Nutritional constraints to grazing ruminants in the millet–cowpea–livestock farming system of the Sahel

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Summary

Growing pearl millet and cowpea in combination with raising ruminant livestock is widely practised in the Sahel. In this farming system, livestock feeding depends mostly on rangeland, fallows and cropland grazing. Nutritional constraints to grazing ruminants stem primarily from feed scarcity and seasonal fluctuations in feed supply associated with low rainfall and poor soil fertility. Low feed quality exacerbates the effects of feed scarcity and seasonality. Some herd management practices result in decreased grazing times and feed intake and (or) increased energy expenditure for walking. Land tenure and use rights, among other socio-economic factors, constrain the nutrition of livestock by limiting herd mobility and access to feed resources. Expansion of cropping areas onto rangeland may result in higher overall feed yields but limits feed availability and access to grazing lands during the rainy season. Nutrition of livestock can be improved with better herd and range management practices, increasing the quantity and quality of feed produced on range and cropland and by using feed supplements. These options need to be profitable and compatible with the resource endowment and production objectives to be adopted by farmers. Policies and institutional arrangements are also required to facilitate herd mobility and access to water and grazing land and to solve and prevent conflicts among users of these resources.

Introduction

Mixed crop–livestock farming and pastoralism are the predominant forms of agricultural production in the Sahel. An important farming system in the region is based on producing pearl millet and cowpea as staple crops, combined with the use of range and fallow lands for livestock keeping (Fernández-Rivera et al. 2004). Cattle, goats and sheep provide food and serve as a source of cash to purchase farm inputs and to cover expenses associated with the family wellbeing. They also provide manure, which is widely used as organic fertiliser to increase millet yields. Cattle, camels and equines provide draft power, especially for transport. With the exception of fattening animals, livestock feeding depends largely on grazing range, fallow and crop lands. Low soil fertility is a major constraint to primary production (van Keulen and Breman 1990), whereas poor nutrition is the main cause of poor livestock productivity (Powell et al. 1996).

This paper focuses on a case study on nutritional constraints to grazing ruminants in the millet–cowpea–livestock farming system of the Sahel. The variation in productivity and weight changes of cattle, goats and sheep is discussed in relation to seasonal fluctuations in feed supply. The paper describes feed availability, quality and use under village situations, the influence of land use and socio-economic factors on livestock nutrition and the response of cattle to nutritional management. Results of the case study are used to examine the relationships between causes, mechanisms and effects of nutritional constraints. We conclude the paper with a discussion of the seasonal variation in the nature of these constraints and an outline of alternatives to improve the nutrition of livestock in the system.

Study site, materials and methods

Study site

The case study was carried out in Banizoumbou, Tigo-Tegui and Kodey, three village lands located 60–90 km east of Niamey, Niger. The area is situated within the Fakara region and includes 10 communities that in 1995 were home to 492 households and 4946 people. In the same year the livestock population included 2624 cattle, 2684 sheep and 2144 goats. The annual rainfall is about 450 mm distributed between June and September. The soils are sandy and generally of low fertility. These village lands were the subject of a comprehensive study on livestock mediated nutrient transfers (Hiernaux et al. 1998). They were selected to represent a wide range in the proportion of land under cultivation (30% in Banizoumbou, 36% in Tigo-Tegui and 62% in Kodey in 1995) and the most common socio-economic and agro-ecological characteristics of crop–livestock systems in the Sahel. A detailed description of the study site was presented by Hiernaux and Ayantunde (2004).

Farmers in the area depend on crop–livestock production. Pearl millet is the staple food and is cultivated either alone or intercropped with cowpea. The herds include mixes of variable numbers and proportions of cattle, sheep and goats and lower numbers of equines and camels. Ruminant livestock graze either freely or supervised by herders, the latter being the most common practice, especially for cattle. Cattle, sheep and goats are generally corralled during the night to collect manure in fields scheduled for cultivation the following cropping season. With the exception of some lactating cows kept on the homestead for the provision of milk and animals unable to walk long distances, cattle are taken on transhumance to the pastoral zone at the beginning of the rainy season and returned to the cultivated zone when millet and cowpea are harvested. Once back in the cultivated zone the herds are taken to graze millet residue fields in intensely cultivated areas before returning to the village lands.

Survey on household characteristics

Surveys were conducted involving 542 households in the three village lands to characterise the production system in terms of socio-economic indicators and resource management strategies in relation to nutrient use and flows (Hiernaux et al. 1998). This paper presents information on cropped area and herd size and composition.

Survey on herd productivity

Herd management and transactions of animals were monitored in 434 herds during 1995–97. This monitoring provided basic information on reproductive performance (birth rates) and mortality of cattle, sheep and goats. Offtake (sales, gifts etc.) and purchases of animals were also recorded.

Feed availability

Between 1994 and 1998 the amount of plant biomass available on rangelands, fallows and cropland was measured every year at the end of the growing season in the three village lands. Aboveground forage mass was also estimated in 1995 and 1996 along the grazing itineraries of two experimental herds, one of cattle and one of sheep and goats in Boundou, a community within the village land of Banizoumbou.

