acacia sieberiana (f)	195	269 *	464*	20*	Reed et al (in press)
Acacia seyal (1)	193	285 *	478*	21*	Reed et al (in press)
Sesbania sesban (1)	157	473	630	48	Reed et al (in press)
Acacia tortilis (f)	336	423	759	53	ILCA (1988a)
Acacia brevispica (1)	237	510	747	53	ILCA (1988a)
Acacia tortilis (f)	206	430*	636	32	Tanner (1988)
Acacia albida (f)	194	401*	595	22	Tanner (1988)
Acacia nilotica (f)	204	347*	551	16*	Tanner (1988)
Acacia sieberiana (f)	212	320*	532	0*	Tanner (1988)

Notes: Animal performance with browse was compared to performance obtained with a standard protein supplement. Browse offered varied with experiment but was calculated to provide the same amount of nitrogen in each experiment. The roughages used were grass hay (ILCA, 1988a), maize stover (Tanner, 1988) and teff straw (Reed et al, in press). Standard supplements were cowpea hay and lucerne (ILCA, 1988a), noug cake (Tanner, 1988; Reed et al, in press) and vetch hay (Reed et al, in press). The browse parts were leaves (1) and fruits (f). *= significantly ($P<0.05$) lower than the value obtained in the same trial for the standard supplement.

In a study (Reed et al, in press) comparing three browses high in polyphenolics (leaves of *Acacia cyanophylla* and A. *seyal* and fruits of *A. sieberiana)* with *Sesbania sesban* (low in polyphenolics) and three standard protein supplements *(Vicia dasycarpa* and *noug* or urea), all of which were fed in combination with teff straw *(bragrostis abyssinica),* tannins appeared to reduce total feed intake.

The amount of browse on offer was determined by its protein content. *Sesbania sesban* has a high content of protein, and was, therefore, fed at a lower amount (180 g/d) than, for example, *A. cyanophylla* (330 g/d) which is low in protein. Sheep consumed almost all of the *S. sesban* offered but only about half of the *A. cyanophylla* offered. Compared with the other two acacias, intake of *A. cyanophylla* was lowest, due to its very high content of insoluble proanthocyanidins. Intake of *A. seyal* was initially also very low, but it increased after the animals got used to the browse.

In an experiment where *A. brevispica* and *S. sesban* were each fed in combination with vetch and teff straw at three levels, intake differed between sheep and goats. Feed refusal by sheep increased as the proportion of *A. brevispica* increased in the diet, suggesting a negative response to tannins. In comparison, goats rejected portions of diets which included both *A. brevispica* and vetch, which might be a negative response to fibre (Woodward and Reed, in press).

The effect of browse on the intake of roughage fed concurrently is an important consideration. When *S. sesban* was fed with teff straw, its high content of nitrogen and low content of fibre and proanthocyanidins caused an increase in teff intake over diets including vetch (Reed et al, in press; Woodward and Reed, in press). Compared with roughage intake obtained with standard supplements, browses with high contents of proanthocyanidins (such as *A. cyanophylla* leaves and fruits of *A. sieberiana* and *A. nilotica)* caused a reduction in roughage intake (Tanner, 1988; Reed et al, in press) (Table 2). Browses with moderate levels of proanthocyanidins led to either improved roughage intake (Woodward and Reed, in press) or intake comparable to that with standard supplements (ILCA, 1988a).

Growth

Animal growth rates reflect total intake and the availability of nutrients in the diet. When there was a reduction in total intake due to the fibre or phenolic content of browse, growth rate was low compared with that obtained with non-tanniferous supplements (Table 2).

Low growth rates were observed in animals fed fruits of *A. sieberiana* and *A. nilotica* (Tanner, 1988) although total feed intake was not very low. Reed et al (in press) found that animals fed *A. sieberiana* fruits and *A. seyal* leaves had low total intake and low growth rates, while feeding *A. cyanophylla* resulted in a negative growth rate. The growth rates of animals fed diets with *A. seyal*improved after a period of adaptation to the browse. The negative effect of tannins in *A. cyanophylla* on growth rate was caused by a reduction in nitrogen availability.

Digestion of fibre fractions

Tannins may reduce cell-wall digestibility by binding bacterial enzymes and/or forming indigestible complexes with cell-wall carbohydrates (Barry and Manley, 1984; Barry et al, 1986; Reed, 1986). The digestibilities of organic matter and the fibre fractions of sheep diets comprising *A. cyanophylla* were depressed (Table 3) because of high contents of proanthocyanidins and soluble phenolics. Neutral-detergent fibre digestibility was also depressed in diets containing two other tanniferous browses, *A. sieberiana* fruits and *A. seyal* leaves.

Table 3. *Digestibility of organic matter (OM), neutral-detergent fibre (NDF) and acid-detergent lignin for sheep fed six diets.*

	Digestibilty (%)			
Browse	Apparent OM	True OM	NDF	Lignin
Acacia cyanophylla	41.0a	54.4a	29.0a	–61.1a
Acacia sieberiana fruits	54.0b	64.0b	37.0b	–35.8b
Acacia seyal	54.0b	70.1d	41.9b	–3.7c
Sesbania sesban	54.0b	66.4c	51.7cd	15.4c
Vetch hay	53.1b	63.6b	49.0c	0.6c
Noug cake	57.3b	67.1c	57.1d	14.9c

Notes: The diets consisted of the browse, teff straw and other supplements fed to provide nitrogen for weight gain of 50 g/d. Values in the same column followed by different letters are

significantly different (P<0.05).
Source: Reed et al (in press).

The digestibility of lignin was negative for all the three acacias used in the trial (Reed et al, in press) (Table 3). In most common feeds, the true digestibility of lignin is not different from zero. However, tannin-protein complexes formed in the digestive tract were recovered as faecal lignin (Reed, 1986), which led to an apparent negative digestibility of lignin.

The interference of tannins with the lignin fraction is further emphasised by a comparison between true dry-matter digestibility and digestibility predicted by the summative equation of Goering and Van Soest (1970) which penalises digestibility for lignin in the feed. However, the penalty for lignin in *A. brevispica* was too high, because digestibility was increasingly underpredicted as *A. brevispica* was added to the diet (Table 4). This suggests that the lignin fraction measured in *A. brevispica* was not true lignin but may have been contaminated by phenolics.

Table 4. *Apparent, true and predicted digestibilities of dry matter and the difference between the true and predicted digestibilities for seven diets fed to sheep and goats.*

Dry-matter digestibility	Diet[1]							SE[2]
	B3	B2VI	B1V2	V3	SlV2	S2V1	S3	
	————————%————————							
Apparent	58.7	59.0	58.5	60.4	62.4	61.7	62.7	0.8
True	73.4	73.8	73.6	74.6	77.0	76.0	78.4	0.6
Predicted	61.8	65.3	69.0	73.2	73.7	74.4	75.1	0.1
True-predicted	11.7	8.6	4.6	1.5	3.3	1.6	3.2	0.6

[1] Numbers in diet designations refer to proportions of nitrogen provided by *Acacia brevispica* (B), *Sesbania sesba* (S) and *Vicia dasycarpa* (V). Teff straw was fed *ad libitum.*
[2] SE = standard error. Source: Woodward and Reed (in press).
Source: Woodward and Reed (in press).

Tannin interference with fibre fractions makes it impossible to determine the nutritive value of browse from chemical analysis, as is done for other forages. The issue will, therefore, be discussed again in terms of determining nitrogen availability.

Utilisation of nitrogen

Tannins can form complexes with protein, and thus their greatest potential negative effect is on nitrogen metabolism. This can be seen when tanniferous browses are compared with non-tanniferous feeds. Tannins have large effects on nitrogen utilisation at each stage of digestion, as is shown below using four parameters.

Rumen ammonia, plasma urea nitrogen and urinary nitrogen. These are the most accessible pools with which to describe nitrogen available to and incorporated into animal tissues. They have been described for both sheep and goats fed diets made up of combinations

of either *A. brevispica* or *S. sesban* plus vetch plus teff straw *ad libitum* (Woodward, 1988) (Table 5), and for sheep given diets composed of *S. sesban, A. nilotica* or *A. seyal* (Rittner, 1987).

Table 5. *Rumen ammonia and plasma urea nitrogen concentrations and daily, urinary, nitrogen loss for goats and sheep fed seven diets.*

	Diet[1]							SE[2]
	B3	B2V1	BlV2	V3	SlV2	S2V1	S3	
Rumen ammonia (mg/dl)	10.6	17.5	24.7	21.8	32.2	29.9	32.0	5.0
Plasma urea nitrogen (mg/dl)	23.2	26.7	30.6	31.9	33.1	36.7	37.1	1.8
Urinary nitrogen (g/d)	4.9	4.8	4.8	5.3	5.7	6.0	6.6	0.2

[1] Numbers in diet designations refer to proportions of nitrogen supplied by *Acacia brevispica* (B), *Sesbania sesban* (S) and *Vicia dasycarpa* (V). Teff straw was fed *ad libitum.* Values shown are averages from samples taken 3, 6, 12 and *24* hours after feeding.
[2] SE = standard error.
Source: Woodward (1988).

