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# Feed Utilization Strategies for Improved Ruminant Production in the Arid Region

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**Abstract:** This review scans through the attributes of feed resources prevalent in the arid and semi-arid zones (ASAZ). The merits of the various biological and chemical attributes of feeds are discussed with a view to suggest those that could yield suitable and reliable indices for selecting potential feedstuffs among forage legumes. The review contends that besides protein content, the rate of degradation and bulk density are two other legume factors that determine the extent of substitution of the basal roughage diet which will vary in direct proportion with roughage quality. The appropriate combinations of roughage and supplements have been advocated for sustainable livestock production in the ASAZ. Whilst most legumes contain more protein than is required to balance the fermentable energy in them and thus are suitable as supplements, their ability to supply both rumen degradable protein and escape protein is varied. The review argues that the slow uptake of supplementation strategies among others is due to unsurmountable logistics which can be eased by creating feed or protein banks. In relation to issues on feed availability the authors suggest that the use of feed resource on a regional scale could be maximized by (1) integrating weather information and satellite images to forecast feed distribution patterns and (2) encouraging the establishment of communal silage pits. Pertinent researchable issues were highlighted.

**Key words:** Arid zone, forage legumes, supplementation strategies, roughage, ruminants.

Jahnke (1982) defines the arid and semi-arid zones (ASAZ) as areas with less than 90 and 90-179 plant growing days (PGD), respectively. The significance of ASAZ, particularly of Africa, is manifested by the high human habitation (46%) and livestock agricultural activities (58%) (Jahnke, 1982). The ASAZs are characterised by low and irregular rainfall (500 mm), high temperature (about 30-52 °C) and poor soils (Payne, 1990).

The intensity of crop and animal farming is low, but certain climatic factors such as ambient temperature, effective rainfall, length of daylight and intensity of solar radiation limit plant growth and hence the quality and quantity of animal feed. The short and erratic rainfall patterns dictate the cultivation of crops with short gestation length, implying less grain and crop residue

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production. In addition, the poor soils and low rainfall cannot support adequate growth and production of forages and browse legumes. Furthermore, these plants have developed certain phenotypic (thorns, thick foliages) and genotypic (secondary chemicals and antinutritional compounds) properties as survival instincts against the harsh environmental conditions, virus, fungus and insects (Salunkhe *et al*., 1990). The fragility of this zone as regards ruminant production is further constrained by the abundance of tsetse flies which cause trypanosomiasis. These limitations are supported by the high land-livestock ratio (11.5 ha/Tropical Livestock Unit (TLU) vs. an average of 4.5) and the low persons per TLU compared to the other ecological zones (Jahnke,1982).

The importance of the contribution of livestock to the employment opportunities and to the nutritional status of the inhabitants of this zone is real and therefore problems associated with the keeping of livestock need to be addressed from a multi-disciplinary perspective. Effective mechanisms are needed to manage the meagre feed resources available to enhance efficient utilization by ruminants. This review will chronicle previous research findings which can be adopted by farmers and researchers to improve livestock production and income generation for the farm family. Particular emphasis will be placed on the arid zones of Africa, though the results can be extrapolated to solve livestock production problems of arid zones in Western Asia, India, Northern Australia and the Americas.

## Nutritional Attributes of Common Feeds

Ruminants in the ASAZs are faced with a variety of feeds throughout the year and at times have to cope with qualitative and quantitative deficiencies. Livestock in this region subsist predominantly on native pasture hays and cereal crop residues which, generally, are low in quality and obligatorily have to be supplemented if any meaningful production level is expected. The latter derives from the fact that roughages are deficient in nutrients (nitrogen, sulphur, phosphorus and other minerals) that are essential for intense microbial activity in the rumen and for the host animal's metabolism. Animals are supplemented with either conventional concentrates (oilseed cakes, brans, middling, molasses) and/or with unconven-

*Table 1. Variation of chemical constituents and intake of unsupplemented roughages fed to sheep and cattle*

| Source | No. | Nitrogen | NDF | Lignin | Intake |
|---|---|---|---|---|---|
| **Sheep** | | | | | |
| Nsahlai and Umunna (1996b) | 12 | 5-11 | 635-793 | 41-154 | 17.4-29.1 |
| | 4 | 11-19 | 551-670 | 38-50 | 26.8-29.1 |
| Mosi and Butterworth (1985) | 4 | 3.7-9.9 | 712-775 | 48-66 | 19.7-26.6 |
| Umunna *et al.* (1995) | 2 | 7.9 | 615 | – | 26.2-28.2 |
| Bonsi *et al.* 1994) | 1 | 5.4 | 790 | 41 | 24.9 |
| **Cattle** | | | | | |
| Abule *et al.* (1995) | 1 | 5.2 | 781 | 52 | 15.6 |
| Umunna *et al.* (1995c) | 3 | 7.4-10.7 | 658-784 | 37-58 | 21.2-22.9 |
| Nsahlai *et al.* (unpubl.) | 10 | 5.4-12.2 | 627-777 | 15.0-30.0 | – |

*Table 2. Characteristics of cluster members of roughages*

| | Cluster one | | Cluster two | | Cluster three | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| Nitrogen | 9.9 - 15.2 | 11.2 | 6.6 - 9.1 | 7.8 | 3.0 - 6.1 | 5.0 |
| Organic matter | 848 - 931 | 905 | 860 - 934 | 900 | 830 - 935 | 901 |
| NDF | 551 - 760 | 650 | 615 - 804 | 715 | 619 - 825 | 753 |
| ADF | 333 - 594 | 403 | 402 - 513 | 453 | 386 - 543 | 449 |
| Lignin | 32 - 110 | 52 | 42 - 77 | 60 | 44 - 66 | 52 |
| Ash | 69 - 152 | 95 | 66 - 140 | 100 | 65 - 170 | 99 |

tional feeds such as forages of herbaceous or tree legumes and other non leguminous browses. Roughages and pastures form the bulk of feed for livestock in this region and it will therefore be appropriate to scan through their peculiarities.

### *Nutritive characteristics of pastures and roughages*

Table 1 demonstrates the variation in the nitrogen, neutral detergent fibre (NDF) and lignin content of roughages as presented in a variety of reports. The intake of non-supplemented roughages (g kg$^{-1}$ live weight) are within the ranges 17-29 for sheep and 16-23 for cattle. This variation in intake would naturally elicit varied levels of productivity. Consequently, feeding of non-supplemented roughages such as teff straw resulted in live weight losses in sheep and cattle while other roughages like oat/vetch or oat hay elicited modest levels of gains (Umunna *et al.*, 1995b,c). It is, therefore, possible that in order to meet requirements for a given level of productivity the required amount of a given supplement is dependent on the quality of the basal roughage. Since it is impossible to study all combinations of roughages and supplements, an accepted strategy would be to put roughages into groups based on some common characteristics and measures of nutritive quality.

Information on the biological indices of nutritive value of tropical feeds is scarce; as such the feeds would be grouped based on chemical attributes. The validity of such classes is assured because some attributes such as N or NDF have been shown to relate strongly with intake and digestibility of roughages (Nsahlai and Umunna, 1996b). A similar inference can be made from the report by Mosi and Butterworth (1985). Nitrogen content in the roughage was the only variable reported in most studies consulted. The inclination was to use N as the delineating variable when grouping roughages using Ward's minimum variance cluster analysis (SAS, 1987). A three cluster solution was selected based on the pseudo-T statistics and is given in Table 2. The N content decreased from cluster one through two to cluster three. The NDF and acid detergent fibre (ADF) contents in roughages followed the reverse trend. Cluster one roughages had the highest quality while cluster three had the lowest.

## Nutritional Attributes of Major Forage Legumes

The wide spectrum of supplements available in the region (including forage legumes)

*Table 3. Chemical composition, in vitro digestibility and synchronization indices of soluble (A-index) and insoluble slow-degrading (B-index) nutrients of some forage legumes*