Experimental herds in Boundou

Between 1994 and 1997, sets of animals including 8 intact, 6 ruminally fistulated and 4 esophageally fistulated males of each of three species (cattle, sheep, goats) were kept in Boundou. Cattle and small ruminants were kept in two separate camps, herded by two different herders and grazed separately within the same village land. Managing these animals followed practices common to the majority of animals in the study site. They were corralled overnight for 11–13 hours to collect manure and were given water once daily. They received no feed supplement other than mineral licks. As the intact sheep and goats reached their mature weight after 2 years of the study, they were replaced by a set of young animals. Nutritional indicators were measured as described below.

Weight changes, diet quality, forage intake and rumen function

The live weight of the intact animals in the two herds in Boundou was determined monthly by weighing them for 3 consecutive days following about 12 hours of overnight fasting. Extrusa samples were collected monthly from the esophageally fistulated animals and analysed for crude protein (CP) and *in vitro* organic matter disappearance (OMD). On 15 occasions between July 1994 and August 1996, faecal excretion was determined during 10 consecutive days in the intact animals using collection bags made of canvas. Intake of digestible organic matter per unit of metabolic weight ($kg^{0.75}$) was estimated from faecal output, OMD and live weight (W, kg) of the animals. Feeding behaviour and water intake (results presented elsewhere) were also assessed in the intact animals. Rumen fluid samples were taken from intact animals every month during three days in the morning before grazing, at noon before watering and in the afternoon after returning from grazing. The rumen fluid was analysed for ammonia concentration (NH3-N). A standard forage (bush hay with composition in g/kg dry matter for crude protein (CP) = 28, neutral detergent fibre (NDF) = 753, acid detergent fibre (ADF) = 509, lignin = 106, and phosphorus = 2.5) was incubated *in sacco* at several seasons for 8, 16, 24, 32, 48, 72, 96 and 120 hrs in the rumen of the fistulated animals. This information was used to estimate rates and extent of disappearance of NDF.

Feeding behaviour

Feeding behaviour was assessed in 10 herds grazing in the 3 village lands (Banizoumbou, Tigo-Tegui and Kodey) in 1995–96. The foraging activities and the location of animals were observed and registered every 5 minutes. The distances walked were estimated by overlaying the grazing itineraries on a Geographical Information System constructed to describe land use. This geo-referenced database included a complete mapping of land units for cropped land, fallows and range of the three village lands.

Improving nutrition through supplementation and grazing management

Monitoring the nutritional status of animals in Boundou was followed by a series of experiments to assess ways to improve livestock nutrition. Effects of night grazing and supplementation were studied in two experiments (Ayantunde et al. 2001). Because of difficulties in controlling the sources of variation under village situations, these two experiments were carried out in the ranch of Toukounous, which is situated about 200 km north-east of Niamey.

In Boundou, Sangaré et al. (2002a) assessed the influence of supplementation on weight changes of cattle and its interaction with mulching on soil fertility and millet yields.

Fernández-Rivera et al. (2003) conducted an experiment in the villages of Katanga and Gouro-Yena to assess the effect of seasonal transhumance and dry-season supplementation on average daily gains and annual weaning rates of cows. These two communities are located within the village land of Tigo-Tegui. In 79 cows that calved between 1999 and 2001, milk offtake (consumption by calves excluded) was determined using 6.3 ± 2.9 records per cow per lactation.

Socio-economic, institutional and policy influences on livestock nutrition

Studies described above address generally the effects of feed availability and herd management on livestock nutrition. Nutrition of livestock is also influenced by socioeconomic and policy factors that act at the level of individual farms, local communities and countries (Williams et al. 1997). Therefore, we include a discussion on these factors as they affect the nutrition of livestock in the study area and, in general, in the Sahel.

Results and discussion

Characteristics of farms in the study area

Two types of producers, namely village farmers and camp farmers, co-exist and interact in this farming system. They contrast by the relative importance of livestock keeping and cropping (Table 1). The village farmers are sedentary and have the traditional right to the land for cropping. They have very few ruminant livestock (1.34 ± 0.18 Tropical Livestock Units (TLU, 1 TLU = 250 kg W). Only 9% of them have more than 5 TLU. The camp farmers, on the contrary, are settled in camps scattered around the villages. They have larger herds (10.8 ± 0.6 TLU on average) and 45% of them manage more than 5 TLU. The village farmers cultivate more land area than the camp farmers. While part of the family of camp farmers remains in the camps year long, other family members move the herds to the pastoral zone of the drier northern Sahel when the rains start, and return them to the cultivated zone after grain harvest.

Table 1. *Characteristics of farms in the study area (1995).*

	Village farmers	Camp farmers
Farms (no)	366	166
Persons/household (no)	9.1	9.6
Land cropped (ha)	14.5	10.5
Land manured (ha)	1.4	4.7
Herd size, heads per household		
Sheep	2.2	19.2
Goats	2.3	36.4
Cattle	3.4	27.6
Milking cows	0.6	5.8

The two groups of producers engage in exchanges of goods and services. These generally involve purchase of food and contracts to regulate access to land and fodder and exchange of manure. Camp farmers also take animals owned by village farms on transhumance on a contract basis. Conflicts may arise due to difficulties in moving herds, accessing grazing resources and damages to crops due to grazing.