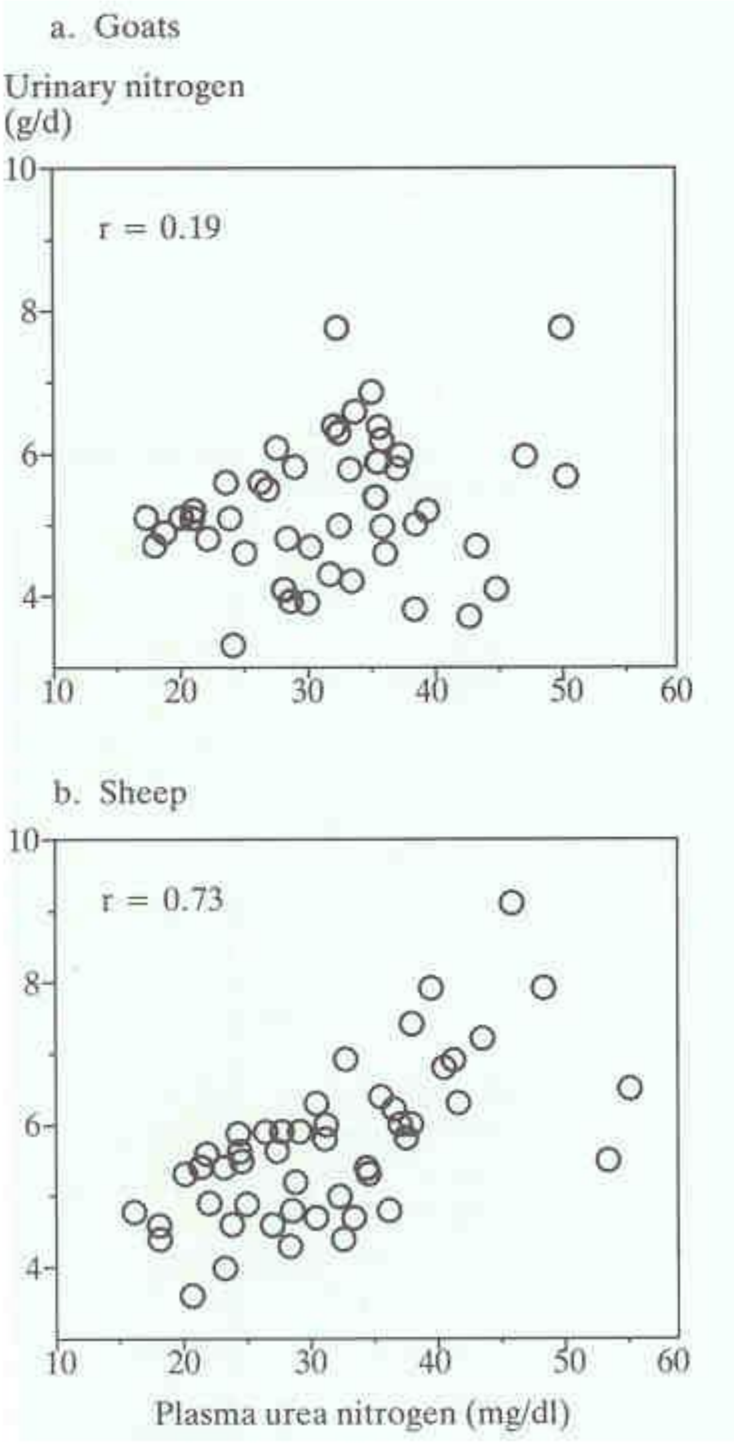
Proteolytic activity in the rumen is indicated by ammonia concentration. Rumen ammonia was highest for diets including *S. sesban* and lowest for diets with increasing amounts of *A. brevispica,*reflecting the rapid fermentation rate of *S. sesban* due to low phenolic and fibre contents (Table 5). Diets with *S. sesban* also had higher concentration of rumen ammonia than diets with *A. nilotica* or*A. seyal* (Rittner, 1987).

Rumen ammonia enters the plasma urea pool after it has been absorbed into the blood and converted to urea by the liver. Endogenous loss from tissue also enters this pool. Excess plasma urea nitrogen is excreted in urine, preventing toxicity in the animal. High values of plasma urea nitrogen indicate an inability of the animal to utilise nitrogen made available by digestion. As with rumen ammonia, plasma urea nitrogen was higher in animals fed diets including *S. sesban* than in those fed diets with *A. brevispica* (Woodward, 1988). Similar results were obtained when diets containing*S. sesban* were compared with diets including *A. seyal* or *A. nilotica* (Rittner, 1987).

When levels of plasma urea nitrogen were compared with levels of urinary nitrogen, a difference was observed between sheep and goats (Figure 1). The correlation between plasma urea nitrogen and urinary nitrogen was high in sheep ($r = 0.73$), but low in goats ($r = 0.19$). Also, urinary nitrogen was markedly lower in goats, which suggests that goats may be able to recycle more urea to the rumen than sheep at high levels of plasma urea nitrogen.

Figure 1. *Correlations between urinary nitrogen and plasma urea nitrogen for sheep and goats fed diets containing* Acacia brevispica *or* Sesbania sesban *combined with vetch hay and teff*

straw.



Source: Woodward (1988).

Faecal nitrogen. This is composed of indigestible feed nitrogen, microbial nitrogen from the rumen, and lower-tract and endogenous (metabolic) nitrogen secreted into the digestive tract but not incorporated into microbial nitrogen (Mason, 1969; Van Soest, 1982). Indigestible feed nitrogen in the faeces is insoluble in neutral detergent and can be estimated by the amount of

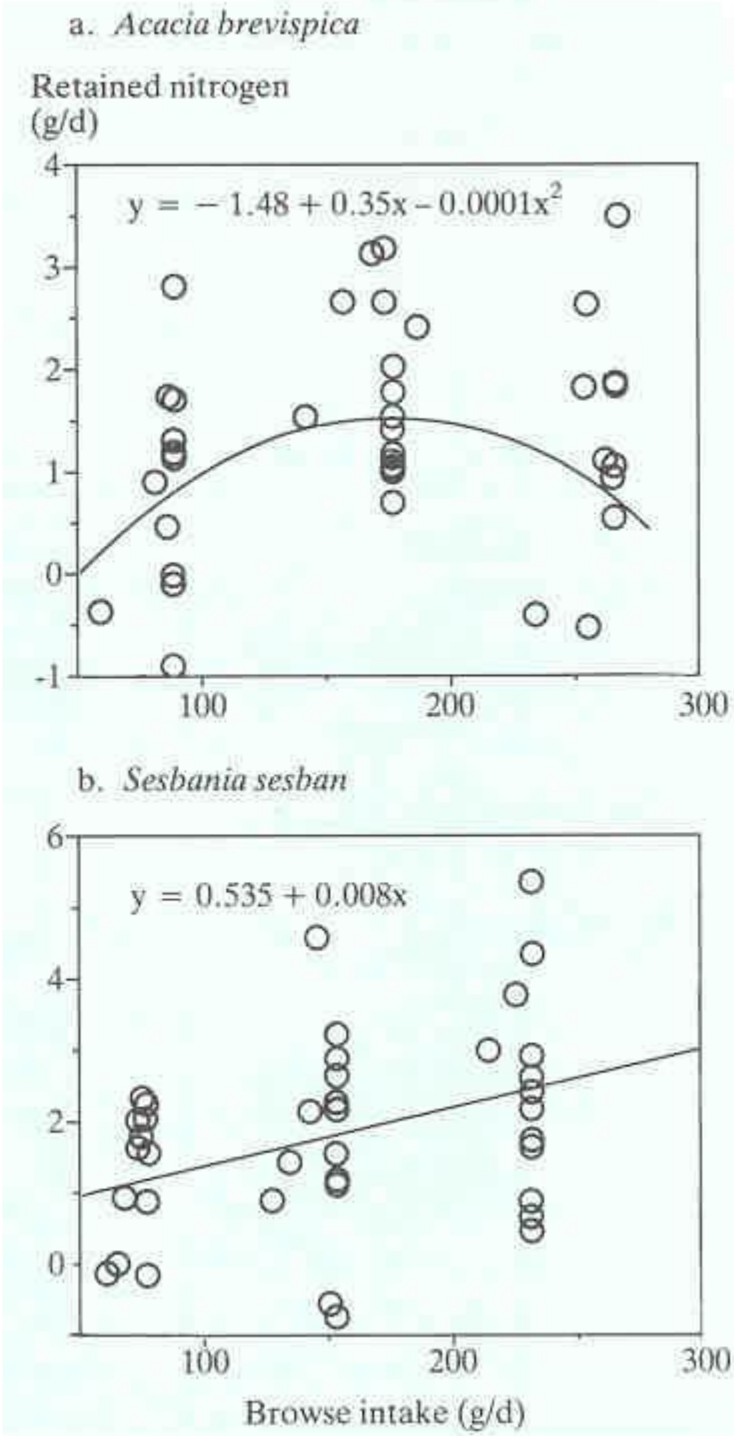
nitrogen in neutral-detergent fibre (NDF-N) (Mason, 1969). Faecal NDF-N may also include indigestible tannin-protein complexes (Reed, 1986).

Higher total faecal nitrogen (which could be accounted for by higher faecal NDF-N) was observed for all diets containing tanniferous feeds (Rittner, 1987; ILCA, 19886; Tanner, 1988; Woodward, 1988; Reed et al, in press). The higher faecal NDF-N values can be attributed to indigestible tannin-protein complexes.

Sheep fed diets containing *A. seyal* had high levels of faecal nitrogen (Reed and Soller, 1987; ILCA, 1988b). This fraction, also called the metabolic increment, is nitrogenous material of endogenous origin, and may result from a higher production of rumen microbes as a consequence of greater recycling of urea from blood to rumen.

Nitrogen retention. This parameter summarises the value of a feed as a source of nitrogen. When *A. brevispica* and *S. sesban* were each fed at three levels in combination with vetch and teff straw, the amount of retained nitrogen was higher for all diets containing browse than for vetch alone (Woodward, 1988) (Figure 2). Nitrogen retention increased as a linear function of intake of *S. sesban,*but increased then decreased as a function of intake of *A. brevispica.* The quadratic term in the regression of retained nitrogen on intake of *A. brevispica* was significant ($P<0.05$).

Figure 2. *Retained nitrogen as a function of intake of* Acacia brevispica *or* Sesbania sesban, *each fed at three levels with vetch arid teff straw.*

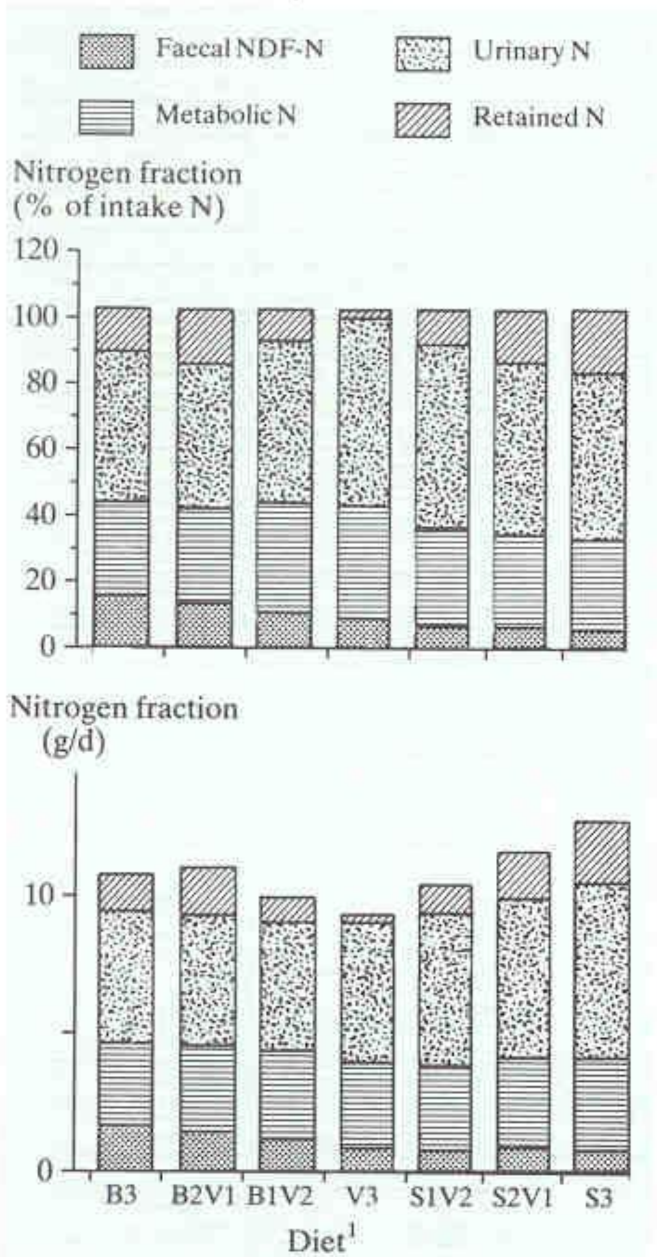


Source: Woodward (1988).