| Forage type | DM | CP | NDF | IVOMD | N:IVOMD | A-index | B-index |
|---|---|---|---|---|---|---|---|
| | | | **Herbaceous legumes** | | | | |
| *Centrocema pascorum* | 27.4 | 18.4 | 51.6 | 73.5 | 4.0 | 1.86 | 1.72 |
| *Cenrocesma plumeri* | 27.2 | 15.7 | 53.4 | 70.1 | 3.6 | 1.07 | 1.32 |
| *Desmodium intortum* | 20.6 | 19.4 | 43.1 | 53.2 | 5.8 | 1.47 | 1.30 |
| *Lablab purpureus* | 17.1 | 18.9 | 44.8 | 67.0 | 4.5 | 1.93 | 1.19 |
| *Lotus corniculatus* | 18.0 | 18.4 | 37.6 | 73.0 | 4.0 | 1.64 | 0.95 |
| *M. atropurpureum* | 22.6 | 20.5 | 57.5 | 59.7 | 5.5 | 2.94 | 0.57 |
| *Medicago sativa* | 26.7 | 19.3 | 35.7 | 70.9 | 4.4 | 1.84 | 0.96 |
| *Medicago polymorpha* | 16.8 | 20.7 | 42.9 | 69.1 | 4.8 | 2.10 | 1.33 |
| *Stylosanthes guianensis* | 21.3 | 17.9 | 49.3 | 59.8 | 4.8 | 1.05 | 1.17 |
| *Stylosanthes hamata* | 26.4 | 20.4 | 44.8 | 70.6 | 4.6 | 1.19 | 0.86 |
| *Trfolium pratense* | 23.3 | 15.4 | 43.5 | 66.6 | 3.7 | 1.22 | 0.98 |
| *Trifolium rueppellianum* | 18.0 | 16.6 | 48.5 | 63.2 | 4.2 | 1.19 | 1.09 |
| *Trifolium repense* | 24.5 | 16.2 | 43.6 | 73.5 | 3.5 | 1.22 | 0.85 |
| *Trifolium tembense* | 20.7 | 19.4 | 46.6 | 72.3 | 4.3 | 1.84 | 0.87 |
| *Vicia atropurpurea* | 27.7 | 23.5 | 39.1 | 65.5 | 5.7 | – | – |
| *Vicia dasycarpa* | 16.3 | 25.9 | 42.0 | 73.6 | 5.6 | 2.55 | 1.30 |
| *Vicia sativa* | 23.5 | 18.9 | 44.5 | 60.4 | 5.0 | 1.30 | 1.30 |
| *Vicia villosa* | 24.1 | 21.4 | 46.5 | 66.3 | 5.2 | 1.96 | 1.10 |
| **Mean** | – | 19.3 | – | 67.1 | 4.6 | 1.66 | 1.07 |
| | | | **Browses** | | | | |
| *Cajanus cajan* | 31.9 | 23.0 | 47.5 | 47.7 | 7.7 | 1.32 | 1.72 |
| *Chamaecytisus palmensis* | 40.0 | 18.0 | 53.3 | 71.0 | 4.1 | 1.07 | 1.32 |
| *Gliricidia sepum* | 27.9 | 21.3 | 64.4 | 53.7 | 6.4 | 2.09 | 1.56 |
| *Leucaena leucocephala* | 35.6 | 21.0 | 34.3 | 55.2 | 6.1 | 0.95 | 1.68 |
| *Leucaena pallida* | 46.8 | 20.8 | 39.3 | 45.4 | 7.3 | 1.17 | 1.43 |
| *Leucaena revoluta* | 41.9 | 20.0 | 40.1 | 49.8 | 6.4 | 1.08 | 0.33 |
| *Leucaena diversifolia* | 45.9 | 18.8 | 45.4 | 38.4 | 7.8 | 1.10 | 1.48 |
| *Sesbania sesban* | 29.5 | 24.3 | 31.4 | 64.5 | 6.0 | 1.71 | 1.34 |
| **Mean** | – | 20.9 | – | 53.4 | – | 1.31 | 1.40 |

Source: Seyoum, 1995.

for livestock need careful assessment and their nutritional attributes evaluated. Most of these forage legumes have already been assimilated into the farming systems as cover-crops, fertility crops etc. Recommendations on their usage would be easily adopted by farmers. Some of their attributes are described in the paragraphs below. Evaluation of cultivated forages has mainly been concerned with adaptation and yield potential. Only few studies have been geared towards assessing nutritional quality of cultivated forages. We will attempt to subdivide them into herbaceous legumes and browses.

*Herbaceous legumes*: In terms of chemical constituents, herbaceous legumes are primarily characterized by high N content and compared to grasses they have high contents of soluble dry matter, lignin and low hemicellulose contents (Smith *et al.*, 1972). Reported CP content of herbaceous legumes under local condition varied from 15% in Trifolium to 26% in *Vicia* with a mean of 19% (Table 3). Literature values of CP contents of tropical forage legumes (herbaceous and shrub) have also indicated ranges of 6 to 17% (Skerman, 1977). Most of the herbaceous legumes have CP content of 15%, a level which is usually required to support lactation and growth suggesting the adequacy of herbaceous legumes to supplement basal diets of predominantly low quality pastures and crop residues. In addition to higher CP contents herbaceous legumes have higher contents of some minerals like Ca, S or possibly P than grasses (Whiteman, 1980).

Digestibility of herbaceous legumes varies considerably depending on the genetic make-up, environment and crop management. Herbaceous legumes under local condition were reported to have *in vitro* organic matter digestibility (IVOMD) of 53 to 74% (Table 3). Tanniferous legumes like *Desmodium* have low digestibility as compared to non-tanniferous ones like *Vicia*. The calculated ratio of dietary N to digestible organic matter indicated a mean of 4.6% which is well above the critical level to support optimum rumen fermentation.

Rumen degradation characteristics of herbaceous legumes also varies considerably depending on crop species, cultivar, accession, stage of maturity and management practices. Most herbaceous legumes are readily susceptible to rumen degradation with faster rate of degradation of insoluble but degradable fraction. The mean parameter estimates of 19 species belonging to 10 genera of herbaceous legumes were reported to be 50.3% for soluble fraction, 42.3% for insoluble but degradable fraction and fractional rate of degradation of 0.0720 $h^{-1}$ (Seyoum, 1995). Among herbaceous legumes proven to grow well under local condition, *Desmodium intortum* has a potential to be used as sources of escape N while the other legumes can only be used as a source of rumen degradable N.

When gross nutrient content in terms of protein-energy interrelationships are taken into account, herbaceous legumes have higher CP (mean of 289 g CP $kg^{-1}$ DOM) than energy suggesting a need for readily fermentable energy source for efficient utilization of CP. Calculated nutrient release synchrony indices of herbaceous legumes also indicated that these forages are suitable supplements since N is released in excess of OM requirements (Seyoum, 1995). Reported mean nutrient release synchrony indices for rapidly degrading fraction and slowly degrading fraction were 1.7 and 1.1, respectively, indicating that about 70% excess N is released at early phase.

*Browse species*: Like other leguminous feeds browse species are also characterized by high N content and low fiber composition. Studies on nutritional characteristics of 18 samples of browse belonging to 5 genera under local condition have indicated a divergent range in composition and nutritive value (Table 3). Crude protein content varied from 18 to 24% with a mean of 21% while IVOMD varied from 38 to 71% with a mean of 53%. These variations could stem from the plant genetic make up, age of the plant, plant part, harvest interval and location.

Reported rumen degradation parameters of N for some browse species varied from 20-50% soluble fraction, 28-70% for insoluble but slowly degradable fraction and fractional rate of degradation of 0.0238-0.0913 $h^{-1}$ (Seyoum,1995). With the exception of *Chamaecytisus palmensis* and *Leuacena leucocephala* which can be used as sources of escape N, the other browse species can be used as sources of rumen degradable N.

Calculated protein-energy interrelationships of browse species give a mean of 404 g CP $kg^{-1}$ DOM (Seyoum, 1995) suggesting CP content is twice of the optimum ratio required for efficient rumen fermentation. The nutrient release synchrony indices of rapidly degrading and slowly degrading fraction of some herbaceous legumes were 1.31 and 1.40, respectively, suggesting excess protein and deficiency of energy at all stages of fermentation.

Some forage legumes are endowed with factors, generally termed anti-nutritional factors, that interfere with their utilization by livestock. Consequently, numerous reports have shown either modest relationships or no relationship between chemical constituents and other measures of nutritive quality such as microbial gas production, *in sacco* degradability, the two-stage *in vitro* digestibility and the *in vivo* digestibility. It is therefore important to identify appropriate indices amongst these indirect methods for measuring nutritive value.

## Identification and Selection of Potential Supplementary Forages

Primary evaluation of feed resources had often involved the two stage *in vitro* digestibility procedure described by Tilley and Terry (1963), the nylon bag technique (Mehrez and Orskov, 1977) and/or the gas production technique (Menke *et al.*, 1979). While the former procedures depend on the disappearance of nutrients through degradation, the latter measures the end-products of fermentation and could serve as a complementary procedure to either of the latter. There are, however, other advocates of the use of chemical constituents to describe feed quality. The importance of chemical constituents in forage legumes cannot be over-stressed because they contain ample quantities of nitrogen, sulphur, phosphorus, calcium and other minerals that are limiting to rumen microbial activity and to host animal's metabolism. However, the correlation between intake or digestibility and chemical constituents has been poor for forage legumes (Nsahlai and Umunna, 1996b). This suggests that although the concentration of essential nutrients can assist in the decision of which species to select as a supplementary feed, these need to be allied with biological measurements to minimize the chance of erroneous selection.

Palatability has been widely used in the initial evaluation of feeds as an index of their intake by ruminants. This has often involved periods ranging from 30 min. to even greater than 12 days using either the cafeteria method or the newly developed methods like that proposed by Ben Salem *et al.* (1994). Results from these trials have been used to rank feeds relative to one another. It has, however, been suggested that preference is affected by seasonality (Schultze-Kraft *et al.*, 1989), which could be explained by the availability of edible bio-mass and/or influence of environmental factors. The reasons why one feed is preferred relative to another are quite diffuse and the influence of macro-constituents as well as secondary plant compounds has not been consistent either. For instance, Paterson *et al.* (1989) showed a negative correlation between preference by cattle and tannin content in *Sericea lespedeza*. In another work by Kaitho *et al.* (1998a.), sheep tended to prefer low tannin species of *Acacia* and *Leucaena* than high tannin ones. With goats, however, there was no tannin dependent trend for preference. In some cases (Siaw *et al.*, unpubl), the correlation between tannin and goats' preference for *Leucaena* lines was positive. These results suggest a similarity between cattle and sheep in their preference for forage legumes and that goats are likely to behave differently. This postulation may not hold true for grasses because Tetteh (1974) and Minson and Bray (1986) demonstrated differential preference by cattle relative to goats and sheep for this class of feeds. This implies that a high stocking rate can be achieved when grazing by mixed species is practiced since livestock differ in what they consume. Siaw *et al.* (unpubl.) proposed that preference and some measure of nutritive value should be used alongside dry season bio-mass production in order to maximize the chance of selecting acceptable and good quality accessions that will stand the harsh conditions of the dry season. The importance of this integrated approach is clearer through the use of a variable termed relative available nutrient index (RANI) which simply estimates the contribution of each accession to the total daily intake of digestible nutrients. Through the use of this variable, some accessions (*L. pallida*) that otherwise would be rejected gained intermediate preference rating. Indeed, *L. pallida* retains a substantial amount of edible bio-mass in the dry season and dully deserves research attention. It is, therefore, quite possible that sheep could serve as a model for cattle, but preference rating for both sheep and goats is required to establish the importance of species in a mixed grazing system. Selection of species for rangeland improvement should consider both the agronomic and nutritive value indices.