Herd productivity

Some indicators of reproductive and productive performance of cattle, sheep and goats obtained from the surveys are given in Table 2. Annual birth rates for cattle, goats and sheep were 18.5, 40.2 and 36.1%, respectively. The birth rate for cattle falls within the range of 3–20% reported by Wilson (1986) for central Mali. Most births occurred towards the end of dry season (May and June). Mortality rate observed in cattle herds (1%) in the study area was low compared to 5% reported for central Mali (Wilson 1986). However, mortality in cattle herds can be as high as 40% (Wilson 1986). The mortality rates observed in goats and sheep were comparable to those reported by Colin de Verdière (1995) for the Filingué region of Niger. Sales often take place to meet family needs for cash. The offtake (sales) of 6% for cattle found in this study is similar to the 7% offtake reported by Wilson (1986) for central Mali.

Table 2. *Productivity parameters of grazing ruminants in western Niger (1995–97).*

Item	Cattle	Goats	Sheep
Herds (no)	169	112	146
Birth rate[a] (%)	18.5	40.2	36.1
Mortality[b] (%)	1.0	4.1	5.2
Sales[c] (%)	5.9	28.3	15.6
Purchases[c] (%)	3.0	14.6	5.9

a. Birth rate is calculated as ratio of births to adult females in the herd.

b. Mortality is the ratio of recorded death to the total number of animals in the herd.

c. Selling and buying rates are ratios of animals sold or bought to the number of weaned animals.

The average daily milk offtake from the 79 cows in Katanga and Gouro-Yena was 1.12 ± 0.556 l/day. This level of offtake, although low, falls within the common range in the Sahel of 0.5–5 kg/day (Wilson 1986) and is similar to that observed by Colin de Verdière (1995) in the Fillingé region in Niger. Fifty-one percent of these cows calved between May and July. With the estimated level of milk offtake per cow and the number of milking cows during the course of the year, milk availability at the household level was estimated at 0.7 and 6.5 l/day for the village and camp farms, respectively.

Body weight changes as indicators of the extent of undernutrition

Cattle showed a regular pattern of body weight changes consisting in gains of 80–100 kg during about 6 months (July to December) followed by a loss of 60–80 kg during about 6 months (January to June) with a net weight gain of about 20 kg per year, whereas small ruminants showed much shorter periods of losses and relatively higher weight increases per year (Figure 1). The live weight changes followed closely the pattern of availability of forage (see below) and this was more notorious in the case of cattle.

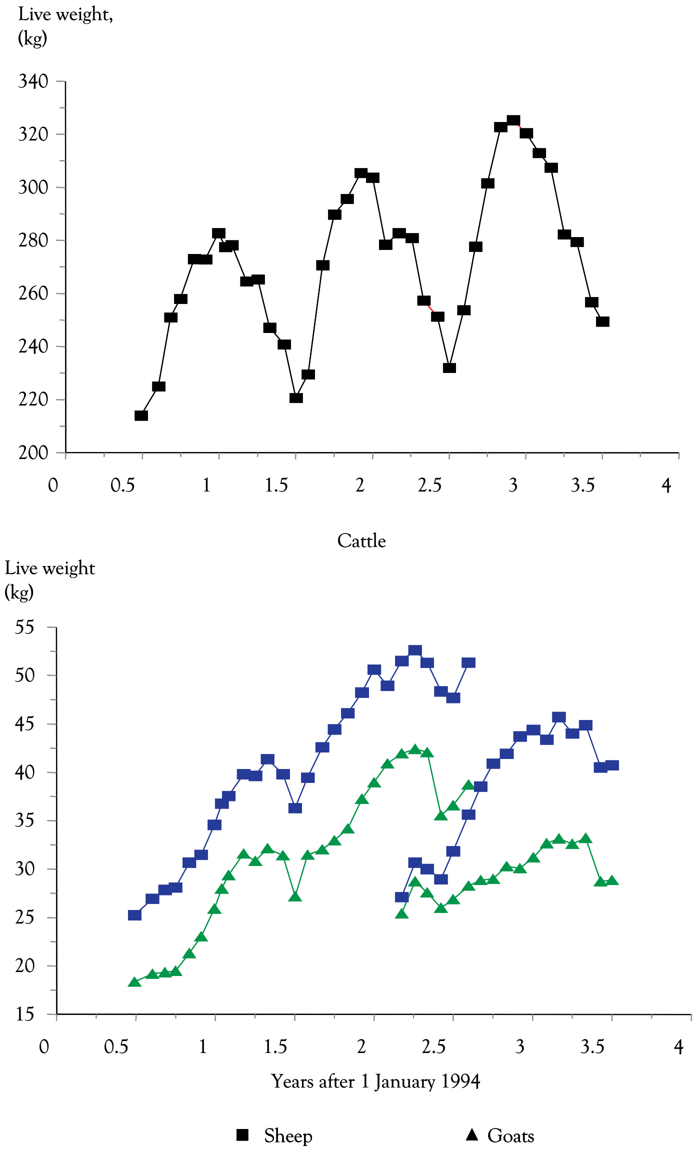

Figure 1. *Live weight changes of cattle, sheep and goats over three years in the village of Boundou in western Niger.*

In the two herds in Katanga and Gouro-Yena, the weight loss of non-lactating, non-gestating cows in the dry season varied between 380 ± 13 and 258 ± 16 g/day (Fernández-Rivera et al. 2003). Other studies showed that during the wet and post-crop harvest seasons, grazing cattle can gain up to 500 g/day (Ayantunde et al. 2001) and an average annual live weight gain of 50 kg (Schlecht et al. 1999b). In the late dry season and the transition period from the dry to the rainy season, cattle can lose as much as 300 g/day. Schlecht et al. (1999b) reported up to 22% body weight loss in non-supplemented cattle during the dry season. These results demonstrate the impact of the drastic seasonal fluctuations in feed supply and quality on the development of body weight.