Partioning of intake nitrogen among faeces, urinary and retained nitrogen explains the difference between *S. sesban* and *A. brevispica* (Woodward, 1988) (Figure 3). For diets

including *S. sesban,*urinary nitrogen increased with increasing proportion of browse in the feed, but remained a constant fraction of intake nitrogen. Also, metabolic nitrogen (expressed in g/d) did not vary but decreased as a fraction of intake (Figure 3). Therefore, nitrogen retention increased steadily.

Figure 3. *Partitioning of intake nitrogen (N) for seven diets fed to intact animals.*



[1] Numbers in diet designations refer to proportions of nitrogen provided by *Acacia brevispica* (B), *Sesbania sesban* (S) and *Vicia dasycarpa* (V).

Source: Woodward (1988).

For diets including *A. brevispica,* faecal NDF-N increased by 2% of intake nitrogen with each incremental increase in *A. brevispica.* The loss of nitrogen in urine was much lower for *A. brevispica* than for *S. sesban,* but it was not significantly different between a diet of *A. brevispica plus* vetch and a diet of *A. brevispica* alone. The lower urinary nitrogen loss offset the increased faecal NDF-N loss sufficiently to increase nitrogen retention with the *A. brevispica* and vetch mixture but not with the browse alone. The ability to compensate for a higher loss of faecal nitrogen with a lower loss of urinary nitrogen was observed also by Rittner (1987), ILCA (1988b) and Reed et al (in press).

Digestibility of nitrogen. In non-tanniferous feeds, the true digestibility of nitrogen is approximately 93% (Van Soest, 1982). For browses used in ILCA's experiments, the true digestibility of nitrogen ranged from 52 to 94% (Table 6). Browses with high contents of proanthocyanidins typically had low nitrogen digestibilities, reflecting the ability of these chemicals to bind protein, thereby reducing its availability to the animal.

Table 6*. Nitrogen digestibilities and contents of soluble phenolics and insoluble proanthocyanidins for nine browses.*

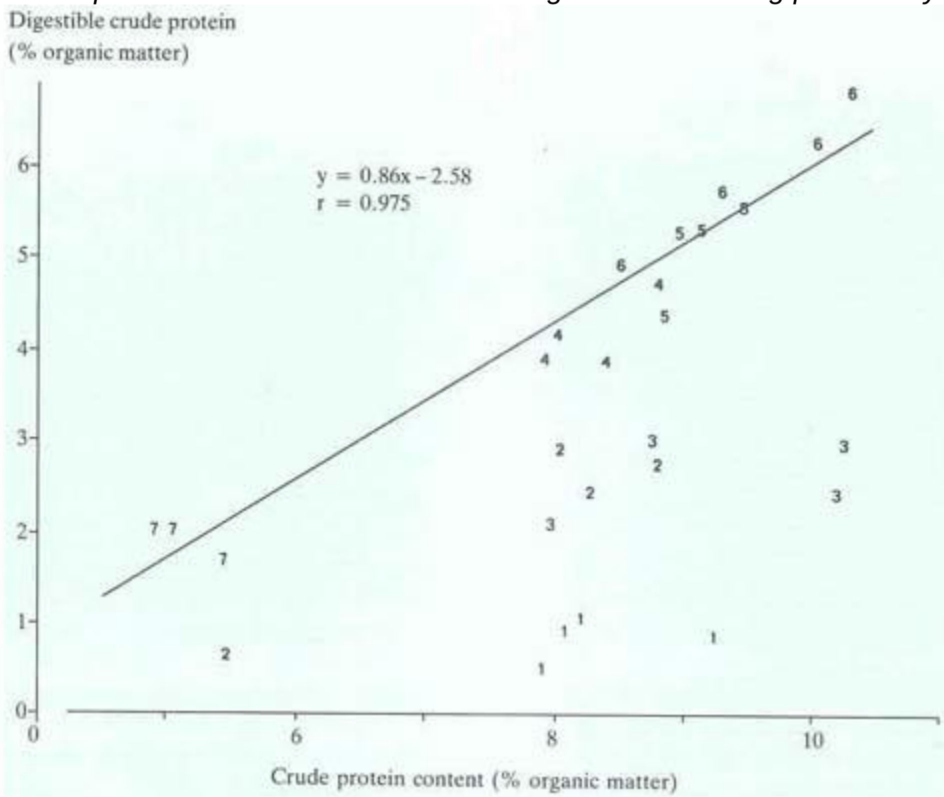
Browse[1]	Nitrogen digestibility (%)							Soluble phenolics (% DM)	Insoluble proanthocyandins (A_{550})
	Source[2]:	Ri	T	I	Re	W	Mean		
Sesbania sesban(l)		92	–[3]	94	90	94	92	17	0.06
Acacia nilotica (l)		90	–	93	–	–	92	34	0.18
Acacia brevispica(l)		–	–	–	–	85	n.a.[4]	24	0.37
Acacia seyal (l)		86	–	84	84	–	85	30	0.30
Acacia tortilis (f)		–	81	–	–	–	n. a.	37	0.31
Acacia albida (f)		–	80	–	–	–	n. a.	36	0.27
Acacia nilotica (f)		–	80	–	–	–	n. a.	44	0.89
Acacia sieberiana(f)		–	70	–	74	–	72	42	0.12
Acacia cyanophylla (l)		–	–	–	52	–	n. a.	39	0.45

[1] Plant parts used were leaves (l) and fruits (f).
[2] Ri = Rittner (1987); T = Tanner (1988); I = ILCA (1988b); Re = Reed et al (in press); W = Woodward and Reed (in press).
[3] Dash (–) indicates that the browse was not studied.
[4] n. a. = not applicable, since only one value is available.

Uniform feed fractions are those fractions for which the digestible amount of the fraction can be related to feed content by a linear regression, with the y-intercept indicating the amount of the fraction which is produced metabolically and appears in faeces (Van Soest, 1982). The true digestibility of uniform feed fractions can be predicted from chemical analysis of the feed, without conducting a feeding trial.

When three tanniferous browses were compared with one non-tanniferous browse and three traditional supplements, the four non-tanniferous feeds fell on a regression line typical of protein (Reed et al, in press) (Figure 4). The three diets including acacias fell below the line, describing non-uniform behaviour caused by the complexing of protein with tannins. The non-uniform behaviour of the protein in browse causes a problem for their use as sources of protein and emphasises the need to understand the chemistry of tannin-protein interactions.

Figure 4. *Regression of digestible amount of protein on protein content, for diets[1] having uniform protein fractions and those including feeds containing proanthocyanidins[2].*



[1] Includes four diets (4, 5, 6 and 7) with non-tanniferous protein supplements.

[2] Refers to diets 1, 2 and 3 which included *Acacia cyanophylla* and fruits of *A. sieberiana* and *A. seyal*, respectively.

Source: Reed et al (in press).

FACTORS AFFECTING THE USE OF BROWSE

Browse is a readily available feed resource and has a role to play in agroforestry. In cropped areas, browse can supplement crop residues, providing animal feed at the cost of the labour needed to harvest it. Most other supplements must be purchased. In grazing areas, browse can provide feed in dry seasons when grass has low nutritional value. The experiments conducted

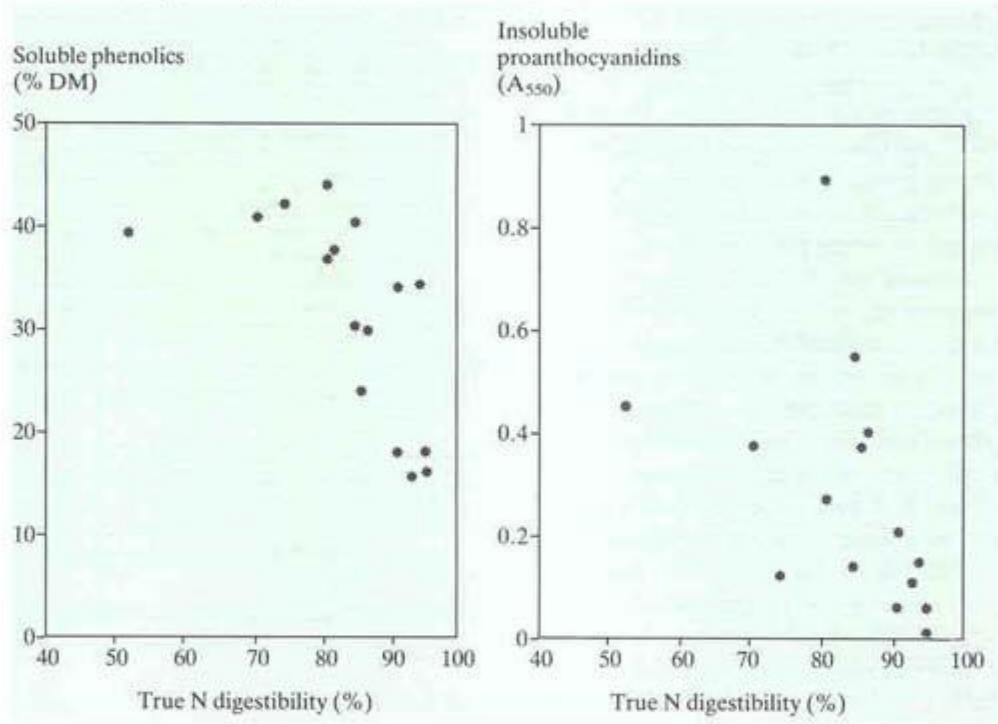
at ILCA highlighted factors that must be considered when evaluating browses for use in livestock systems.

Chemistry of browse

Research at ILCA has shown that polyphenolics in browse, especially proanthocyanidins, affect the availability of protein to, and the nitrogen metabolism of, ruminants. The complexity of tannin chemistry has made it difficult to define chemical fractions that have predictable effects.

The two fractions measured at ILCA, acetone-soluble phenolics and neutra-detergent insoluble proanthocyanidins, have nutritional relevance. However, their effect on nitrogen digestibility, for example, is variable (Figure 5). Hence, it is necessary to look at the effects of individual compounds. This can be accomplished using chromatographic techniques in combination with animal experiments. ILCA has conducted such research, but the determination of the effects of individual compounds is still in the early stages.

Figure 5. *Relationship between soluble phenolics or insoluble proanthocyanidins and the true nitrogen (N) digestibility for browses used in ILCA trials.*



Sources: ILCA (1988b); Tanner (1988); Reed et al (in press); Woodword and Reed (in press).