It is known that forage legumes contain an array of compounds which confer upon them anti-quality attributes. These include tannin, saponin, flavonoid etc. Some of these may have a direct effect on the host animal while others affect, principally, rumen micro-organisms (El Hassan, 1994). It is therefore important to evaluate forage legumes from their nutritive as well as from their anti-quality attributes. Although animal trials provide the most accurate estimate of the nutritive value of a feed, it would be an onerous task if the widely varied species/accessions of forage legumes are to be evaluated individually. Inter- and intra-specific variation in degradability has been demonstrated in several reports (Siaw *et al.*, 1993; Nsahlai *et al.*, 1994; 1995a, 1995b). It was therefore thought that an *in vitro* method such as the gas production (GP) technique (Menke *et al.*, 1979) could be used for an early evaluation of forage legumes and browses. The postulation was based on the observation that gas production was positively related to intake (Blummel and Ørskov, 1993) and to microbial N synthesis (Krishnamoorthy *et al.*, 1991; Hillman *et al.*, 1993). However, results have not been particularly convincing. For instance, Siaw *et al.* (1993) and Nsahlai *et al.* (1995b) observed no relationship between gas production and degradability, probably because some forage legumes may ferment and yield proportionately less gas. Nsahlai *et al.* (1995b) contends that the latter is likely if microbial fermenters of end products of cell wall depolymerisation are affected adversely by the digesta. Research resources will be usefully deployed if they are targeted to identify simple indicators of the presence and the degree of potency of anti-fermentation factors in forage legumes.

There are, however, strong indications that gas production (GP) is more strongly related to digestibility than it is to the intake of forage legumes (Nsahlai and Umunna, 1996b). This increases the optimism held on behalf of this procedure as a promising method for diagnosing the presence of anti-nutritional factors in feeds (Khazaal *et al.*, 1993). Consequently, the gas production technique has been used in conjunction with other chemicals such as polyethylene glycol to segregate the effects of tannin. However, tannins are not the only culprit chemicals that could interfere with ruminal fermentation. It is thus important to identify a robust procedure that is independent of the varied secondary plant chemical mediators. Such a procedure, necessarily, should be biological. An adaptation and extension of the gas production technique integrated with the nylon bag procedure may yield the required protocol. For instance, fermentation of independent substrates such as Napier grass and NDF in MPT digesta indicated that the major effect of anti-fermentation factors in browses would be manifested *in vitro* in prolonged lag phase preceding the onset of NDF-GP and in slowed rate of GP from napier grass (Nsahlai *et al.*, 1995b). These *in vitro* observations were remarkably correlated to *in vivo* effects of forage legumes on the digestibility of NDF. The application of this procedure where gas production equipment is unavailable would entail evaluating the fermentation pattern of an independent non-problematic feed and/or that of NDF extracted therefrom in the rumen of animals (preferably sheep) previously fed adequate levels of the test forage.

Visual appraisal as well as chemical analysis reveals the fact that forage legumes are fibrous and are, therefore, bound to be bulky. Since the basal feeds are bulky, any supplement that competes favorably for space in the rumen will inevitably cause substitution. Supplementation of roughages with adequate quantities of rumen degradable browses invariably alleviates N deficiency (Bonsi *et al.*, 1994; Umunna *et al.*, 1995a, b; Nsahlai and Umunna, 1996a), such that the degree of replacement of the basal roughage is strictly dependent on the rate at which the forages disappears from

*Table 4. Dry matter and nitrogen degradability constants (g kg$^{-1}$: W=solubility, PD = potential degradability, ED=effective degradability; C =rate of degradation (h$^{-1}$); TL =lag phase (h)) and nutrient release synchrony indices of accessions of Cajanus cajan, Chamaecytisus palmensis, Acacia, Leucaena and leacaena crossses, Sesbania and Erythrina*

| | Fresh leaves | | | | | Dry leaves | | | | | DU |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | W | PD | C | ED | N | W | PD | C | ED | DN g kg$^{-1}$ residue |
| *A. siberiana* (2002) | 34.4 | 482 | 898 | 0.092 | 795 | 33.0 | 319 | 693 | 0.052 | – | 282 |
| *A. saligna* (7345) | 20.4 | 309 | – | – | – | 24.0 | 186 | 833 | 0.088 | – | 273 |
| *C. cajan* (11443) | 32.3 | 386 | 853 | 0.134 | 767 | 38.0 | 328 | 918 | 0.049 | – | – |
| *C. cajan* (12842) | 32.1 | 598 | 901 | 0.132 | 845 | 35.7 | 265 | 972 | 0.063 | – | 260 |
| *Calliandra calothyrsus* | – | – | – | – | – | 36.0 | 221 | 992 | 0.033 | – | 260 |
| *C. palmensis* (15061) | 29.5 | 260 | 964 | 0.076 | 765 | 30.5 | 342 | 943 | 0.066 | – | 454 |
| *C. palmensis* (15064) | 27.3 | 640 | 956 | 0.070 | 861 | – | – | – | – | – | |
| *E. bentipoene* (14992) | 24.8 | 655 | 891 | 0.075 | 824 | 34.0 | 151 | 779 | 0.114 | – | 119 |
| *E. variegata* (14994) | 28.0 | 549 | 857 | 0.060 | 755 | – | – | – | – | – | |
| *Gliricidia sepium* | – | – | – | – | – | 39.0 | 288 | 801 | 0.107 | – | 431 |
| *L. lecucocephala* (71) L | 27.0 | 454 | 928 | 0.048 | 745 | 40.5 | 156 | 899 | 0.073 | – | 175 |
| *L. leucocephala* (14198) | 33.0 | 192 | 859 | 0.089 | 691 | 34.1 | 258 | 903 | 0.035 | 603 | |
| *L. lecucocephala* (14200) | – | – | – | – | – | 32.7 | 301 | 913 | 0.030 | 608 | |
| *L. pallida* (14203)P | 34.6 | 531 | 848 | 0.042 | 717 | 31.0 | 367 | 814 | 0.024 | 565 | 172 |
| *L. pallida* (14196) | – | – | – | – | – | 33.7 | 446 | 866 | 0.022 | 625 | |
| *L. pallida* (14189) | – | – | – | – | – | 34.1 | 486 | 813 | 0.030 | 569 | |
| *L. pallida* (14977) | 26.3 | 432 | 843 | 0.018 | 587 | – | – | – | – | – | |
| *L. pallida* (16305) | 38.1 | 324 | 922 | 0.034 | 642 | – | – | – | – | | |
| *L. revoluta* (14201) | 43.7 | 551 | 892 | 0.089 | 806 | 32.8 | 296 | 847 | 0.037 | 601 | |
| *L. revoluta* (14202) | – | – | – | – | – | 31.3 | 387 | 677 | 0.032 | 534 | |
| L x P (16302) | 39.6 | 250 | 878 | 0.125 | 756 | – | – | – | – | – | |
| L x L. diversifolia (16303) | 34.2 | 269 | 891 | 0.052 | 662 | – | – | – | – | – | |
| *L. pulverulenta* | – | – | – | – | – | 30.0 | 81 | 518 | 0.036 | – | 210 |
| *S. sesban* (10865) | 43.0 | 566 | 974 | 0.140 | 902 | 38.5 | 288 | 950 | 0.071 | – | 663 |
| *S. sesban* (15019) | 41.5 | 676 | 963 | 0.118 | 905 | – | – | – | – | – | |
| *S. sesban* (15022) | 41.4 | 541 | 981 | 0.114 | 889 | – | – | – | – | – | |
| *S. sesban* (15036) | 45.7 | 564 | 976 | 0.169 | 914 | 36.7 | 456 | 879 | 0.086 | 770 | |
| *S. sesban* (15025) | – | – | – | – | – | 47.5 | 336 | 983 | 0.060 | 766 | |
| *S. sesban* (2007) | – | – | – | – | – | 35.7 | 486 | 925 | 0.091 | 816 | |
| *S. sesban* (2000) | – | – | – | – | – | 36.8 | 504 | 906 | 0.064 | 777 | |
| *S. sesban* (15020) | – | – | – | – | – | 39.2 | 451 | 1009 | 0.059 | 821 | |
| *S. goetzei* | – | – | – | – | – | 40.0 | 247 | 856 | 0.060 | – | 415 |

Source: Nsahlai *et al.* (1995a, b); Seyoum (1995); Umunna *et al.*. (1995); Bonsi *et al.* (1995a). Kaitho *et al.* (In press).