Forage availability

Results on forage mass available on rangelands, fallows and crop residues during October 1994 and June 1995, averaged for the three village lands, are presented in Table 3. The standing herbage was characterised by marked inter-annual fluctuations. For instance, in Banizoumbou, standing herbage was 1298 and 733 kg/ha of dry matter (DM) at the end of growing season of 1994 and 1995, respectively. By the end of dry season, the standing herbage had declined significantly to 225 and 113 kg DM/ha, respectively. The end of growing season for herbage also coincided with peak of availability of millet stover. Moderate to high amounts of millet stover were available in all villages from harvest time to February (middle of the dry season), but the last 3 months (April to June) of dry season were characterised by a remarkable feed scarcity.

Table 3. *Seasonal fluctuations in standing herbage, weed and millet stover mass (kg DM/ha; mean ± sem) in three villages of western Niger (B = Banizoumbou; T = Tigo Tegui; K = Kodey).*

	Herbage on range			Weeds on cropland			Millet stover on cropland		
Village	B	T	K	B	T	K	B	T	K
Oct 94	1298±39	1303±56	1024±57	107±1	108±2	114±1	1461±40	1519±56	1475±52
Feb 95	502±61	615±95	586±121	63±14	70±12	70±9	802±155	813±184	958±100
June 95	225±13	237±15	111±9	48±5	50±5	21±4	346±70	364±84	421±48
Oct 95	733±24	838±37	820±31	172±5	208±12	188±5	1600±35	1625±46	1541±52
Feb 96	373±55	382±74	396±100	104±9	105±15	102±5	532±109	557±126	606±93
June 96	113±6	79±4	70±4	25±1	23±1	27±1	229±26	215±26	191±22

The aboveground plant mass in 1995 and 1996 along the grazing itineraries of the experimental cattle and small ruminant herds in Boundou is shown in Figure 2. Only from September to December the herds were grazing areas with more than 1000 kg DM/ha of plant aboveground mass. At the end of the dry season and beginning of the rainy season, the total plant DM was only about 200 kg/ha. These levels of forage availability result in extended grazing times, which lead to higher energy expenditures for walking (Schlecht et al. 2003), and in excessively low consumption rates per hour (Ayantunde et al. 2001). Thus animals are not able to consume forage as per their physical capacity.