Effects of browse on ruminants

The studies of browse species at ILCA showed the formation of tannin-protein complexes to be the major effect of polyphenolics in browse, leading to reduced digestibility of nitrogen. The consequences for the animal were an increased faecal nitrogen excretion and a lower rumen fermentation rate.

When an extreme amount of nitrogen was bound, as was the case with *A. cyanophylla*, the animal could not achieve positive nitrogen balance and would eventually starve. When the phenolic content was very low (as with *S. sesban*, for instance), fermentation was so rapid that excess ammonia had to be excreted as urea in urine. This represented loss of nitrogen as well as of the energy required for detoxification.

Most of the other species evaluated in ILCA's studies had effects which were between the extremes described above. Their moderate levels of proanthocyanidins reduced nitrogen availability enough to slow rumen fermentation, thereby resulting in little excess ammonia. The consequently lower plasma urea nitrogen reduced loss of nitrogen in urine. More efficient recycling of plasma urea nitrogen to the rumen may also have contributed to a lower loss of nitrogen in urine. Thus in animals eating feeds with moderate levels of proanthocyanidins, higher faecal nitrogen loss was offset by lower urinary loss. Another advantage of such browses is that the lower fermentation rate of their nitrogen helps improve the utilisation of fibrous crop residues, which also ferment slowly.

The disadvantage is that proanthocyanidins bind protein into complexes, which lowers both the digestibility of crude protein and its availability to animals. The amount of browse offered must, therefore, take into account the lower digestibility of protein. The additional browse needed to provide an adequate amount of protein will depend on the degree to which protein availability is reduced by proanthocyanidins.

Finally, the possibility of animals becoming adapted to browse must be considered. This appears to occur with animals eating *A. seyal*, whose feed intake and performance improved after 7 weeks. Adaptation may be possible with other browses as well, although the mechanism is not understood.

CONSIDERATIONS FOR EVALUATION AND MANAGEMENT OF BROWSES

The concentrations of soluble phenolics and insoluble proanthoeyanidins in browses vary with season (Woodward, 1988), site (Le Houérou, 1980) and individual plant. *Acacia cyanophylla* is an example of regional variation. It has been fed to small ruminants with good results in West Africa (Dumancic and Le Houerou, 1980) but in East Africa, it has proved to be a poor feed (Reed et al, in press).

Evidence for the variation in phenolic concentrations within species and among the collections made for ILCA's experiments is given in Table 1. The reasons for the different concentrations found may have to do with plant strategy for defence against herbivores (Janzen, 1979) or with response to soil and climate (Le Houérou, 1980). In either case, variation must be considered when selecting species and individuals for propagation or when generalising results obtained in one region to another.

In some management systems, browse may be harvested and stored for feeding during the dry season. Rittner (1987) has shown that the effect of storage on phenolic concentration varies with species: the phenolic content of *A. nilotica* was not influenced by storage, but it shifted from the insoluble to the soluble fraction in *A. seyal*. Once again, the need to evaluate individual species is apparent.

With respect to fruits, Tanner (1988) observed that in some cases it may be advantageous to process them to reduce bulk and mechanical damage to the rumen. He also found variation between species in the number of seeds which escape digestion. He suggested that scarification or other treatment may increase the utilisation of fruits from tanniferous browse.

CONCLUSION

The International Livestock Centre for Africa has made good progress in under-standing the positive and negative effects of browse on the nitrogen metabolism of ruminants. Although there is still much to be learned before the nutritive value of browse can be predicted from chemical analysis alone, nutritionally important fractions have been identified. ILCA's research shows that the contents of insoluble proanthocyanidins and soluble phenolics in feed are related to nitrogen digestibility.

Browses with moderate levels of phenolic compounds, such as leaves of *A. brevispica, A. seyal* and *A. nilotica* and fruits of *A. albida* and *A. tortilis,* are promising protein supplements. Although the phenolics in these species reduce nitrogen availability, the negative effect is partially offset by lower urinary loss of nitrogen, allowing adequate animal performance.

Sesbania sesban has low levels of phenolics, typical of such standard high-protein leguminous forages as lucerne *(Medicago sativa). Acacia seyal* is a potentially useful feed if animals are allowed to adapt to it. Animals did not perform well with *A. cyanophylla* leaves and fruits of *A. sieberiana* and *A. nilotaca.* These conclusions cannot automatically be generalised to other areas, but knowledge of the phenolic content of these species from other regions would make it possible to predict performance.

The use of browse can improve animal feeding systems but individual browse species must be evaluated according to their effects on the metabolism of individual animals.

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Trends in on-farm performance testing of cattle and sheep in sub-Saharan Africa

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SUMMARY

THIS PAPER *reviews the need for, and the objectives of, performance testing in the African production environment. The zonal distribution of cattle and sheep populations is discussed, and the major factors limiting animal performance are highlighted. Past, present and future trends in performance testing are then assessed and the advantages and disadvantages of on-farm and on-station performance recording are evaluated.*

INTRODUCTION

Sub-Saharan Africa has a great need and considerable potential for increased production from cattle and sheep. Both species are functionally integrated into farming systems, and there is a clear association between particular breed populations and particular ecological environments. Before animal performance under the prevailing ecological and economic conditions can be improved, detailed information is needed on the specific functions of cattle and sheep in production systems, on their performance potential under different levels of management, and on the current disease situation and feed availability. Such information can be obtained through livestock performance testing on stations and on farms.

This paper summarises past and present experiences with livestock performance testing in sub-Saharan Africa and outlines the role of networks in improving on-farm testing through the use of standardised testing methods and rapid data handling and feedback.

CATTLE AND SHEEP PRODUCTION SYSTEMS

Populations

Sub-Saharan Africa is a diverse ecological environment comprising arid and semi-arid rangelands, subhumid and humid lowlands and temperate highlands, and characterised by an association of specific breed types with particular ecological zones. The distribution of cattle and sheep populations by zone is shown in Table 1, the highest concentrations of these species being in the drier and highland areas.

Table 1. *Distribution of cattle and sheep populations by ecological zone in sub-Saharan Africa (SSA).*

Zone	Land area (% of SSA)	Cattle (%)	Sheep (%)
Arid	36	20.7	35.7
Semi-arid	18	30.6	22.2
Subhumid	22	22.7	13.6
Humid	19	6.1	7.9
Higland	5	19.9	20.6

Source: Jahnke (1982).

About 75% of all livestock in sub-Saharan Africa are kept by smallholders (agropastoralists or mixed crop–livestock farmers), about 20% by pastoralists and only 5% on ranches. African livestock production systems are directed towards economic security and food production. Smallholders and pastoralists aim at maximising returns per unit land area, rather than returns per animal. Specialised production systems are gradually appearing, but only in ecologically and economically favourable areas such as the Kenyan highlands. Most specialised herds are very small, which considerably limits opportunities for within-herd selection.

Livestock have diverse economic and social functions in African farming systems. They provide foods, inputs to crop production in the form of traction and manure, and fibre and skins. Contrary to common belief, most livestock production systems in sub-Saharan Africa are output oriented and cannot be depicted as merely subsistence systems (SEDES/INSEE, 1966; Eddy, 1979; White and Meadows, 1981; Sempeho, 1985; Gryseels, 1988; Danckwerts, n. d.). Animal traction, for example, accounts for about 40% of the gross value of food and non-food outputs of cattle, beef accounts for about 35%, milk for about 20% and manure for about 5% (S. Sandford, ILCA, Addis Ababa, Ethiopia, personal communication).

Performance

Cattle. African cattle can be classed into four major types: the fairly large North Sudan Zebu, the Small East African Zebu, the Sanga of the south and the taurine breeds in West and central Africa (Epstein, 1971). These populations were selected for their multipurpose performance and ability to cope with environmental stress. When raised under extensive management with few external inputs, their performance is characterised by slow juvenile growth, late sexual maturity, long calving intervals and generally modest milk yields (Wilson, 1983; Trail, 1985; de Leeuw, 1986; Otchere, 1986; Wagenaar et al, 1986).

Breed differences seem to be less important for the productivity of African cattle than environmental and management influences. Major production constraints are associated with management and husbandry, the nutrition × disease complex and the seasonality of feed availability, especially in the traditional system with communal grazing. A comparison of all outputs from cattle in Botswana's traditional system and calf weight only from ranches showed that the traditional system is almost twice as productive in liveweight equivalents (9.91 kg/ha/year) as ranching (5.01 kg/ha/year) (de Ridder and Wagenaar, 1984).

Sheep. These are classed into four main types: the small, thin-tailed hair sheep of West and central Africa, the large, thin-tailed hair sheep in the Sahel, the fat-rumped Somali sheep and the fat-tailed hair sheep of East and southern Africa (Ryder, 1984).

Because of the long-term adaptation of sheep to specific environments, their performance matches production conditions. Most sheep in sub-Saharan Africa are aseasonal breeders, and some are also highly fecund. Overall productivity per ewe is largely determined by natural production conditions, but even under unfavourable conditions sheep are more productive on the basis of body weight than cattle (Wilson, 1982; Armbruster, 1987).

The major constraint on sheep productivity is high reproductive wastage (up to 40%) which greatly reduces selection possibilities. More frequent lambing and lower mortality thus need to be emphasised, while increased litter size and growth rate are of lesser importance (Peacock, 1985; Armbruster, 1987).

Management practices strongly influence sheep performance, the differences between flocks exceeding 200% (Peacock, 1987). Reduced performance is often due to a combination of nutrition and disease/ parasite problems which could be tackled through better management. Therefore, a careful analysis of management practices under all production circumstances is desirable.