*Table 5.* *Nitrogen content (N; g kg$^{-1}$* dry matter), N degradability constants (W=solubility, PD=potential degradability, C=rate of degradation), and the digestibility in pepsin-HCl of N in 24-h nylon bag residues (DUDN; g kg$^{-1}$ residue)

| Type | N | W | PD | C | DUDN |
|---|---|---|---|---|---|
| **Herbaceous legumes** | | | | | |
| *Centrosema pascorum* | 29.5 | 605 | 927 | 0.079 | 0 |
| *Centrosema plumeri* | 25.1 | 683 | 927 | 0.062 | 0 |
| *Desmodium intortum* | 31.1 | 285 | 909 | 0.043 | 457 |
| *Lablab purpureus* | 30.1 | 380 | 937 | 0.100 | 555 |
| *Lotus corniculatus* | 29.5 | 544 | 926 | 0.070 | 255 |
| *Macroptilium atropurpureum* | 32.8 | 716 | 902 | 0.045 | 118 |
| *Medicago sativa* | 30.9 | 605 | 913 | 0.095 | 385 |
| *Medicago polymorpha* | 33.1 | 380 | 911 | 0.085 | 385 |
| *Stylosanthes guianensis* cv cook | 28.7 | 380 | 947 | 0.065 | 350 |
| *Stylosanthes hamata* cv verano | 32.7 | 380 | 931 | 0.072 | 350 |
| *Trifolium pratense* | 24.7 | 357 | 938 | 0.074 | 324 |
| *Trifolium rueppellianum* | 26.6 | 385 | 900 | 0.075 | 324 |
| *Trifolium repense* | 25.9 | 485 | 921 | 0.062 | 324 |
| *Trifolium tembense* | 31.1 | 505 | 888 | 0.061 | 324 |
| *Vicia atropurpurea* | 37.7 | 409 | 866 | 0.079 | 448 |
| *Vicia dasycarpa* | 41.4 | 615 | 991 | 0.093 | 448 |
| *Vicia sativa* | 30.3 | 468 | 971 | 0.079 | 448 |
| *Vicia villosa* | 34.2 | 579 | 984 | 0.072 | 448 |
| **Fruits of leguminous plants** | | | | | |
| *Acacia albida* | 20.9 | 431 | 849 | 0.086 | |
| *Acacia siberiana* | 20.5 | 500 | 785 | 0.055 | |
| *Acacia tortilis* | 21.4 | 431 | 865 | 0.091 | |
| **Oilseed cakes** | | | | | |
| Cottonseed (undecorticated) | 43.0 | 62 | 925 | 0.050 | 515 |
| Cottonseed (decorticated) | 86.0 | 107 | 827 | 0.050 | – |
| Flax | 42.8 | 267 | 918 | 0.050 | 433 |
| Groundnut | 91.4 | 465 | 994 | 0.082 | 308 |
| Noug | 55.4 | 365 | 938 | 0.122 | 420 |
| Mustard | 62.7 | 707 | 910 | 0.118 | 282 |
| Sunflower | 51.7 | 615 | 960 | 0.234 | 806 |

Source: Sibanda *et al.* (1993), Nsahlai *et al.* (1995b), Seyoum (1995).

the rumen (McMeniman *et al.*, 1988; Bonsi *et al.*, 1994; Umunna *et al.*, 1995a, b). Considerable variation in the rate of degradation and in the effective degradability of dry matter has been demonstrated for both browse (Kibon and Orskov, 1993; Siaw et al., 1993; Nsahlai *et al.*, 1995a, b; Seyoum, 1995) and herbaceous (Seyoum, 1995; Nsahlai and Umunna, 1996b) legumes. Nsahlai *et al.* (1995b) therefore, advocated and demonstrated that forage legumes can be classified using DM degradability into groups that have different rates of substitution of the basal roughages.

Supplementation of roughage diets is principally aimed at alleviating nutritional deficiencies in the rumen, thus enhancing the utilization of roughages. It has been proposed that in order to maximize the capture of rumen degradable N and to optimize microbial growth and efficiency, ruminal supply of nutrients (N and energy) should be synchronized (Johnson, 1976). Sinclair *et al.* (1993) outlined a procedure for determining the synchronization index using *in situ* N and OM degradability; these related positively with microbial N synthesis for complete diets (Sinclair *et al.*, 1993) and for diets supplemented with forage legumes (Umunna *et al.*, 1995b). Synchronization indices for most forage legumes ranged from moderate to poor because N was released in excess of that required to satisfy organic matter requirements (Nsahlai *et al.*, 1995a; Seyoum, 1995). Thus, in accordance with Henning *et al.* (1991), different quantities of mixtures of readily and slowly degradable energy substrates are needed to optimize the overall assimilation of N by rumen micro-organisms. That is why Nsahlai *et al.* (1995a) suggested the use of synchronization index as one of the functional classification criteria for forage legumes. Thus, Bonsi (1996) on adding a limited amount (50 g) of crushed maize grain to the diets of Ethiopian Menz sheep offered browse supplements and teff straw basal diet, observed insignificant increases in dry matter intake, digestibility and nitrogen utilization compared to the control animals.

The above index necessitates determining N in forage legumes and also in residues withdrawn from the rumen after various periods of incubation. The task is rather onerous particularly where diversity in forages is big. A procedure that can adequately predict N degradability would considerably reduce analytical cost. All proteins have a rumen degradable (RDN) and undegradable (UDN) fraction. They differ in the proportion of the degradable fraction and in the rate at which the latter fraction degrades. Some commendable approaches partition RDN into quickly degraded N (QDN, e.g. urea) and slowly degraded N (SDN). Protein degradability values of some supplements used in Sub-Saharan Africa are given in Tables 4 and 5. Seyoum (1995) observed that with the exception of Desmodium, Leucaena and Tagasaste that had post ruminal N digestibility of 16.0, 15.6 and 16.0%, respectively, most forage legumes contained limited amounts of UDN that would undergo post ruminal digestion.

Among the oilseed cakes it appears only cottonseed and flax cakes could supply appreciable amounts of digestible UDP. Most of these protein sources are therefore good sources of RDN which could be estimated using a model of the form: ND_P=DM_P(1-) suggested by Nsahlai *et al.* (1995a), where ND_P is the N degradability parameter, DM_P the corresponding dry matter degradability parameter and the deviation of the ratio of ND_P:DM_P from unity expressed as a function of chemical constituents (g $kg^{-1}$). Using this principle, the following equations have been proposed

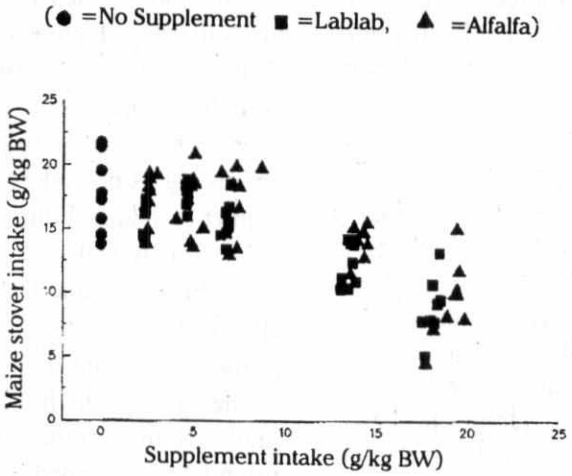

*Fig. 1. The effect of quantity of lablab and alfalfa on maize stover intake.*

for estimating the effective degradability of N (NED; g $kg^{-1}$) in fresh and dry leaves of browse legumes.

NED (Fresh)= DMED[1-(0.1151-0.0007 CELL-0.07334 LHR)] (Nsahlai *et al.*, 1995a)

NED (Dry)= DMED[1-(1.21-0.02N -0.001 NDF)] (Kaitho *et al.*, 1998b)

where CELL is cellulose, LHR is lignin/hemicellulose, NDF is neutral detergent fibre. Comparisons between various N categories will be made in a variety of circumstances to illustrate the variation in responses.

## Supplementation Strategies

Methods currently employed to enhance digestibility and intake range from physical to chemical treatment of the basal roughage diet. A strategy advocated by Wahed and Owen (1986) is to offer a surplus of straw, thus exploiting the selective ability of small ruminants. However the full benefit of each of these methods can only be achieved if associated with strategic supplements providing nitrogen, sulphur or any essential nutrients deficient in the basal roughage diet.

### *Effects of supplementation with forage legumes (FLs)*

Intake: At the ILRI Debre Zeit laboratory, only a few studies had examined the effect of supplementing roughage diets with graded levels of leguminous forages (Bonsi *et al.*, 1994; Wiegand *et al.*, 1995; Abule *et al.*, 1995). In these studies total DM intake increased with supplementation and accords with previous observations by Mosi and Butterworth (1985) and McMeniman *et al.* (1988). There is, therefore, a perceived advantage for supplementing roughages with legumes since productivity depends primarily on the intake of digestible nutrients.