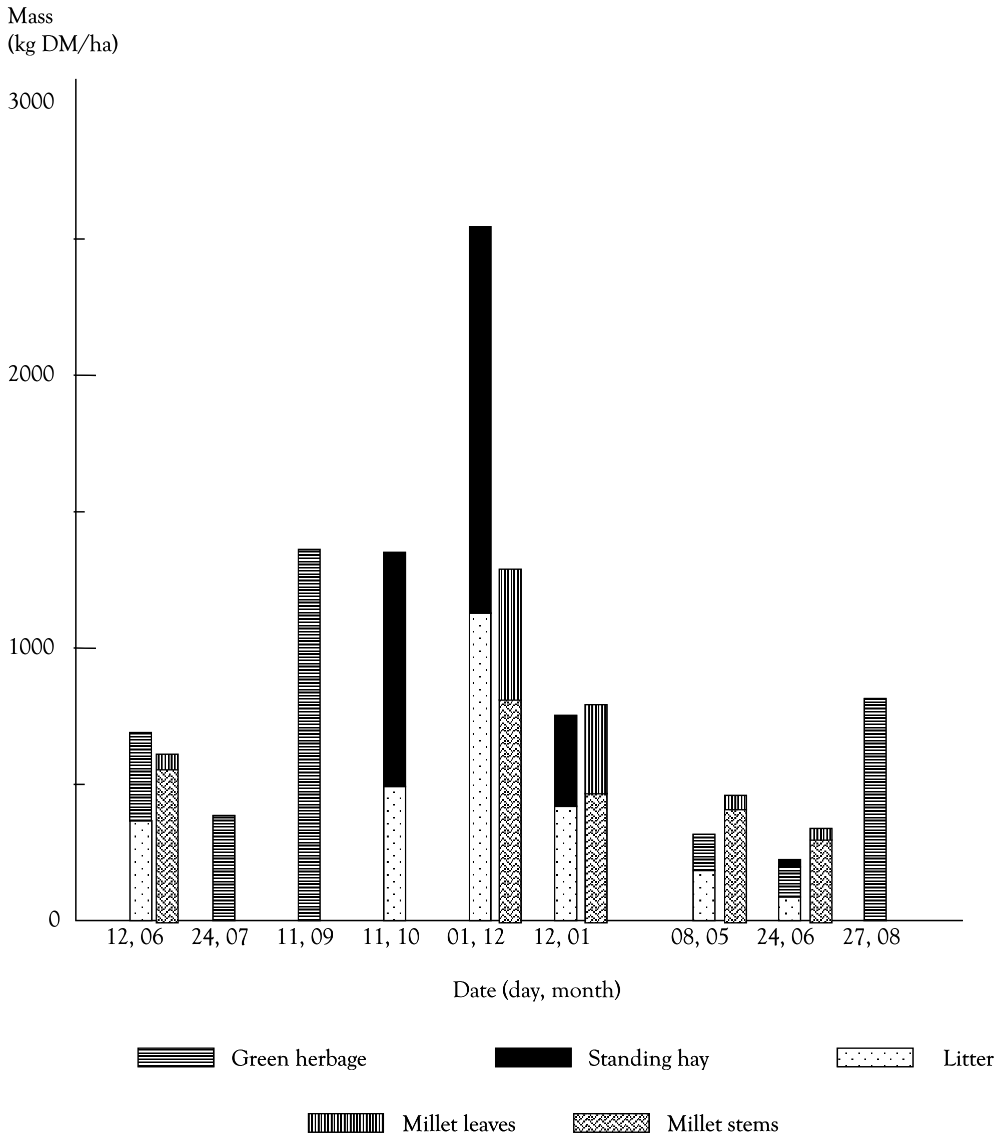

Figure 2. *Forage availability along grazing itineraries of cattle in 1995 and 1996 in the village of Boundou, western Niger.*

The herbaceous layer of Sahelian rangelands is generally characterised by a low plant density of the dominating annual graminae (Glatzle 1992). The productivity of natural rangelands is more strongly limited by lack of nutrients than by lack of water (Breman and de Wit 1983). Rangeland production is characterised by seasonal and inter-annual variation, but also by a large spatial variation in specific locations (Hiernaux 1996). Mean primary production ranges from 600 kg DM/ha in the northern Sahel with 200 mm of annual rainfall to 2400 kg DM/ha in the southern Sahel with 600 mm. The wide local variation in herbage production is explained by variation in soil type, rainfall distribution, runoff water patterns based on topography and geomorphology, and botanical composition of the herbaceous layer. As explained below, pastures may become inaccessible due to fragmented cropping and/or the expansion of dry season gardening in low-lying areas. Browse is important as animal feed, especially in the late dry season. The average annual foliage production of browse is approximately 150 and 50 kg DM/ha in the southern and northern Sahel, respectively, which is less than one-tenth of the average annual production of herbaceous layer (Glatzle 1992). In many locations the significance of browse as animal feed appears to be lower than is widely assumed. Availability of herbaceous and browse forage is greatly affected by drought. Prolonged and widespread drought results in dramatic reduction of forage yield and changes in plant species composition (Hiernaux 1996). Lack of feed and water ultimately leads to livestock mortality and changes in herd composition. In general, cattle are much more affected by drought than small ruminants, particularly goats (Powell et al. 1996).

Forage quality

Large seasonal changes in nitrogen (N) and phosphorus (P) concentrations in herbage and millet residues were observed in Boundou (Figure 3). The peak values of N and P in the standing herbage corresponded with the vegetative stage (around August) after which the nutritive quality declined rapidly. After the rapid fall, the feed quality, especially of grasses, remained constant and excessively low for most of the dry season. Results from analyses of extrusa samples collected in the same village from the esophageally fistulated animals are presented in Figure 4. Because of the selective behaviour of grazing ruminants, the protein content and digestibility of diets selected by esophageally fistulated animals were normally higher than those of the herbaceous standing mass.

Variation in CP and OMD (Figure 4) indicated both seasonal and inter-annual fluctuations in feed quality, with the highest values in the wet season and the lowest at the end of the dry season. Small ruminants tended to select a diet of better quality than cattle. However, Ayantunde et al. (1999) showed that cattle grazing Sahelian rangelands also exhibit a high degree of diet selectivity. Animals prefer some specific foraging locations and plant species, while avoiding others. This selection is also exhibited among plants parts (leaves, stem, seed and fruit). Breman and de Wit (1983) observed that zebu cattle selectively grazed a diet 2–5% higher in CP than that of the standing mass. The results of their study suggest that supplementation in the dry season with energy and or protein-rich feeds needs to consider the selective foraging behaviour of the grazing ruminants and the differences among animal species for optimal benefits.

Feed quality of the herbaceous layer in Sahelian rangelands tends to be inversely proportional to rainfall (Breman and de Wit 1983). In the southern Sahel, where nitrogen is more limiting than water, the crude protein (CP) content of herbage declines rapidly to values of 3–6% by the end of the growth cycle whereas in the north where water is the growth-limiting factor, herbage may contain up to 12% CP at the end of growth cycle (Glatzle 1992). There is thus a strong difference between north and south in the nutritional quality of Sahelian rangelands. Nutritional quality varies among plant species, but the variation within a species class (grass, legume and non-legume) is lower than between classes, that is, grasses and forbs (Ayantunde et al. 1999). Millet residues are on average of lower quality in terms of N and P content than the standing herbage.