PERFORMANCE TESTING

Needs and objectives

Performance testing is a goal-oriented, systematic process of collecting and analysing data on economically important performance traits and management practices under defined production conditions. The objectives of performance testing are to:

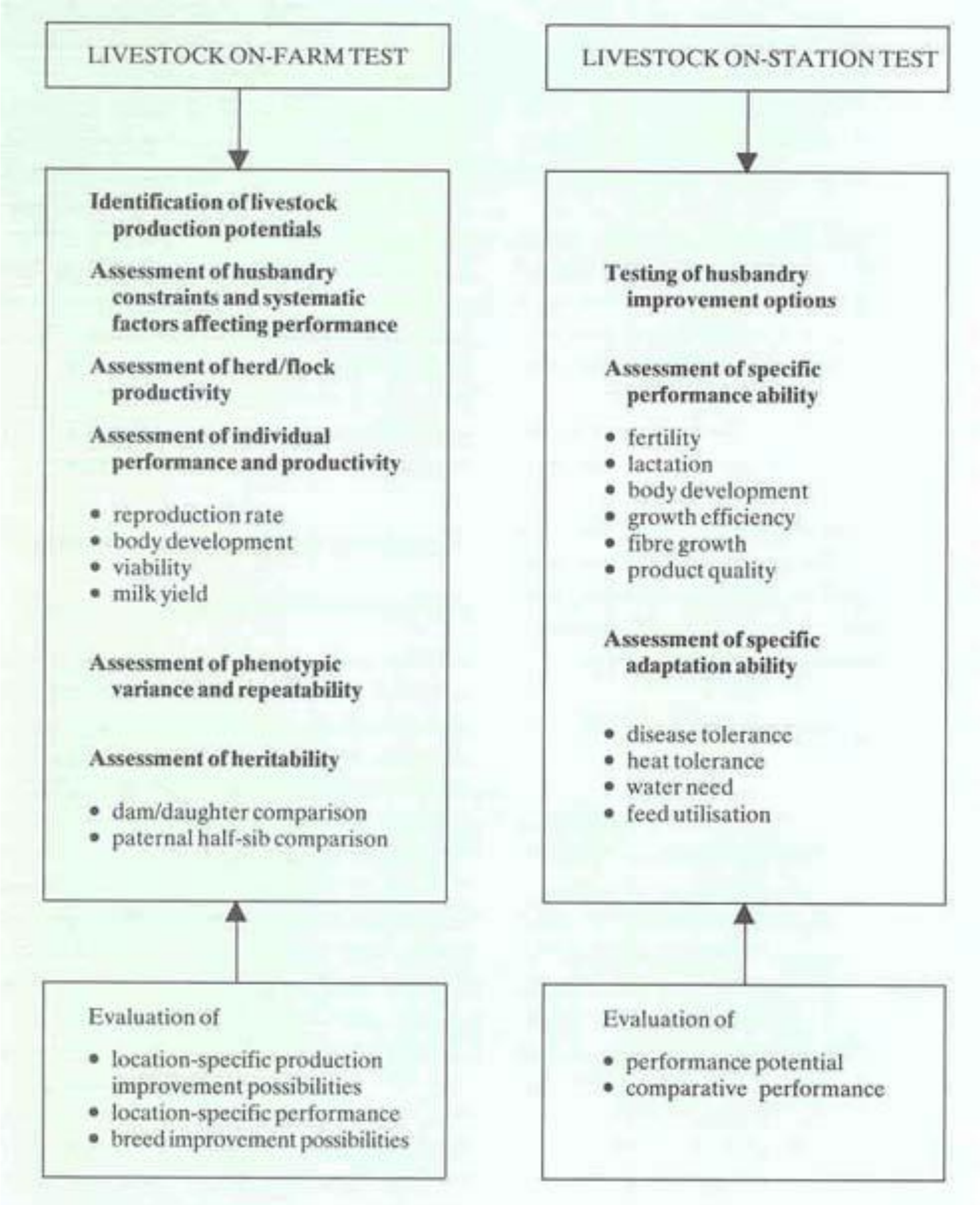
- identify and quantify non-genetic constraints to animal performance in order to improve husbandry, hygiene and feeding,
- facilitate the economic evaluation of the production process and of technical interventions,
- characterise and assess breed performances under defined production conditions,
- contribute to breed improvement through objective selection of breeding stock.

Performance testing is useful and justified only if results are made available to those engaged in livestock breeding and development, i.e. farmers, extension agents, researchers and policy makers.

Approaches to performance testing

The significant long-term effects of management on animal performance, and the immediate impact of improved husbandry, hygiene and feeding, underline the need for on-farm testing. Collecting information on animal performance on the farm makes it possible to identify production prospects, as well as different management variables and their effects on the production process. It is also helpful in identifying problem areas needing more in-depth assessment of cause-effect relationships and production aspects in which improvements can be made (Figure 1).

Figure 1. *Complementarity of on-farm and on-station testing.*



Data on individual reproduction and production traits are required to assess herd/flock productivity and phenotypic variation of traits. However, genetic parameters can only be estimated under controlled breeding, which is difficult to implement on farms because of the small size of farm flocks/herds and mixed herding on communal pastures.

On-farm performance testing provides information on location-specific production conditions and location-specific performance of individual animals or breeds, as well as on breed improvement options appropriate to particular systems. Breed comparisons and assessment of specific performance abilities are essential for evaluating the relative merits of breeds, but these tests are unlikely to be implemented on the farm because they require many animals of several breeds over several years to assess production potential in a single environment.

These conditions are fulfilled in complementary livestock on-station tests, as was demonstrated by the classical beef-cattle breed comparisons implemented in Botswana and Zimbabwe (APRU, 1986; Tawonezvi, 1987; Ward, 1987). On-station trials are required to assess responses of animals to improved management and feeding. However, their accuracy, and hence their relevance to subsequent on-farm performance recording, is usually influenced by genotype × environment interactions.

Trends in performance testing

Past performance testing

A comprehensive review of cattle breed studies in Africa by Trail (1981) listed 500 papers published between 1949 and 1978. Of these, only 20% gave comparative information on two or more breeds and only 5% included information which allowed breed comparisons based on productivity indices. The majority of the papers (56%) related to indigenous cattle breeds, 30% were on crossbreeds and 14% on exotic breeds. Growth was measured in 72% of the papers, reproductive performance in 41%, milk production in 33% and viability in only 18% of the papers. The review did not cover management × animal performance interactions, but there is considerable evidence that one of the most important objectives of performance testing – improved management and production efficiency – received little attention in early testing activities.

Searches on ILCA's in-house database, the FAO Agricultural Information System (AGRIS) and the database of the Commonwealth Agricultural Bureaux International (CABI) identified references to a further 139 studies of on-farm and on-station performance testing of cattle and small ruminants carried out in sub-Saharan Africa between 1978 and 1987 (see Separate Bibliography).

As expected, the number of references found reflected the relative sizes of regional livestock populations: the most numerous were references from East and southern Africa, followed by references from West and central Africa. Predictably, references to cattle (85) outnumbered those to small ruminants (54). For both cattle and small ruminants, on-station testing (47 and 33 studies, respectively) was reported more frequently than on-farm testing (38 and 21 studies).

On-station studies were mainly experimental, while on-farm studies were predominantly diagnostic, aimed at assessing non-genetic constraints to production but often covering only a limited number of factors. Health status was seldom recorded on-station; when it was recorded on-farm, it was not evaluated in relation to performance. More than half of the reports were short-term studies during which it is not possible to assess reproductive performance and viability, nor, for that matter, to evaluate animal productivity and the relative importance of its components.

Objectives. The principal objectives of performance recording on stations and on farms were different and depended on the duration of the study. Short-term experimental and diagnostic studies on stations and all diagnostic testing programmes on farms were aimed at assessing non-genetic factors (excluding disease) and their effects on performance. Genetic factors generally received little attention. This contrasted with the majority of medium- and long-term on-station experiments which were mainly concerned with breed evaluation and related genetic research.

The objective of most on-farm studies was systems analysis to identify non-genetic husbandry constraints; only a small proportion investigated possibilities for genetic improvement. Data on genetic improvement usually came from large-scale commercial farms. Two long-term on-station/ on-ranch breed performance comparisons specifically highlighted the need to evaluate indigenous breeds before embarking on crossbreeding programmes. One of them was done in Zimbabwe, and compared the indigenous Tuli, Nkone and Mashona breeds with Africander, Brahman, Sussex and Charolais cattle (Ward, 1987). The other was done in Botswana by the Animal Production Research Unit and compared the local Tuli and Tswana breeds with Africander (Buck et al, 1982). Both studies indicated the outstanding overall performance of indigenous breeds in beef production.

Implementation. On-station studies were usually financed and executed by the relevant ministries of national governments, with occasional assistance from donor agencies. National governments were also the main source of reports on short- and medium-term studies.

Most long-term studies on-station involved international agencies, such as the International Livestock Centre for Africa (ILCA). The Centre has been a major executing agency for long-term systems studies published in the 1980s, which reflect the change in emphasis from on-station performance testing to on-farm research, stimulated principally by collaborating agencies.

Relevance to production systems. On-station production systems described in the literature invariably include husbandry methods which are not used in the traditional system, such as routine disease control, exotic breeds, restricted breeding season, planted forages and fencing. The experimental results were therefore more relevant to commercial farms than to the predominant traditional sector. Moreover, because of administrative constraints, on-station performance was often below expected levels.

Awareness of the need to direct research towards the prevailing production systems has increased during the past 10 years, with the result that studies now include a diagnostic stage to identify the complex factors influencing output, which is then followed by component research. The increasing number of reports describing livestock performance on farms is a direct result of this change. True on-farm performance recording has been focused on non-genetic factors, but methodologies are being developed to facilitate research on genetic improvement in production systems with small flocks and herds.

Current performance recording

Performance recording is currently being undertaken throughout sub-Saharan Africa, but small ruminant programmes, particularly those implemented on farms, are more common in West Africa, and cattle programmes are more frequent in East and southern Africa (Table 2). Most on-station work is funded and executed by national governments, whereas the majority of on-farm programmes have external participation and/or funding. Most countries have on-station comparisons of breed and crossbreed performances, and generally there are concurrent selection programmes based on the performance testing of a major local breed or breeds.

Table 2. *Current programmes for on- farm and on-station performance recording.*

	Small ruminants		Cattle	
	On-farm	On-station	On-farm	On-station
West Africa				
Benin	D+M+G*	?	?	?
Burkina Faso	D	?	?	?
Côte d'Ivoire	D+M+G*	GS	D+M*	GB+GS
Mali	D+M*	?	?	?
Niger	–	GS	?	GB+GS
Nigeria	?	GB+GS	?	GB+?
Senegal	D+M*	GB+GS	?	?+GS
Togo	D+M+G*	GB+GS*	?	?
The Gambia	?	?	D+M*	GS*
Central Africa				
Burundi	D+M+G*	GB+GS*	?	?
Cameroon	?	GB	?	GB+GS
Congo	D*	GS*	?	?
Gabon	?	?	?	GB+GS
Rwanda	?	GB+GS	?	GB+GS
Zaire	?	?	D+M+G*	?
East Africa				
Ethiopia	D+M*	GB+GS*	D*+?	GB+GS
Kenya	D+M+G*	GB+GS*	M+G	GB+GS
Somalia	D*	?	?	?
Tanzania	?	?	D+M+G	GB+GS
Southern Africa				
Botswana	D+M*	GB	D+M+G*	GB+GS
Madagascar	?	?	D+M+G*	GB+GS
Malawi	?	?	D+M+G	GB+?
Mozambique	D	GB	M+G	GB+GS

Notes: An asterisk (*) indicates external agency participation and/or funding. Question mark (?) indicates a possibility that the particular research was done but was not reported in literature. Dash (-) means that the research was not carried out. D = diagnosis of technical constraints on farms; M = testing/monitoring of management improvements on farms; G = testing/monitoring of genetic improvement on farms; GB = breed comparison on stations; GS = within-breed selection on stations.