However, the required level of feeding will depend on the goal of the strategy

*Table 6. Effect of degradability (g kg$^{-1}$) of forage legumes (FLs) on voluntary roughage intake (VRI)*

| Sources | Roughage | FLs | 24-h degradability | SI* (g d$^{-1}$) | VRI (g d$^{-1}$) | Total (g d$^{-1}$) |
|---|---|---|---|---|---|---|
| 1 | Oat hay | Tagasaste | 506 | 221 | 692 | 913 |
| | | Sesbania | 829 | 219 | 672 | 891 |
| | | None | – | 0 | 773 | 773 |
| 2. | Teff straw | Leucaena | 661 | 232 | 466 | 698 |
| | | Sesbania | 848 | 237 | 526 | 763 |
| | | None | – | 0 | 516 | 516 |
| 3. | Oat hay | Lablab | 590 | 219 | 539 | 758 |
| | | Sesbania | 845 | 219 | 610 | 829 |

1=Umunna *et al.*, 1995b; 2= Bonsi *et al.*, 1994; 3= Nsahlai and Umunna, 1996.
*SI= supplement intake.

because the level of supplementation with FLs that optimizes basal roughage intake may be different from that which optimizes digestibility or production parameters. Figure 1 depicts the variation of maize stover intake with graded levels of supplementation with lablab (*Lablab purpureus*) and alfalfa (*Medicago sativa*) by cattle (Nsahlai *et al.*, unpubl.). It was deduced from the latter study that VRI is maximum when FL is fed at rate of 0.5% of live weight (M).

Responses to supplementation depend on feed and animal factors; the former including the quality of basal roughage and of FL. Table 6 gives results of three studies indicating that FLs that ferment rapidly replace the basal roughage to a lower extent than those that ferment slowly. There are other studies indicating that the bulk density of a forage legume (g ml$^{-1}$) may be a more important factor than fermentation rate. For instance, although fruits of *Acacia albida* had slower fermentation rate than leaves of *Sesbania*, the former is denser and thus replaced teff straw to a lesser extent than *Sesbania* (Table 7). This same argument will explain why fresh *Leucaena* replaces the basal roughage to a greater extent than dry leucaena (Table 7). It is also quite possible that other quality attributes (by-pass digestible N) of feeds could play a part. For instance, sesbania had a lower replacement rate of the basal roughage than lablab (Nsahlai and Umunna, 1996a), but sustained similar replacement as tagasaste (Umunna *et al.*, 1995b). This could be due to the fact that the potential post-

*Table 7. Effect of bulk density (g ml$^{-1}$) of forage legumes on voluntary roughage intake (VRI)*

| Sources | Roughage | FLs | 24-h degradability | Bulk density | SI* (g d$^{-1}$) | VRI (g d$^{-1}$) | Total (g d$^{-1}$) |
|---|---|---|---|---|---|---|---|
| 1 | Teff straw | Acacia pods | 644 | 0.231 | 271 | 561 | 831 |
| | | Sesbania | 865 | 0.141 | 210 | 530 | 740 |
| | | Noug cake | – | – | 155 | 558 | 743 |
| 2. | Teff straw | Dry Leucaena | 661 | 0.150 | 257 | 522 | 781 |
| | | Fresh Leucaena | 726 | 0.390 | 265 | 460 | 727 |
| | | Sesbania | 848 | 0.160 | 260 | 506 | 763 |
| | | None | – | – | – | 733 | 733 |

1= N Sahlai *et al.*, 1995; 2= Bonsi *et al.*, 1996 *SI= supplement intake.

*Table 8. The relationships between voluntary roughage intake (VRI, g kg$^{-1}$ live weight) or total dry matter intake (DMI, g kg$^{-1}$ live weight) and forage legume (FL) intake (FLI, g kg$^{-1}$ live weight)*

| | FL range | N* | Equation | $R^2$ | P< |
|---|---|---|---|---|---|
| **Voluntary roughage intake (VRI, g kg$^{-1}$ live weight)** | | | | | |
| **Cattle** | | | | | |
| Cluster 1 | 0 - 8.5 | 19 | 23.6 - 0.30 FLI | 0.16 | 0.09 |
| Cluster 2 | 0 - 10.0 | 7 | 19.0 - 0.25 FLI | 0.21 | 0.30 |
| Cluster 3 | 0 - 15.0 | 11 | 19.2 - 0.10 FLI | 0.22 | 0.14 |
| **Sheep** | | | | | |
| Cluster 1 | 0 - 11.0 | 9 | 27.9 - 0.84 FLI | 0.87 | 0.001 |
| Cluster 2 | 0 - 12.1 | 37 | 23.8 - 0.08 FLI | 0.01 | 0.66 |
| Cluster 3 | 0 - 31.0 | 49 | 24.5 - 0.65 FLI | 0.70 | 0.0001 |
| **Total dry matter intake (DMI, g kg$^{-1}$ live weight)** | | | | | |
| **Cattle** | | | | | |
| Cluster 1 | | 19 | 27.5 + 0.15 FLI | 0.02 | 0.58 |
| Cluster 2 | | 7 | 25.3 + 0.03 FLI | 0.00 | 0.916 |
| Cluster 3 | | 11 | 24.4 + 0.44 FLI | 0.65 | 0.003 |
| **Sheep** | | | | | |
| Cluster 1 | | 9 | 27.9 + 0.17 FLI | 0.21 | 0.21 |
| Cluster 2 | | 37 | 27.0 + 0.55 FLI | 0.16 | 0.014 |
| Cluster 3 | | 49 | 26.6 + 0.24 FLI | 0.16 | 0.005 |

*N = number of observations.

ruminal digestible N is lower in sesbania (5%) than in tagasaste (16%) (Seyoum, 1995).

The variation in voluntary roughage intake with increasing FL intake was examined and the results are summarized in Table 8. It is not surprising that VRI decreased with increasing FL intake (FLI); however, the rate of decrease of VRI with FLI was highest for the best quality roughage group and low for the other two groups. It is therefore quite possible that the level of supplementation with FL that will optimize VRI may differ with the quality of the basal roughage. The rate of increase of total dry matter intake with increasing FL (g g$^{-1}$ FL) ranged from 0.15 to 0.44 in cattle and from 0.17 to 0.55 in sheep, being lowest for the best quality roughages.

### *Roughage degradation and particle passage rate*

Intake of roughages is known to be influenced by a composite of factors, amongst which are some kinetic variables such as degradation and particle passage rates. When FLs are fed to ruminant in sufficient amounts, they alleviate ruminal N, S and other mineral deficiencies, thus increasing the intensity of rumen microbial activity (McMeniman *et al.*, 1988; Said and Tolera, 1993; Bonsi *et al.*, 1994; Umunna *et al.*, 1995a). FLs also supply readily fermented structural carbohydrates, which according to Silva and Orskov (1988) could stimulate the activity of fibrolytic micro-organisms. These observations may explain why supplementation of low N roughages is associated with an almost two-fold increase in the rates of degradation

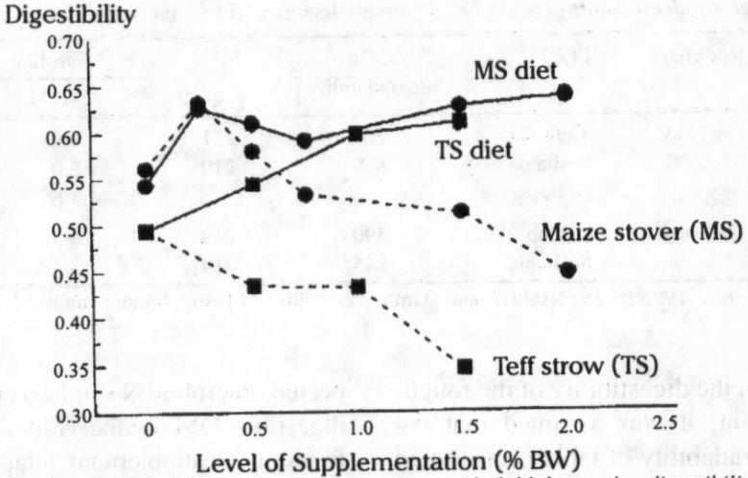

*Fig. 2. Effect of level of supplementation with lablab on the digestibility of DM and of roughage.*

(Table 9) and of passage (Abule *et al.*, 1995; Bonsi *et al.*, 1994). However, with good quality roughages like oat hay, supplementation has not always yielded positive responses (Nsahlai *et al.*, 1996a; Umunna *et al.*, 1995a), which could be related to the observation by Umunna *et al.* (1995a) that sheep fed oat hay alone sustained optimal ruminal ammonia concentrations (Satter and Slyter, 1974). Consequently, unpublished observations (Nsahlai *et al.*) depicted in Fig. 2 showed that responses to supplementation with FL decrease with increasing quality of the basal roughage.