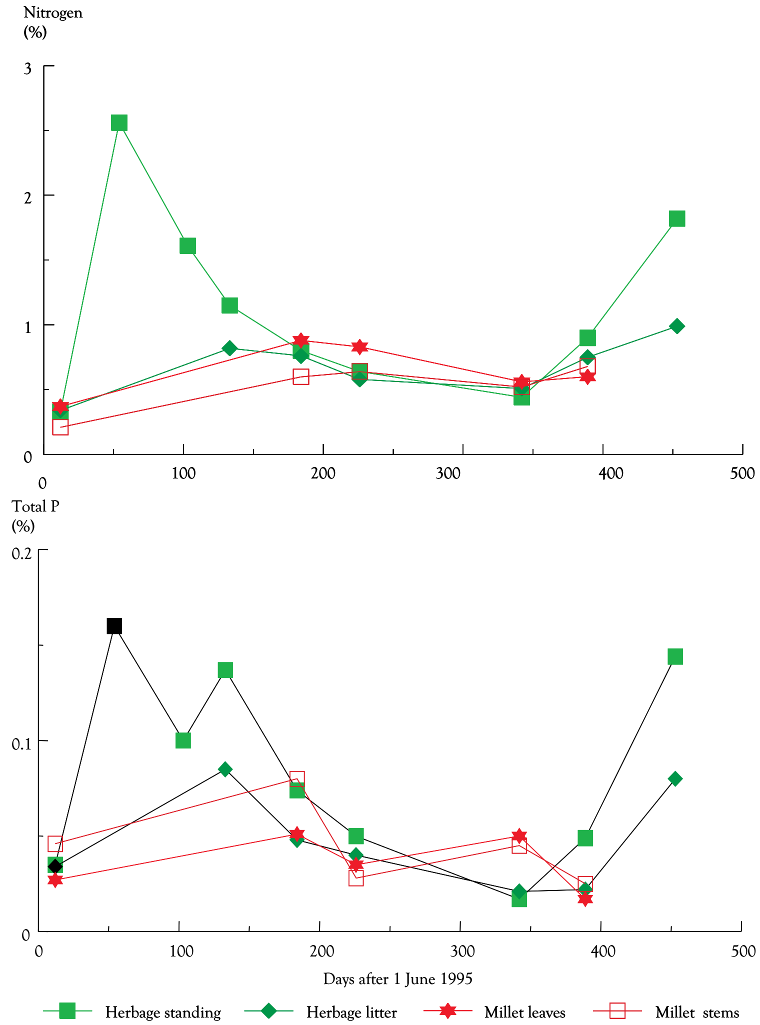

Figure 3. *Seasonal changes in nitrogen and phosphorus concentrations in herbage and millet residues in Boundou, western Niger.*

Forage intake

Results on daily intake of digestible organic matter (g per kg of $W^{0.75}$) by cattle, sheep and goats observed in Boundou are presented in Figure 5. Small ruminants had higher digestible organic matter intake (DOMI) per unit of metabolic weight than cattle. In cattle, DOMI ranged from 15–35 g/kg $W^{0.75}$ per day whereas values for sheep and goats ranged from 20–55 and 8–45 g/kg $W^{0.75}$ per day, respectively. The peak values were observed in the rainy and post harvest seasons when forage availability was relatively high and the animals also had access to harvested millet fields. The decline in DOMI as the dry season progressed is the response to the decrease in feed availability and quality. However, forage intake in the early dry season (harvest season) when animals have access to harvested millet fields in addition to the natural pasture can be higher than in the wet season. The body weight changes of small ruminants (Figure 1) followed a similar trend than that observed for DOMI (Figure 5). The DOMI observed in cattle were much lower than values of 30–50 g/kg MW per day reported in other studies in the Sahel (Schlecht et al. 1999a; Ayantunde et al. 2001). Intake values for cattle, especially during the season of high quality and abundant forage in 1995, were extremely low, possibly underestimated as result of excessively low estimates of faecal output.

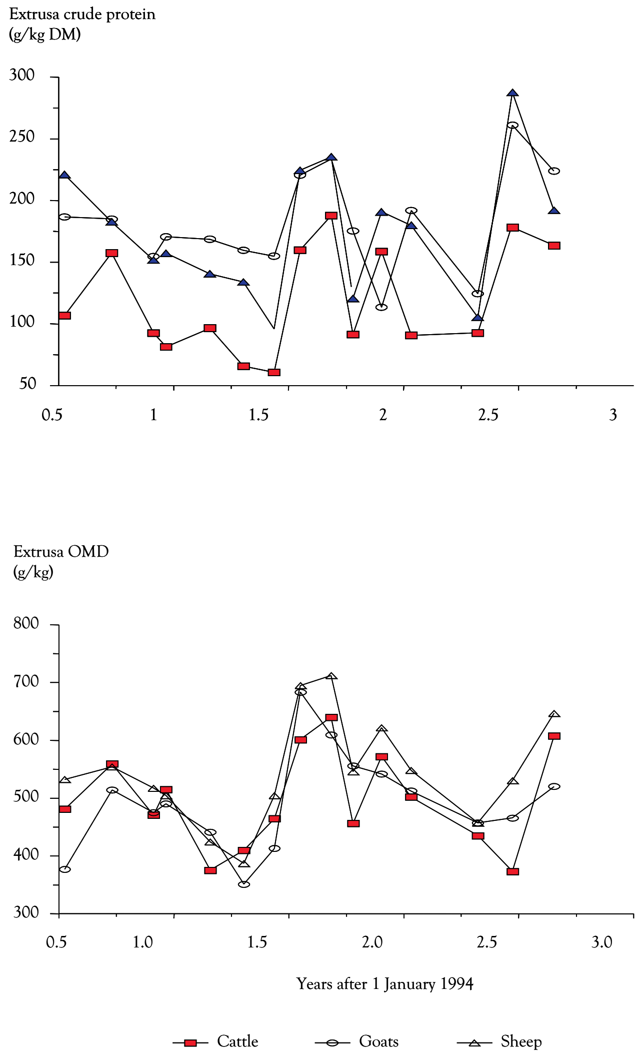

Figure 4. *Crude protein and organic matter digestibility (OMD) of extrusa selected by cattle, sheep and goats in Boundou in western Niger.*