Target production systems. The target production system for on-farm performance recording is small-scale, mixed crop-livestock farming. There are two exceptions to this. One is the recording of small ruminant performance and health in the pastoral system of Somalia, which

has been undertaken jointly by the Somalian Government, ILCA and GTZ since 1983 in 200 meat-producing flocks of mixed species. The other is cattle performance recording in countries, such as Kenya and Zimbabwe, which have large-scale beef or dual-purpose (milk and meat) production on ranches and in specialised dairies.

On-farm recording in national beef and dairy schemes is organised as in the developed countries. Daily records of reproductive events, milk yield and/or liveweight are kept by the farmer and these are checked monthly by staff of the coordinating institution. The main objectives of such programmes are to select replacement sires and heifers and to monitor husbandry practices. Contract matings are used to produce artificial insemination bulls.

Phases and their duration. The first phase of performance recording is *diagnostic,* usually lasting 2 to 3 years. Well established programmes subsequently include *on-station intervention testing* of 3 to 4 years, during which *on farm testing* of husbandry, hygiene and breeding interventions is already generally possible. On-farm testing is also backed by breed improvement programmes.

Development projects designed to introduce small-scale dairy units (e.g. in Kenya, Tanzania and Botswana) may have a reduced diagnostic phase. Interventions are tested on-station early in the programme and are released for on-farm testing when proven, which may take between 1 and 5 years. Established technologies can be transferred from other systems in similar locations at the beginning of the project. In dairy development projects, on-farm recording serves primarily the objectives of monitoring and improving management, hygiene and breeding practices. It also serves as a basis for assessing the economic efficiency of the improved livestock production subsystem and its integration into the mixed farming system.

Strategic research in collaborative networks

The preceding examples demonstrated the use of on-farm performance recording to improve location-specific livestock production systems. Other on-farm recording programmes, such as those carried out in Côte d'Ivoire, Ethiopia, Gabon, Gambia and Zaire, contribute to strategic research on animal health and production in the tsetse-infested areas of Africa. Performance recording on farms also plays a significant role in the work of the African Trypanotolerant Livestock Network which brings together scientists from national agricultural research systems (NARS) and from ILCA and the International Laboratory for Research on Animal Diseases (ILRAD) to study the complex interactions which influence trypanosomiasis and its effects on livestock performance.

The research coordinated by the network covers all the major aspects of trypanosomiasis and its control, but focuses on the use of trypanotolerant livestock. Data on tsetse parameters and animal health and production are collected monthly at various network sites, using standard techniques and procedures. These data are analysed monthly, using centralised data processing complemented by on-site computing facilities. The network's coordinating office in Nairobi is staffed by ILCA and ILRAD, and gives technical support to the national programmes through training courses, field supervision and data processing and interpretation. Progress made is assessed at periodic meetings of network collaborators, and on the basis of this assessment, protocols are modified and future research and development programmes are planned (ILCA, 1986; 1987).

The African Trypanotolerant Livestock Network is not the only collaborative research network active in sub-Saharan Africa. There are now others, such as the Small Ruminant Research Network which has collaborative programmes in Congo, Côte d'Ivoire, Ethiopia, Kenya, Mali, Somalia and Togo, and whose objective is to carry out strategic research on small ruminants in such key areas as the economics of production, breed evaluation and improvement, feeding systems, reproductive wastage, and management. Other collaborative research networks being developed by NARS in sub-Saharan Africa are the Cattle Research Network and the Animal Traction Network. As a result of these developments, on-farm recording is expected to expand rapidly in the next 5 years.

FUTURE PROSPECTS

Complementarity of on-farm and on-station testing. Collecting, analysing and using data on technical, economic, biological and genetic parameters is the basis for improving livestock production in Africa. The information available at present is not sufficient to guide system improvement and breeding, despite the positive trend towards system-oriented, on-farm performance testing. On-farm testing programmes are difficult to implement in Africa due to infrastructural problems, lack of funds and constraints linked to the production system (Table 3). In addition, the numerous management structures, practices and skills observed in smallholder and agropastoralist systems greatly increase the number of covariates to be incorporated in the model, and this impairs continuous data recording.

Table 3. *Constraints to on-farm testing of livestock performance.*

Factor	Problem	Solution
Representative sample of households and animals	Covariate distribution (environment, systems, livestock production pattern)	Conduct baseline survey for sample collection
Ownership of animals	Consent to participate	Provide information on objectives of testing and feedback
Owner attitude	Identification of animals	Provide information on objectives of testing and feedback
Animal mobility	Locating herds for performance measurement	Monitor performance frequently and provide feedback
Length of production cycle	Risk of losing animals; effect of covariates	Use large sample size; estimate correction factors
Asynchronous production	Aseasonal breeding	Monitor traits at regular intervals
Management viability	Factors affecting performance	Select sufficiently large representative sample to monitor management pattern
Communal grazing	Mating structure; information on parentage	Identify paternal half-sib groups (blood grouping)
Multiple output	Multipurpose breeds	Measure different traits; assess economic importance; assign biological and economic weightings to individual outputs
Small herd/flock size	Confounded farm and animal effects (if <2 animals/class/farm);	Exclude single-animal farms; correct for farm effects; synchronise production; use

	difficult simultaneous comparisons	grouped herd/flock comparisons
Single-sire herd/flock	Confounded sire and flock/herd effects	Use different sires or artificial-insemination group- breeding schemes

Under these circumstances, success can only be guaranteed by using large stratified samples, regular data collection and efficient data handling to give immediate feedback. Multiple outputs and small herd/flock structures constrain breed performance characterisation and evaluation and reduce the impact of genetic improvement schemes.

On-station testing (as outlined in Figure 1) can only be beneficial if on-station management practices simulate those used on the farms. Similarly, livestock on-farm testing schemes should be complemented by on-station programmes which conform with the ecological environment and management practices prevailing in the field.

Genetic improvement. Genetic improvement schemes must have a field base to be successful. Because of single-sire flocks/ herds, communal grazing and small herd/ flock sizes in the smallholder systems, group breeding schemes with open, nucleus breeding units on stations may continue to predominate in sub-Saharan Africa. Such units must be supported by effective dissemination of the selected improved stock, and of superior sires bred through artificial insemination.

On-station breeding units also may provide the centre for initial gene introduction and for rapid distribution of superior genotypes through multiple-ovulation-embryo-transfer (MOET) schemes, which, as Smith (1988) states, area model for the role of sophisticated technology in improving indigenous breeds and developing production systems. MOET schemes can achieve immediate improvement through selection of foundation animals and attain faster and more effective performance improvement rates, while being able to test for traits difficult to record in the field, such as disease tolerance and feed conversion efficiency.

Data management. Developments in computing are facilitating the handling of performance data and associated information collected in farming systems research and development programmes. Most African countries now have on-site facilities for data entry and preliminary analysis; final analyses and interpretation may, however, need to be done centrally.

Despite advances in computer technology, the lack of effective mechanisms for analysis and feedback of results and recommendations to farmers, researchers and extension agents, remains a major constraint to livestock development in sub-Saharan Africa. The objectives of performance testing can only be achieved if the collected data can be quickly analysed and interpreted and recommendations made and implemented promptly. And only then can farmers, researchers and extension agents collaborate effectively.

To facilitate this process, ILCA has developed a data entry analysis system called IDEAS, which has been distributed to more than 50 research sites in sub-Saharan Africa. IDEAS incorporates both a standardised performance recording system and an analysis system for herd management decisions, and it can interface with software for other analyses that may be required.

The importance of efficient data management and rapid feedback of results cannot be overemphasised, particularly in on-farm testing programmes. These programmes offer the

possibility of effectively integrating microcomputer technology and appropriate software in livestock performance testing, thereby overcoming some of the major difficulties experienced in the past with handling field data and providing feedback.

Organisation of standardised testing. The impact of on-farm testing schemes will be measured in terms of their ability to improve livestock management and productivity. Plasse's (1982) management prerequisites to ensure successful testing programmes are rarely fulfilled under African conditions; rather, most management aspects are part of a complex exercise requiring a systems approach to performance testing if improvement possibilities are to be fully understood.

The systems approach in performance recording combines data on the farm environment (markets, services etc) with those on farm subsystems and on herds/ flocks. It requires a standardised recording approach, a predetermined data recording structure, and an efficient data handling and analysis system. Assigning the development, implementation and analysis of these tasks to collaborative research networks may speed progress, avoid duplication and attract additional funds for on-farm performance testing.

CONCLUSION

About 75% of Africa's livestock are in smallholder farming systems, where they fulfil several functions and are a major source of cash income. Livestock performance can be increased through improved management and output specialisation. However, the production problems identified and the improved technologies proposed must be relevant to the prevailing production system. On-farm comparative breed evaluation, as well as assessment of specific performance ability and technology development, can be complemented by on-station performance testing.

During the last decade, on-farm performance testing was expanded considerably, but on-station programmes were more widely reported. Most of the on-farm tests reported in literature were short-term studies which could not assess the whole production process and often did not match health and management data with performance.

Although on-station breed comparisons are valuable, their application is limited by high costs and genotype × environment interactions**.** These problems can be overcome by widespread on-farm testing within collaborative networks, based on standardised methods and enabling rapid data handling and feedback of results. Complementary on-farm and on-station performance testing organised within networks could also support genetic improvement programmes.

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Interactions between agronomy and economics in forage legume research

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SUMMARY

FORAGE PRODUCTION *techniques suitable for cultivated and fallow land in the subhumid zone of Nigeria are discussed. Integrating forage legumes into the farming systems benefited both soil fertility and structure. Undersowing, inter-row sowing and fodder banks were found to be suitable methods of establishing forage legumes, requiring minimum inputs. The adoption of undersowing and inter-row sowing was found to depend on the relative values of food grain and fodder. Dry season supplementation with forage legumes from fodder banks markedly improved calf survival and helped reduce animal sales due to nutritional distress. Owners of fodder banks also benefited from increased yields of cereals grown in rotations to combat nitrophilous grasses invading fodder banks over the years.*

INTRODUCTION

Lack of dietary crude protein in natural forage is the most serious constraint to ruminant livestock production in the subhumid zone of West Africa (ILCA, 1979). This constraint could be alleviated by feeding forage legumes, provided that appropriate forage production techniques can be identified. There is no single best technique, because the nature and combination of constraints on forage production in the zone vary. Moreover, even in the same ecological circumstances, forage production techniques have to be adapted to suit the varying economic priorities of the intended beneficiaries.

The International Livestock Centre for Africa (ILCA) has, since 1979, conducted multidisciplinary research at its site in Kaduna, Nigeria, to develop suitable forage production techniques. A summary of ILCA's forage research in the subhumid zone is given in Kaufmann et al (1986). This paper highlights the interactions between agronomy and economics in developing forage production techniques for the two main land-use situations in the zone, cultivation and fallow.

MATERIALS AND METHODS

The target group

There are four production systems in the subhumid zone of Nigeria: the pure pastoral system, with cattle and sheep as the main enterprises; the agropastoral system, where cattle production predominates but some cropping is also done; the multiple enterprise system with mainly cropping and some cattle ownership; and the pure cropping system.