*Digestibility and microbial N synthesis*: Low quality roughages generally exhibit low digestibility; thus various attempts to manipulate the rumen ecology are generally aimed at enhancing roughage utilization. Fig. 2 summarizes result from two trials with cattle (Ebro *et al.*, 1996a; Nsahlai *et al.*, unpubl.). This figure indicates that dry matter digestibility increases with the level of supplementation, but the increase in digestibility is more dramatic for teff straw which is a poorer quality feed than maize stover. In order to estimate the influence of graded levels of supplementation

*Table 9. Variation of degradation parameters with basal roughage quality offered to ruminants with (+) or without (-) supplementation*

| | Cluster one | | Cluster two | | Cluster three | |
|---|---|---|---|---|---|---|
| | - | + | - | + | - | + |
| Washing losses | 203 | 203 | 204 | 184 | 167 | 154 |
| A | 141 | 195 | 173 | 157 | 118 | 139 |
| B | 417 | 443 | 500 | 503 | 546 | 555 |
| (A+B) | 558 | 639 | 673 | 661 | 664 | 695 |
| c | 0.032 | 0.036 | 0.024 | 0.026 | 0.013 | 0.022 |
| TI | 4.6 | 1.7 | 2.3 | 1.5 | 2.3 | 1.8 |

*Table 10. Effect of degradability* ($g\ kg^{-1}$) of forage legumes (FLs) on microbial N synthesis

| Source | Roughage | FLs | 24-h degradability | SI* ($g\ d^{-1}$) | Microbial N synthesis ($g\ d^{-1}$) | ($g\ kg^{-1}$ DOM) |
|---|---|---|---|---|---|---|
| 1 | Oat hay | Tagasaste | 506 | 221 | 4.6 | 13.2 |
| | | Sesbania | 829 | 219 | 8.0 | 17.4 |
| | | None | – | 0 | 4.6 | 13.4 |
| 2. | Oat hay | Lablab | 590 | 219 | 5.3 | 17.4 |
| | | Sesbania | 845 | 219 | 5.7 | 17.7 |

1= Umunna *et al*., 1995b; 2= Nsahlai and Umunna, 1996; *SI=supplement intake.

with lablab on the digestibility of the roughage component, it was assumed that the effective degradability of lablab constituted 0.75 of its apparent digestibility. Trends on the digestibility of the roughage indicated a maximal value at a supplementary level of 0.25% of the live weight.

Few studies have examined the effect of supplementation with FLs on microbial N synthesis in sheep (Umunna *et al*., 1995b; Bonsi *et al*., 1995a; Nsahlai *et al*., 1995a) and in cattle (Ebro *et al*., 1996b). As expected, microbial N synthesis increased with digestible OM intake (Fig. 3) which is a function of supplement intake. Results reported by Umunna *et al.* (1995b) showed a tendency of improved efficiency of microbial N synthesis with Sesbania relative to Tagasaste (Table 10), which was interpreted as a beneficial effect due to rapid fermentation rate. This interpretation, however, has not been confirmed in other reports. Although at the same level of intake of digestible OM, microbial N synthesis ap-

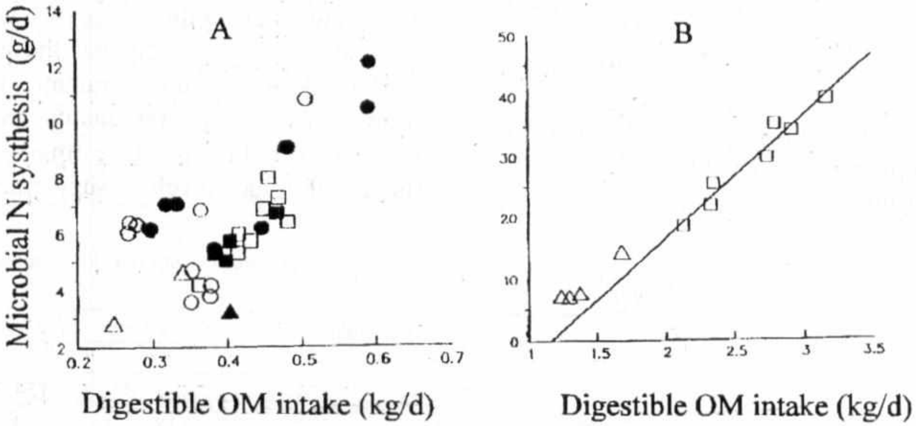

*Fig. 3. The relationship between microbial N efficiency and digestible organic matter (OM) intake for sheep (A) and cattle (B) fed roughages alone (Δ), supplemented with maize grain (MG; ▲), oilseed cake (OSC; o), OSC + MG (●), forage legume (FL; ◻) or FL + MG (■).*

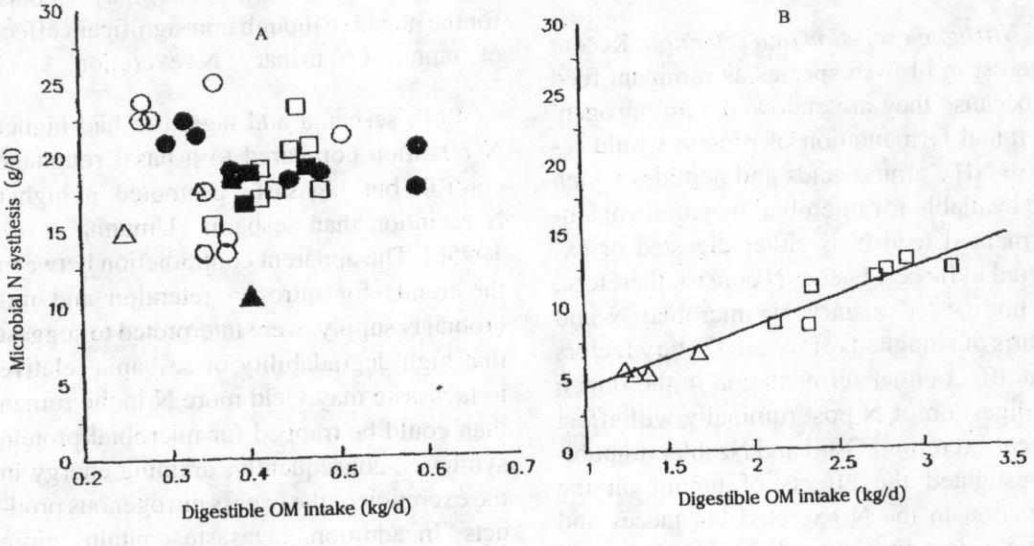

*Fig. 4. The relationship between microbial N efficiency and digestible organic matter (OM) intake for sheep (A) and cattle (B) fed roughages alone (Δ), supplemented with maize grain (MG; ▲), oilseed cake (OSC; o), OSC + MG (●), forage legume (FL; □) or FL + MG (■).*

pears to be higher for concentrate than for FL supplements (Fig. 3); results obtained under identical conditions have not shown this advantage and the apparent difference may be the result of the basal roughage quality.

The efficiencies of microbial N synthesis appear to be similar between concentrate and FL supplements (Fig. 4). This implies that besides the supply of digestible nutrients (OM, N), these FLs may not contain significant levels of other microbial growth factors. Microbial N efficiency generally increased with digestible OM intake for cattle, and on the whole are lower than the ranges reported in the literature. All studies from which microbial synthesis data were obtained used urinary purine derivatives as microbial marker. The model for deriving microbial N from PD data has two important components: the endogenous contribution to urinary PD and the recovery of microbial (exogenous) purine bases as purine derivatives in urine. The former has been determined for local breeds of cattle (Osuji *et al.*, 1996) but the latter relies on data from temperate breed. It is quite likely that this model over estimates the recovery of purine bases as urinary PD, and thus under estimates both the microbial

N supply and the efficiency of microbial N synthesis. These results are, therefore, rather indicative than real.

*Nitrogen excretion and retention*: Recent interest in browse species as ruminant feed is because they are endowed with nitrogen. Ruminal fermentation of protein would release $NH_3$, amino acids and peptides which are available for microbial metabolism. Unfermented feed N is either digested or excreted in faeces. Faeces N consist, therefore, of undigested dietary N, microbial N and debris of sloughed off tissue. Dietary factors that affect either fermentation in the rumen or digestion of N post ruminally will affect faecal excretion. Osuji and Nsahlai (unpubl) investigated the effects of tannin on the variation in the N excreted via faeces and urine using literature data. They showed that total N intake accounted for 62.1% (P) of the variation in faecal N, soluble phenolics (SOLP) for 17.4% (P) and proanthocyanidins for (PR) 0.1% (P). The following equation was used to describe faecal N (FN) excretion.

$$FN = 1.09 + 0.32\ (0.036)\ NI + 0.003\ (0.0009)\ SOLP + 0.04\ (0.081)\ PR;$$

($R^2 = 0.83$, p; Osuji and Nsahlai, unpubl).

An attempt to partition the variation in urinary N indicated that NI accounted for 32.2% (p) of the variation, PR for 0.02% (p) and SOLP for 3.74% (p). The large effect of NI on either faecal N or urinary N output is as expected. The significant effect of soluble phenolics on faecal N excretion may be due to the fact that the non-condensed tannin component or soluble phenolics is most reactive at low pH (3-5) and beyond the rumen may complex protein irreversibly thus favoring excretion in faeces. This together with the fact that proanthocyanidins affect N degradability adversely (Nsahlai *et al*., 1995a) may account for the negative though non significant effect of tannin on urinary N excretion.

Both sesbania and tagasaste had higher N retention compared to a basal roughage control, but tagasaste promoted a higher N retention than sesbania (Umunna *et al*., 1995b). The apparent contradiction between the trends for nitrogen retention and microbial N supply, were interpreted to suggest that high degradability of sesbania relative to tagasaste may yield more N in the rumen than could be trapped for microbial protein synthesis, consequently, draining energy in the excretion of the excess nitrogenous products. In addition, tagasaste contains more by-pass digestible N than sesbania (Seyoum, 1995). A similar conclusion was reached by Bonsi *et al*. (1994), when they compared leucaena to sesbania. Bonsi *et al*. (1994) suggested that 17g leucaena/kg $M^{0.75}$ and 22 g sesbania/kg $M^{0.75}$ may be optimal for total intake. When they used N balance as an index of productivity, they suggested 22 g sesbania/kg $M^{0.75}$ was closer to the optimum and that higher levels were required for Leucaena. It appears that there is an apparent contradiction between the level of supplementation that optimizes roughage intake and that which optimizes productivity.