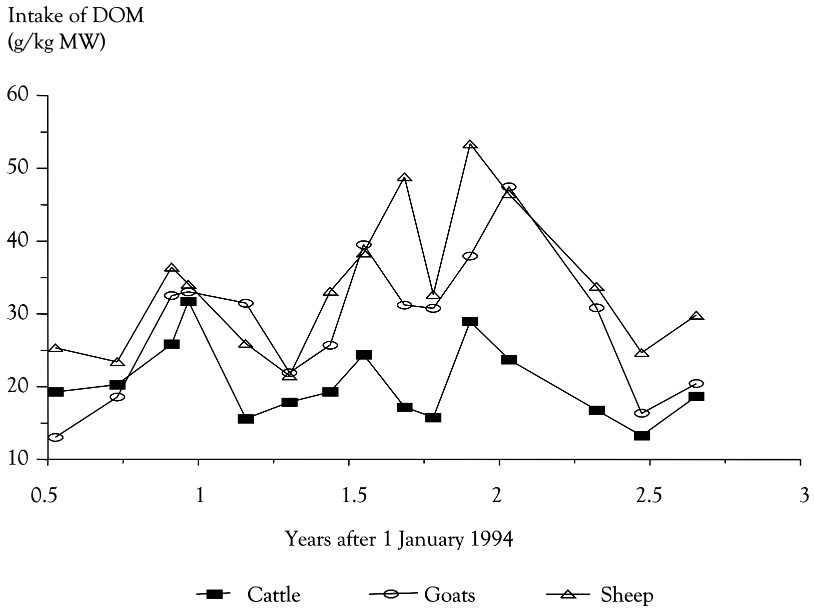

Figure 5. *Intake of digestible organic matter (DOM) by cattle, sheep and goats in the village of Boundou in western Niger.*

Rumen environment and function

During most of the year, the NH_3-N concentration in the ruminal fluid was lower in goats than in sheep, and cattle had lower ruminal NH_3-N concentrations than small ruminants (Figure 6). Concentration of ammonia in the rumen fluid of cattle was less than 70 mg/l for most of the dry season, whereas in small ruminants it did not appear to limit rumen function at any of the sampling times. These results are similar to those observed in cattle, sheep and goats grazing rangeland and crop residues fields in Sadoré, Niger, about 100 km south-west from the study site (Fernández-Rivera 1994; Powell et al. 1996). In the present study, large seasonal variations in *in sacco* NDF disappearance rates were observed (Figure 7). Cattle tended to have lower NDF disappearance rates than sheep, possibly because of the lower protein content of the ingested diet and consequently reduced ruminal NH_3-N levels. In spite of the high protein concentrations of their diets, goats had lower NDF disappearance rates than sheep, possibly due to consuming tree leaves high in tannin content. The most common tree in the range and fallow lands across the study sites (and broadly distributed in the Sahel) is *Guiera senegalensis*. The leaves of this tree are poorly digested and contain high levels of tannins (Zoulaideni 1994).

The present results illustrate that the environmental conditions and the digestive microbial activity in the rumen of cattle, goats and sheep grazing year-round on crop residues and rangelands vary seasonally and that at the end of the dry season they appear to be sub-optimal for fibre digestion and microbial growth, especially in cattle. The differences in rumen NH_3-N levels and extent of fibre degradation across species are likely the consequence of differences in feeding behaviour and type and quality of forage consumed.

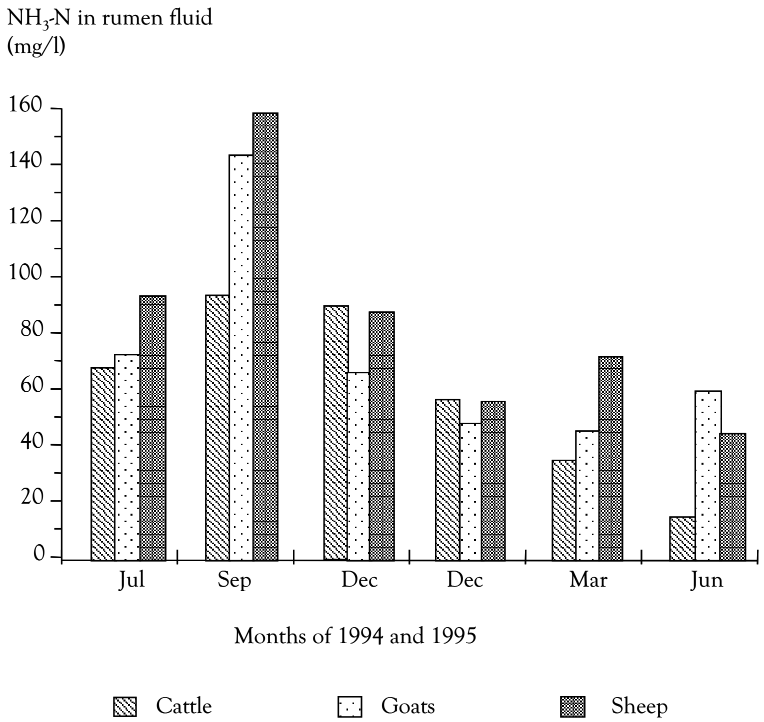

Figure 6. *Seasonal changes in ammonia in rumen fluid of cattle, sheep and goats in western Niger.*