Since the problems associated with working with purely pastoral groups appeared to outweigh the expected benefits (ILCA, 1979), sedentarised agropastoralists were initially chosen as the primary target group for ILCA's forage research. However, because of the close link between agropastoralists and crop farmers, both these groups were eventually included in the study. Forage production interventions tested on cultivated land and fallow are described in Mohamed-Saleem (1986a and b).

Constraint identification

Constraints to forage production were identified through literature review, sociological and economic studies and, most importantly, by interacting with farmers involved in the testing of proposed forage interventions. Adoption of forage techniques was found to be limited by all factors of production.

Land ownership. In West Africa, land is owned by indigenous ethnic groups involved mainly in cropping. They have traditional procedures for allocating land for subsistence cropping to non-indigenes (such as the agropastoralists). The granting of land to an immigrant is a privilege which may be withdrawn even after the person has been resident in the area for a long time. Transient land ownership thus constitutes a major constraint to sustained forage production by agropastoralists.

Labour. Despite their professed greater interest and major investment in cattle, labour for cropping is high on agropastoralists' list of priorities. Demand for labour is greatest during planting. This is so because, although total annual rainfall is fairly reliable in the subhumid zone, the early rains can be very erratic and the soils are prone to surface capping, which makes them virtually impossible to till until the rains have started. Moreover, labour for hire is scarce at planting time, and so all the family labour available is used to plant cereals for subsistence.

Capital. Lack of capital to invest in forage production is another constraint. Compared with farmers, agropastoralists in the subhumid zone of Nigeria are rich, the value of their herds often exceeding US$ 7000. Under a free-access grazing system, owners do not get any benefit by reducing stocking rates. If there are no significant opportunity costs to be realised by reducing herd size, and if, in addition, the rate of inflation is high, then it makes good financial sense to keep animals as long as possible because owners can earn more from price appreciation than from any other investment. The greatest risk owners face is calf and young-stock mortality. However, the mortality of animals which have survived to maturity is low, and there are always butchers ready to buy sick animals before they actually die.

Management. Although agropastoralists are aware of the value of crop residues as supplementary feed, they do not grow plants specifically to feed their animals. They grow cereals and non-cereal crops in rotations, but this is because rotating the crops helps maintain soil fertility and control *Striga hermonthica,* a plant parasite which attacks the roots of cereals.

Agropastoralists are also fully aware of the beneficial effects of fallowing on soil fertility. However, because clearing new land for cultivation is hard work, fallowing becomes less attractive in communities from which many young people have emigrated to towns. The older farmers are prepared to accept low yields, presumably because this gives them a higher return per unit of labour.

SOURCES OF SUPPLEMENTARY FEED

A possible source of crude protein is the agro-industrial byproduct, cottonseed cake, which might be purchased with cash obtained from sales of surplus sorghum. However, agropastoralists do not have sufficient labour and land to produce enough sorghum grain for sale, and cottonseed cake is not readily available. Purchasing supplementary feeds is thus not a practical solution, except for a small fraction of herd owners. Supplementing animals with legume forages grown on cultivated land and on fallows improves their nutrition, and the production techniques developed are within the reach of smaller producers.

Interventions on cultivated land

The first attempt at introducing fodder plants on cultivated land was by way of undersowing the most readily available forage legume, *Stylosanthes hamata cv* Verano, under the most widely grown cereal, *Sorghum bicolor.* The undersowing technique was chosen because it does not require any extra labour for land preparation for the forage.

Ideally, the legume should be planted at the same time as the sorghum so as to minimise labour input, but stylo then fiercely competes with sorghum for light and nutrients. If, however, the legume is planted 3 to 6 weeks after sorghum, reductions in sorghum grain yields are minimal (Table 1).

Table 1. *Break-even sorghum grain:stylo price ratios for different undersowing times, Kurmin Biri, Nigeria, 1980–82.*

Planting pattern	Sorghum		Stylo dry matter (kg/ha)	Available CP[1](kg/ha)	Break-even sorghum grain:stylo CP price ration
	Grain yield (kg/ha	Crop residue (kg/ha)			
Undersowing in 1980					
Sole sorghum	1226	7503	n.a.[2]	180	ng1[3]
Stylo undersown					
With sorghum	357	1303	4010	490	1.00:2.80
3 weeks after	1224	3719	1729	281	1.00:0.02
6 weeks after	1287	4260	702	178	ngl
9 weeks after	1240	3919	408	142	ngl
Undersowing in 1981					
Sole sorghum	2192	8796	n. a	255	ngl
Stylo undersown					
With sorghum	480	2367	4334	592	1.00:5.08
3 weeks after	1550	3524	3215	493	1.00:3.54
6 weeks after	1918	5385	2464	415	1.00:1.71
9 weeks after	1980	7463	456	283	1.00:7.57
Inter-row sowing in 1982					
Sole sorghum	1491	6159	n. a.	188	ngl
Intercropped stylo	1390	5262	1803	410	1.00:0.45

[1] CP = crude protein.

[2] n.a. = not applicable.

[3] ngl = no grain loss.

Source: Adapted from Mohamed-Saleem (1986a).

Whether or not undersowing is adopted depends also on the relative values of crude protein (CP) from grain and stylo. Table 1 shows that undersowing stylo 3 to 6 weeks after sorghum gives as attractive grain: stylo CP price ratios as sole grain production.

The competitive effect of simultaneous undersowing can further be reduced by changing the crop geometry from mixed sowing on one row to planting stylo and sorghum on alternate rows. This technique, known as 'inter-row' sowing, has been tested by ILCA as an alternative to undersowing.

Inter-row sowing is possible because traditional planting rates in the subhumid zone of Nigeria are very low, ranging from 30 000 to 40 000 plants per ha. To increase grain yields under sole cropping, a population density of about 120 000 plants per ha would be required, but such high plant densities cannot be recommended to the farmers because they traditionally intercrop cereals with soya bean. When the grain crop is planted at twice the traditional seeding rate on every second ridge, the total grain plant population traditionally accepted per hectare can be maintained, while freeing alternate ridges for forage legumes. In addition, inter-row sowing (Figure 1) does not affect grain yields per hectare.

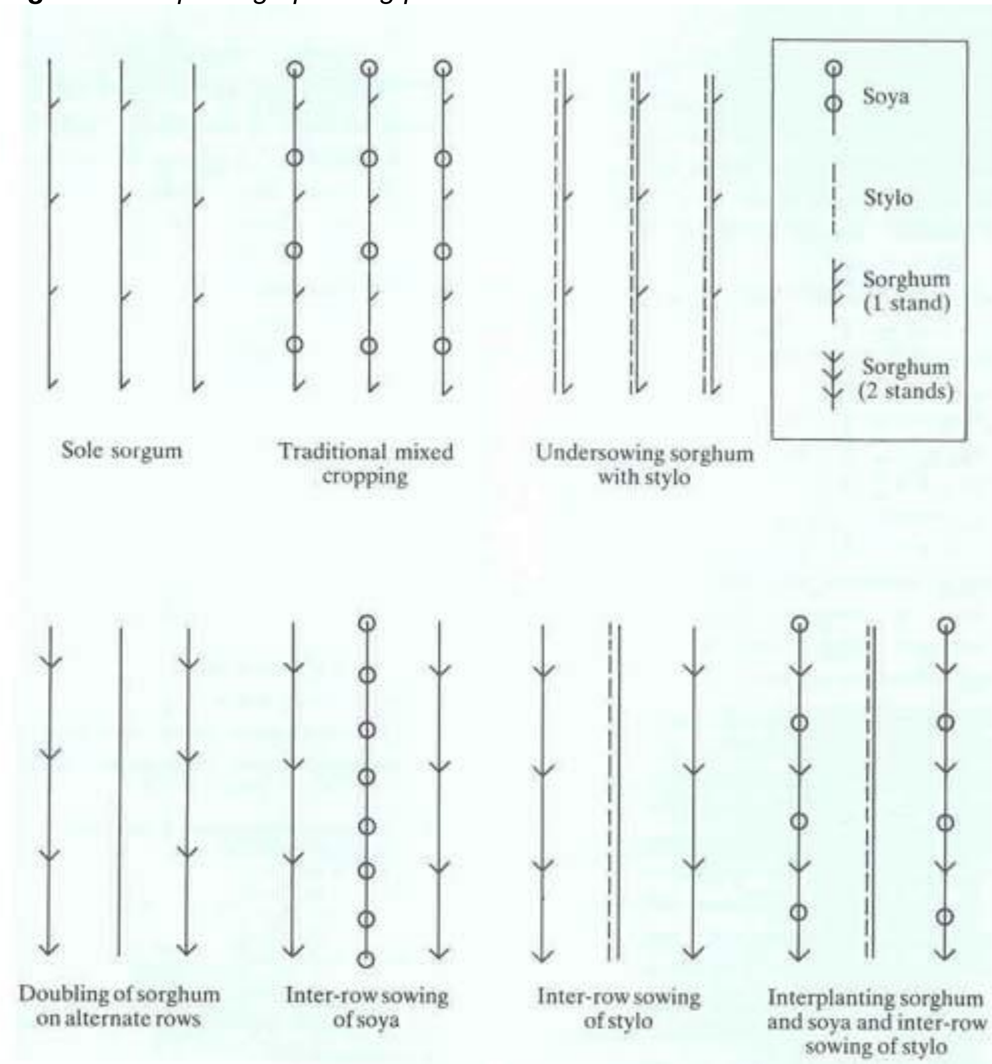
The data in Table 1 suggest that when sole-crop sorghum yields are low, undersowing and inter-row sowing are very attractive techniques, but when, as in 1981, sorghum yields are higher, the additional crude protein from stylo would have to be very valuable for the techniques to be adopted. Undersowing and inter-row sowing would thus appear to be most appropriate in the last year of rotations, when they would have the additional advantage of being a cheap method of establishing legume fallows.

The price ratios given in Table 1 do not include the labour involved in planting stylo. Although the operation is not very laborious, any additional labour demand is unwelcome, especially during the period 3–6 weeks after initially planting sorghum while more sorghum and other crops are still being planted. To overcome the problem of additional labour demands, ILCA conducted trials with other legume species which are less competitive than stylo in the early days after planting. It was found that *Centrosema pascuorum, Alysicarpus vaginalis* and *Macroptylium lathyroides* could be planted simultaneously with sorghum without depressing grain yield.

While crop competition after planting limits the utility of undersowing, interrow sowing is of little interest to the agropastoralists because of the small size of their fields. A typical agropastoralist owns 50 head of cattle and cultivates 1.5 ha of land. Assuming that he can undersow half his cultivated land with legumes, expecting a dry-matter yield of 4000 kg/ha of which 50% may be consumed by cattle, then, if stylo averages 9% crude protein, 2.5 kg dry matter would be required to provide a minimal supplement of 0.25 kg crude protein per head per day. The agropastoralist would thus have produced sufficient food for only 5 animals over the 180-day dry season.