*Live weight gain (LWG)*: There was a wide variation in the LWG of animals given roughages supplemented with FLs. This variation could be a consequence of the quality of the basal roughage (Umunna *et al*., 1995b), quality of the FL (Woodward and Reed, 1989; Tanner *et al*., 1990;

*Table 11. Effect of supplementation with forage legumes on the growth rate and efficiency (FCR, gain/feed) of sheep*

| Source | Roughage type | Supplement | | Live weight gain ($g\ d^{-1}$) | FCR |
|---|---|---|---|---|---|
| | | Type | Intake ($g\ d^{-1}$) | | |
| 1 | Teff straw | None | 0 | -20 | -0.040 |
| | | Leucaena | 193 | 38 | 0.050 |
| | | sesbania | 192 | 42 | 0.060 |
| 2 | Oat hay | None | 0 | 15 | 0.020 |
| | | Lablab1 | 180 | 28 | 0.036 |
| | | Sesbania1 | 182 | 35 | 0.043 |
| | | Tagasaste | 149 | 25 | 0.033 |
| 3 | Teff straw | Lablab (L) | 217 | 46 | 0.053 |
| | | L + Maize | 91 | 60 | 0.068 |
| | | Sesbania (S) | 218 | 47 | 0.053 |
| | | S + Maize | 90 | 71 | 0.074 |

1= Bonsi, 1995; 2= Umunna *et al.*, 1995b; 3= Nsahlai and Umunna, 1996.

Wiegand *et al.*, 1995), the productive stage, breed or species of animal. It was not possible to synthesize these reports in the context FL-growth-enhancing quality attributes because there is no clear reconciliation between these reports on the indices of quality in the FL class of feeds. Consequently, the inclination has been to blame anti-nutritional factors such as tannin (Woodward and Reed, 1990; Wiegand *et al.*, 1995) for poor response to FL supplementation, when it is conceivable that other anti-nutritional factors may be involved; for instance besides tannins *Acacia siberiana* contains cyanogenic glycoside of which detoxification in supplemented animals necessitates ample dietary supply of methionine and vitamin $B_{12}$. Some reports (Table 11) showed the beneficial effects of FLs.

Cattle: Generally, supplementation of cluster one roughages enhanced live weight gain, with very little difference between FLs and concentrates. However, for cluster two roughages, it appears that for the same level of supplement intake, concentrates sustained higher live weight gains than FLs. It would be interesting to compare FLs to concentrate in terms of the efficiency of utilization of digestible OM in excess of maintenance for growth and for other production traits, but appropriate data is scarce.

Sheep: Data on live weight gain is noticeably lacking for cluster one roughages. However, for clusters 2 and 3 roughages, supplementation enhanced LWG without any clear distinction between FLs and concentrates. Most importantly, there is considerable variation in LWG following supplementation with FLs and may be due to the reasons advanced above. It will help to identify easy-to-measure indices of quality of FLs that contribute reasonably to the observed variation.

Milk production and reproduction: Milk production responses to supplementation with FLs is one of the least explored areas (Khalili and Varvikko, 1992; Muinga *et*

*Table 12. Effect of supplementation on milk yield (from Muinga et al., 1993)*

| | Level of Leucaena | | |
|---|---|---|---|
| | 0 | 4 | 8 |
| Intake kg $d^{-1}$ | | | |
| Napier | 7.8 | 8.2 | 8.2 |
| Total | 7.8 | 9.3 | 10.4 |
| Milk yield (kg $day^{-1}$) | 7.3 | 7.7 | 8.3 |
| Liveweight change (kg) | | | |
| Days 15-63 of lactation | -37.0 | -10.0 | -10.0 |
| Days 64-112 of lactation | -18.0 | -10.0 | -10.0 |

*al.*, 1992b). Khalili and Varvikko (1992) substituted concentrate with *Sesbania sesban* and observed linear decreases in total DM intake and milk yield, indicating that *Sesbania* is inferior to concentrates. However, *Sesbania sesban* has been shown in terms of milk yield and live weight change, to be as effective a supplement as cottonseed cake, when supplemented to lactating crossbred cows given a napier grass basal diet (ILCA, 1990). Muinga *et al.* (1992a, b) supplemented napier grass fed to lactating cows with graded levels of *leucaena* and showed that *leucaena* supplementation increased total DM intake and milk yield (Table 12). These increases in milk yield may be associated with increased supply of nutrient (Bonsi *et al.*, 1994). One important observation was the reduced live weight loss during early lactation. Large weight losses during early lactation as seen with the unsupplemented diet, may prejudice the chance of conception and seriously affect subsequent productivity.

Supplementation of *Panicum maximum* with increasing levels of mixed browse (*Leucaena* and *Gliricidia*) increased lamb survival and growth rates prior to and after weaning (ILCA, 1986/87). Calves supplemented with *Sesbania sesban* had comparable weight gains to those supplemented with cottonseed cake (ILCA, 1988). In another trial, pre-weaned calves consumed similar quantities of milk (ILCA, 1988); but those that were supplemented with grazing had gains of 82 g $day^{-1}$. Supple-

*Table 13. Effects of supplementation with leguminous browses on kid and lamb survival*

| | Unsupplemented | Supplemented | Source |
|---|---|---|---|
| **Offspring survival (%) to:** | | | |
| Weaning | | | |
| Sheep | 50 | 89 | ILCA (1986/87) |
| Goats | 58 | 87 | ILCA (1988) |
| Sheep | 70 | 92 | ILCA (1988) |
| **24 week of age:** | | | |
| Sheep | 50 | 62-100 | ILCA (1987) |
| Goats | – | 36-94 | ILCA (1987) |
| Productivity index (kg lamb weaned/ewe/day | 8.7 | 10.2-13.5 | ILCA (1985/86) |

mentation of milk with *Acacia tortilis* (pods) and *Acacia brevispica* (leaves) enhance live weight gains of calves by 65 and 45%, respectively. Supplementation of pregnant West African Dwarf sheep with *Leucaena* increased lamb birth weights and subsequent growth rates. As indicated in Table 13, supplementation of does or ewes with browse legumes enhanced kid and lamb survival during the period they are most susceptible to adverse environmental conditions and consequently increased the productivity index. Other studies have shown that productivity (kg offspring weaned per dam per year) increased by 1.41 kg for sheep and by 0.64 kg for goats per additional 100 g of browse DM consumed per day (ILCA, 1987). When supplementation was restricted to late pregnancy and during lactation, there was no effect on kid birth weight and growth rate, but in sheep lamb growth rates increased during late lactation (ILCA, 1988). Although, these studies highlight the potential of browse legumes to improve reproductive efficiency, there is a significant lack of data on the long-term effects of FLs on production and reproduction parameters.

*Time of feeding*

The fresh and sun dried forms of foliage of some legumes such as sesbania degrade fast when fed as supplements. For efficient utilization of the nutrients especially nitrogen released, energy from the low quality roughage is required, but this is not so due to its slow nutrient release, thus denying the animal from being a beneficiary of the concept of synchronization. Bonsi *et al.* (1996) in an attempt to circumvent this problem fed the protein source (sesbania supplement) either in the morning or in the evening or both when sheep were offered teff straw diet *ad libitum*. Some gains were observed for intake, digestibility, microbial protein production and growth, though not significant for the evening or twice supplement offered animals. Farmers can thus offer fast degrading supplements in the evening or twice daily without detrimental effects. The high diurnal temperatures normally recorded in this zone coupled with the heat generated from metabolic activities as a result of feeding could possibly influence the production trends in the ASAZ in the negative direction. It will therefore be appropriate to feed livestock in the early morning hours or late evenings and if possible at night as being done for poultry.

## Other Forms of Supplements

The ASAZ produces diverse forms of supplements which include cereal grains (maize, sorghum, millet) and oil seed cakes (cottonseed cake (CSC), sunflower cake, noug cake (NSC), groundnut cake). A detailed discussion on these supplements has been undertaken elsewhere (Nsahlai, Bryant, Umunna and Bonsi; In press) which suggested that the variability in the roughage intake response to protein to be related to (1) basal roughage processing method such as treatment with ammonia/urea and pelleting, (2) intrinsic roughage factors such as the N and sulphur concentrations and digestibility of roughage, (3) whole diet factors such as the roughage proportion in the diet, the source of energy in the supplement and the quantity of UDN and RDN and (4) animal factors such as the farm animal species and the physiological or productive state.