Another problem is selecting the animals which should be supplemented. Agropastoral herds are management units owned collectively by several members of a household, and any management practice proposed must be acceptable to all those who have a vested interest in the herd. In the circumstances it would be invidious, if not socially impossible, for the nominal head of the household to select just a few animals for supplementation. And since the small fields of the agropastoralists cannot possibly supply enough forage for all their animals, agropastoralists would probably continue to depend on crop residues produced on the much larger and more numerous farmers' fields.

Figure 1. *Crop forage planting patterns.*



Farmers have not shown much interest in undersowing and inter-row planting, because they do not gain any financial benefit from growing forages. In parts of the subhumid zone where cattle are still rather scarce and competition for crop residues is not yet keen, farmers pay agropastoralists to bring their cattle to the fields to deposit manure and clear stubble and weeds. How ever, this is likely to change as population pressure builds up and competition for land intensifies. In all heavily cultivated areas, cattle owners are obliged to pay for crop residues produced on farmers' fields, which makes undersowing or intercropping forage legumes more attractive to farmers.

INTERVENTIONS ON FALLOW LAND

According to Young and Wright (1980), at least 30% of the land in the subhumid zone should be under fallow to restore fertility and sustain crop yields. Natural grasses and forbs are not very good fallows because they do not grow vigorously. The soil tends to be exposed to high surface temperatures and surface erosion for long periods, and the grass roots are not very effective in maintaining sufficient levels of organic matter in the soil. In addition, the poor grazing value of indigenous grasses limits the economic use of the land during the fallow period.

Soil fertility and the quality of grazing could be improved by introducing forage legumes into natural fallows. Early during the testing of the technique the question arose whether or not stands of forage legumes sown on fallows should be enclosed. ILCA's first attempt to produce forages without fencing failed, and so did government range improvement schemes. Then, when the idea of fencing was introduced, there were doubts as to whether agropastoralists would be permitted to erect fences round improved fallows, as this would convey a certain degree of permanence and suggest private ownership. However, it soon became apparent that deciding on how big an area should be enclosed was more crucial than fencing itself.

The area of fallow set aside for forage production would, naturally, depend on the pressure on land for cultivation but, in general, it was assumed to be no greater than about twice the area of land traditionally cultivated by landowners. Given an average farm size of about 2.5 ha (Powell, 1986), the effective limit on even large areas of unused fallow would thus appear to be about 4 ha.

Besides the size of enclosures there were two other critical management issues to be resolved - land preparation for the forage crop and grass control. Potential solutions to these problems were found by observing the behaviour of herds. For example, animals confined in a kraal overnight destroy vegetation with their hoofs and break the surface of the land, and this gave the researchers the idea of using cattle to prepare land for forage crops. Also, cattle's preference for grass over young legume plants could be exploited for the control of fast-growing grasses that tend to smother young legumes (Otsyina et al, 1987).

Based on these observations, confined units of intensive forage production, also known as fodder banks, were designed to meet the following economic objectives of agropastoralists:

- increased cow productivity and calf survival
- increased total herd welfare and elimination of distress sales
- increased crop yields, and
- increased security of tenure.

The cost of establishing and maintaining a 4-ha fodder bank are shown in Table 2. A comparison of the recurrent cost of producing 1 kg of crude protein from fodder banks with the market price of an equivalent amount of crude protein in cottonseed cake showed that crude protein from fodder banks is cheaper (Table 3). Besides, depending on cottonseed cake is riskier than depending on fodder banks, because the supplement is not always on the market and its price is subject to inflation.

Table 2. *Capital and recurrent costs of a 4-ha fodder bank with metal fencing, subhumid Nigeria, 1989.*

Input	Establishment			Maintenance	
	Unit	Cost/unit (₦[1])	Total cost (₦)	Requirement	Cost (₦)
Fencing	800 m	5.50	4400.00	10% replacement	440.00
Seed	40kg	15.60	624.00	25% reseeding	156.00
Fertilizer	600 kg	1.20	720.00	600 kg	720.00
Labour	40 man-days	5.00	200.00	20 man-days	100.00
Total cost			5944.00		1416.00

[1] ₦= naira; US$ 1 = ₦ 7.3 (1989).
Source: ILCA (International Livestock Centre fog

Table 3. *Costs of obtaining crude protein from a 4-ha fodder bank and from cottonseed cake, subhumid Nigeria, 1989.*

Item	Quantity or amount
Fodder bank (4 ha)	
Dry matter produced	16 000 kg
Dry matter available	8 000 kg
Crude protein (CP) content[1]	720 kg
Capital cost	5 944 ₦ [2]
Recurrent cost	1.96 ₦/kg CP
Cottonseed cake	
Crude protein	720 kg
Required dry matter at 30% crude protein content	2 400 kg
Capital cost	0
Recurrent cost [3]	2.27 ₦/kgCP

[1] Assumes 9 % crude protein content in available dry matter.
[2] ₦=naira; US$1=₦7.3 (1989).
[3] Calculated as ₦680/t of cottonseed cake, at 30%crude protein.
Source: ILCA (International Livestock Centre for Africa), Kaduna, Nigeria, unpublished data.

A more complete financial appraisal of fodder banks required that their capital and recurrent costs be compared over time with the value of improvements obtained in animal productivity due to dry-season supplementation. The benefits realised were determined in a 5-year study of more than 2000 head of cattle in 40 cooperating agropastoral herds (Table 4). Forty per cent of the herds had access to fodder banks of reasonable quality and were classified as supplemented. The rest of the animals were classified as unsupplemented, although owners

may occasionally have purchased feeds and their animals may have had occasional access to fodder banks.

Table 4. *Effect of dry-season supplementation on the productivity of Bunaji cattle under traditional management, subhumid Nigeria, 1979–84.*

Character	Unsupplemented herds	Supplemented herds	Improvement (%)
Cow survival (%)	92.2	96.0	4.1
Calving rate (%)	53.8	58.1	8.0
Calf survival (%)	71.8	86.3	20.2
Calf weight (kg)	98.1	103.4	5.4
Milk offtake/lactation (kg)	300.2	312.5	4.1
Productivity index[1] (kg)	51.5	69.1	34.2

[1] Productivity index = weight of 1-year-old calf + liveweight equivalent of milk/cow/year.
Source: ILCA (International Livestock Centre for Africa), Kaduna, Nigeria, unpublished data.

Dry-season supplementation had a major effect on calf survival through increased milk production. The low increase in milk offtake for consumption suggests that the first priority of the owners was indeed increased calf survival, not milk for human consumption. The 8% improvement in calving rate is remarkable considering that the increased fertility of dry cows was counteracted by the protracted lactational anoestrus of the cows whose calves would have died if the dams were not supplemented. However, Otchere (1986) found a lengthening of the calving interval 2 years after supplementation was started, indicating that the fertility response took longer to manifest itself than the lactational anoestrus effect.

Early in the study it was observed that participating herd owners were not following the management strategies recommended by researchers. In particular, they did not restrict fodder banks to pregnant and lactating cows, which had been identified in the pre-study modelling as the best strategy to increase herd productivity. The use of fodder bank was restricted to a few hours per day during the dry season, but all animals were allowed on the fodder bank at the same time. This 'equal treatment' was at first attributed to the complex ownership patterns among agropastoralists, but analysis of herd offtake showed that owners with fodder banks were less likely to have to sell distressed animals than those without.

The initial constraint analysis had not revealed the fact that, each year, animals had to be sold due to nutritional distress. Since avoiding this problem appeared to have a more immediate benefit than, for instance, increased calf survival which could be realised in cash terms only after several years, the economic role of feed supplementation had to be reassessed.

The analysis also has to take into account the fact that fodder banks tend to deteriorate over the years. This is so because increasing soil fertility encourages an invasion of nitrophilous grasses and forbs that compete with stylo. The invasion could be combated by rotational cropping with cereals, which would have the added benefit of increasing crop yields which must be compared with the cost of foregone stylo.

The economic viability of fodder banks has been appraised using a model which, despite problems of collecting data on agropastoral herds, can simulate fairly well the consequences of supplementation on livestock productivity over time (von Kaufmann et al, ILCA, Kaduna, Nigeria, unpublished data). The model accounts for important factors which are time-related to animal productivity, and is, therefore, more useful than such economic tools as gross margins and linear programming. It was validated by comparing predicted and actual offtake from the herds, recorded by scientists other than those who designed the model.

The analysis was based on 1989 market prices, with the price for milk being rather conservative to ensure that the model applies to rural producers who, because of their remoteness from urban markets, cannot sell milk at the best price obtainable. Its results indicated that fodder banks could be attractive investments (Table 5). Owners of fodder banks could benefit from reduced forced sales and increased crop yields. Stylo regenerates under the crop, so it is possible to have a rotation, whereby cropping continues around the fodder bank. In addition, stylo makes the soil easier to work, thus reducing labour for tilling (Tarawali et al, 1987).

Table 5. *Economic returns on fodder banks in subhumid Nigeria over 10 years[1].*

	Net present value[2] (₦[3])	Internal rate of return (%)	10th-year herd value		10th-year incremental net revenue (₦)
			Without fodder bank (₦)	With fodder bank (₦)	
Improved herd productivity (IHP)	1 414	22.5	49 907	90 833	4 950
IHP plus reduced forced sales	7 538	34.1	49 907	90 833	7 138
IHP plus increased crop yields	9 395	36.3	49 907	90 833	8 544

1 In 1989 prices.
2 Calculated at 20 % discount rate.
3 ₦ = naira; US$ 1 = ₦7.3 (1989).
Source: ILCA (International Livestock Centre for Africa), Kaduna, Nigeria, unpublished data.

CONCLUSION

Cattle productivity in the subhumid zone of Nigeria can be improved by supplementing animals during the dry season with crude protein. Growing forage legumes on the farm was perceived to be more advantageous than purchasing cottonseed cake and other protein supplements on the market, because they are costly and their supplies are highly erratic. But apart from this, incorporating forage legumes into the prevailing farming system has the advantages of increasing soil fertility and improving soil structure so that tilling becomes less laborious.

Although ecologically suitable forage production techniques were developed for both cultivated land and fallows, the adoption of these techniques depended on their economic viability. An economic evaluation of undersowing and inter-row sowing showed that these techniques are profitable if used in the later stages of crop rotations when grain yields are low. They were more

likely to be adopted by farmers in highly populated areas where the numbers of livestock are high and the competition for crop residues is keen.

Establishing fodder banks on fallows appears to lie a particularly attractive investment. Based on recurrent costs, crude protein produced in fodder banks is cheaper than protein purchased in the form of cottonseed cake. Dry-season supplementation of animals has a long-term financial benefit in the form of increased animal sales due to increased calf survival. It also helps reduce nutritional distress, thereby reducing financial losses due to forced sales. Owners of fodder banks also benefit by increased crop yields due to the increased soil fertility in fodder banks.

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