*Table 14. Intake, digestibility, urine volume, N retention and live weight gain of sheep fed two sorghum stover varieties (SV) supplemented with oilseed cakes (CSC = cottonseed cake; NSC = noug (Guizotia abyssinica) cake) (source: Nsahlai et al.,* 1998)

| | Bird resistant SV | | Non-bird resistant SV | | SEM (D.F.=12) |
|---|---|---|---|---|---|
| | CSC (n=4) | NSC (n=4) | CSC (n=4) | NSC (n=4) | |
| Liveweight (kg) | 26.2 | 22.7 | 25.4 | 24.1 | |
| **Intake (g $d^{-1}$)** | | | | | |
| Dry matter (DM) | 676 | 702 | 685 | 668 | 10.8 |
| Nitrogen (N) | 17.6 | 13.1 | 19.5 | 14.3 | 0.10 |
| **Digestibility (g $kg^{-1}$)** | | | | | |
| DM | 559 | 475 | 551 | 513 | 5.6 |
| N | 696 | 611 | 723 | 704 | 5.7 |
| **Excretion, retention and gain** | | | | | |
| Urine volume (ml $day^{-1}$) | 547 | 1009 | 898 | 724 | 53.2 |
| N retention (g $d^{-1}$) | 4.2 | 1.2 | 4.4 | 4.3 | 0.23 |
| (g $kg^{-1}$ N intake) | 230 | 99 | 256 | 301 | 16.1 |
| (g $kg^{-1}$ DN) | 330 | 164 | 355 | 428 | 25.1 |
| Liveweight gain (g $d^{-1}$) | 52 | 37 | 62 | 49 | 2.7 |
| Efficiency (g gain $g^{-1}$ digestible OM) | 0.149 | 0.121 | 0.181 | 0.169 | – |

In another study (Nsahlai *et al.*, 1998) an interesting interaction between sorghum variety and type of oilseed cake occurred on N transaction and water utilisation. The dilution effects of oilseed N on the effect of sorghum variety on faecal N, urinary N and N retention were partly removed by expressing these as proportions of either N intake and/or digestible N. The proportion of N intake that appeared in faeces was therefore higher for the bird resistant (BR) than for the non-bird resistant (NBR) variety. It is thus possible that the BR fosters higher proportional faecal N losses in view of its endowment with tannins (Table 14). The interaction of cake with sorghum variety on urinary N losses appears to be a true effect because the tendency persisted even when urinary N was expressed as a proportion of digestible N. Consequently, similar proportions of digestible N appeared in urine for the BR and NBR varieties when sheep were supplemented with CSC (0.66 *v.* 0.69) while important varietal differences occurred in the case of NSC (0.84 *v.* 0.57). There are two possible reasons which derive from the fact that phenolic compounds and excess ammonia require detoxification in the liver prior to excretion. The conversion of ammonia to urea requires *c.* 4 moles of ATP per mole of urea. There is also evidence that at high ammonia loads, it may be expedient to remove ammonia by a pathway which involves the donation from amino acids of one -$NH_2$ group which combines with another derived from ammonia (Beever, 1996). Furthermore, diets including the BR sorghum variety also require substrates such as glutathione, glucuronic acid, sulphate, glucose or cysteine which conjugate with phenolic compounds to form water soluble catabolic products for excretion (Cheeke and Palo, 1995). The combined effect of the two processes could accentuate the energy deficit, as well as cause an imbalance in amino acids that are supplied for tissue protein synthesis. Consequently, sheep given BR plus NSC had the lowest daily gain (Table 14) and excreted copious amounts of urine in a bid to eliminate waste substances (Table 14). Since sorghum is a crop for the semi-arid regions (Reed, 1987; Alhassan *et al.*, 1988), it is quite likely that although the bird-resistant trait increases crop yield, it has resulted in a feed that is rather less suitable for livestock in this production environment, where water shortages are frequent. It will therefore be appropriate and cost effective for farmers to grow BR variety of sorghum for grain and the stover used for fuel or organic manure in water deprived areas of the arid zone while the NBR type is cultivated with the primary aim of using the stover as feed.

## Research Opportunities

In practice animals go for a few days without water in the ASAZ during the dry months of the year. It is during this period that browses contribute substantially to the daily energy intake of ruminant livestock. Since stress factors provoke plant synthesis of anti-nutrition factors it is conceivable why research on potential browse supplement for this zone has been and should continue to be interested in detoxification methods and/or applying principles about the mode of action of anti-nutritional factors to a nutritional advantage. Furthermore, the varieties of sorghum which is a major crop of ASAZ are bred to be bird-resistant as a result of their high contents in phenolic compounds. Unfortunately, little is known about the consequence of water shortage on the use of diets containing appreciable amounts of tanniferous feeds.

Feed availability is one of the major constraints to the productivity of livestock in ASAZ. With the exception of the Ethiopian Highlands, the trough generally occur towards the end of the dry period while the peak is somewhere around mid wet season. Thus in order to ensure year-round availability of feed, feed conservation during periods of abundance is paramount and most be allied with strategic feed budgeting. Consequently, Coppock (1993) has suggested that hay making may be all that is required to improve livestock productivity in the arid and semi arid zones. There is a perceived need for research to address issues of post-harvest feed-processing and storage during this period when rainfall results in the abundance of particularly nutritious herbaceous legumes and other forages without severe losses in quality due to moulding, respiration etc.

On a regional scale, advisory offices engaged in feed resource modelling and inventory need to be set up with the goal of supplying guidelines of the spatial distribution and abundance of feeds in grazing lands to nomadic and semi-nomadic farmers. Research into the use of geographic information system (GIS) for remote sensing of satellite images and/or aerial photographs should be used co-jointly with meteorological data to forecast in advance the spatial distribution patterns and quantitative abundance of feeds. This strategy could improve feed resource planning and harvesting, and thus livestock productivity while attempting to avert the negative impact of livestock on the environment. Other research options include *inter-alia*: (1) Feed development/ post harvest technologies; (2) simulation modelling of intake of livestock fed on predominantly roughage diets; (3) detoxification strategies for the varied FL and roughage containing anti-nutritional constituents; (4) calibration of the PD procedure for use in estimating microbial N synthesis; (5) in-depth long and short term studies on the effects of forage legumes on reproduction and milk production; (6) identification of synergistic effects among types of Fls and other N-rich feeds and (7) On-farm testing of developed technologies.

## Implications and Conclusions

If the strategy is to enhance roughage intake, it does not make sense to supplement a good quality roughage with any source of nitrogen. Consequently fertilized or young and succulent grasses will sustain maximum intake without any form of N supplementation. In such grasses feed-N may be so soluble that supplementation with moderate amounts of a readily available energy may increase productivity. However, as the quality of roughage deteriorate with age (cereal straws, matured grasses) supplementation with urea and/or with a readily fermentable N source (QDN sources such as oilseed cake, forage legumes) may be all that is required to maximize roughage intake. The exception is tannin-rich sorghum stover which when supplemented with a QDN source (such as noug cake) has been associated with copious urinary output and poorer performance relative to cottonseed cake (Nsahlai *et al.*, 1998). In such a situation where tanniferous feeds are offered, water should be provided ad libitum. In both scenarios, any contemplation to offer a protein source should consider treating protein to increase its resistance to microbial attack in the rumen without interfering with its availability during post-ruminal digestion. The latter strategy is probably more important for high producing animals such as growing, pregnant and lactating ones. In addition, animals given poor quality roughages will however benefit from increased intake when fed on moderate amounts of undegradable protein. In times of plenty, ample quantities of the basal diet should be offered to enhance intake of the most digestible portions of the roughage.

Forage legumes that undergo rapid fermentation and/or are less bulky (pods of fruits of tree legumes) could be offered to livestock at high rates without severely compromising the intake of low quality roughages. It appears a daily allowance of 0.5% of the body weight is the amount required to maximize roughage intake in cattle, which is much different from that which is required to maximise productivity. Only a few forage legumes appear to contain reasonable amount of bypass digestible protein amongst which are *Calliandra, Desmodium*, *Sesbania goetzei*, tagasaste and *Leucaena*.

At this point, it is necessary to take cognisance that despite enormous benefits accruing from supplementing livestock, this technology has not been widely adopted by nomadic farmers for various reasons, amongst which is the insurmountable logistics. To overcome logistic problems, ILRI advocated the use of feed banks (otherwise termed protein bank by Cheeke (1991)) planted with nutritious perennial forage legumes (*Stylosanthes*) which could be grazed for a restricted period, of say 0.5 to an hour daily, as livestock return from pasture to kraals. To enhance efficient use and minimise management problems associated with communal use of resources, we would like to advocate individual ownership of feed banks or some form of profit-oriented decentralised management scheme. Ideas about community and/or family grass silage pits have been conceived for the semi arid zone of northern Ghana (Bonsi and Tuah, pers. Com.) while issues surrounding its implementation are yet to be resolved.

Another method would be for semi-nomadic farmer to adopt the technology of inter-cropping (herbaceous legumes cropped with cereals). Unpublished result (ILRI, Debre Zeit) show that although the yield of sorghum grain is compromised when the latter is inter-cropped with lablab, the ensuing residues are of a quality that could sustain production in high yielding dairy cows. Such residues could be used in a similar fashion as the feed bank to supplement livestock after grazing. This strategy could be integrated with the establishment of alleys of leguminous fodder trees. Furthermore, fallow lands could be planted to perennial leguminous fodder plants to supplement feed shortages during the dry months especially in the arid zones where land availability outstrips demand. Such a unit should be properly managed and judiciously grazed to prevent overgrazing the legume species.

Livestock production in the arid regions need a sustainable governmental and non-governmental support and a concerted approach from the crop and allied sectors (post-harvest division of agricultural engineering). Numerous issues raised and discussed in this paper could serve as a platform for future research and adoption by researchers and farmers in this region especially in Africa.

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