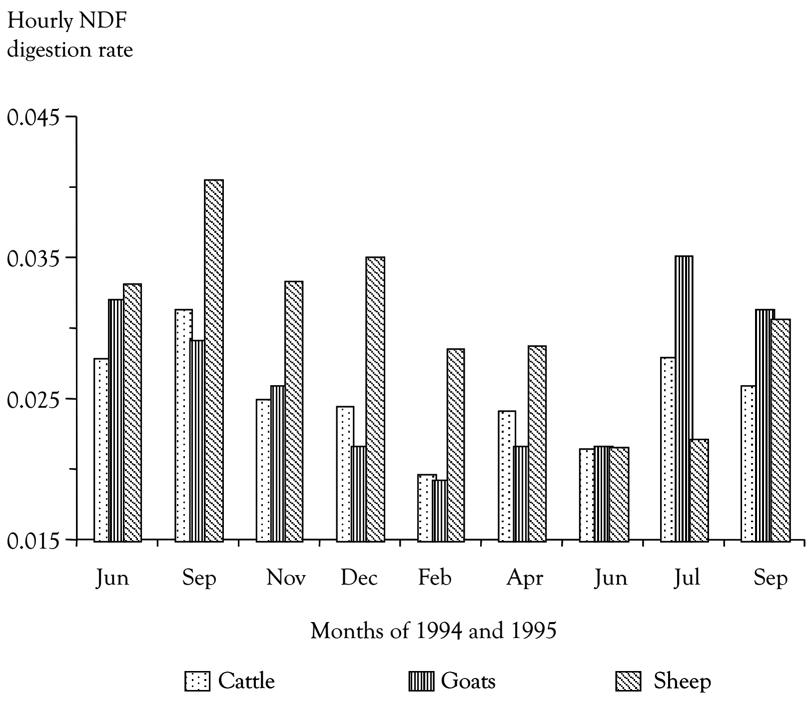

Figure 7. In sacco *disapperance rates of neutral detergent fibre (NDF) in cattle, sheep and goats in the village of Boundou, in western Niger.*

Herd management and undernutrition

Herd management can affect access to grazing land, and length and spatial orientation of grazing itineraries, time allowed for grazing, frequency of watering and access to crop residues. This case study assesses the effects of transhumance, corralling or night grazing and supplementation.

Transhumance

Transhumance is a common practice in the West African Sahel. It is based on more or less regular seasonal migrations from a permanent homestead. The motives for seasonal herd migration include access to better range resources in terms of quality and plant species diversity and protection of crops from damage by grazing ruminants (de Leeuw 1984). The animals are normally taken on transhumance to the pastoral zone of the northern Sahel during the rainy season. By moving north, higher quality forage and different species mixtures are obtained. The wet season grazing areas are also the location of sites for the 'cure salé', a practice of taking animals to lick soil in specific locations. This practice is believed to cover certain mineral deficiencies and act as a purge ridding stock of endo-parasites. Herd size is often positively related to degree of mobility (de Leeuw 1984).

In the study on transhumance of cattle conducted with the two herds in Katanga and Gouro-Yena, the animals covered 347 km in going on and returning from transhumance in the northern Sahel (Figure 8). The transhumance took about 100 days, which covered the growth period of crops in the south. Seventy-eight days were spent grazing in the north (Figure 8). When the animals returned from the long transhumance to the north at the time the millet fields were harvested, they were taken again onto a shorter transhumance to graze crop residues in the cultivated zone. The distance covered during the short transhumance was 86 km and it only lasted for about one month. Results from the study on both long and short transhumance showed that cows in transhumance tended to gain more weight during the post-harvest season than those under sedentary system (435 ± 23 vs. 383 ± 22 g/day, Fernández-Rivera et al. 2003). These studies showed that transhumance of cattle complements feed resources between the cultivated and pastoral zones. It is an adaptive strategy to cope with feed scarcity, in that it enables livestock holders to subsist and exploit the grazing resources of the pastoral and cultivated zones.

Night corralling versus night grazing

Common herd management practices in the Sahel such as herding mode (shepherding or free ranging), night grazing, watering and corralling affect time available for grazing by the animals. By corralling livestock directly on fields overnight after daytime grazing, the nutrients in faeces and urine, especially nitrogen and phosphorus, are deposited on the croplands (Powell et al. 1996). These manuring practices result in a net transfer of nutrients from rangelands and fallows to croplands. Though corralling to collect manure is an important soil amendment strategy in the Sahel, it is at the expense of the animals' need to graze in the night, especially during the dry season. When the animals are used to deposit manure in the crop fields, conflicts arise between the need for animals to graze long enough to have adequate feed intake and the need to improve soil fertility of the arable land.

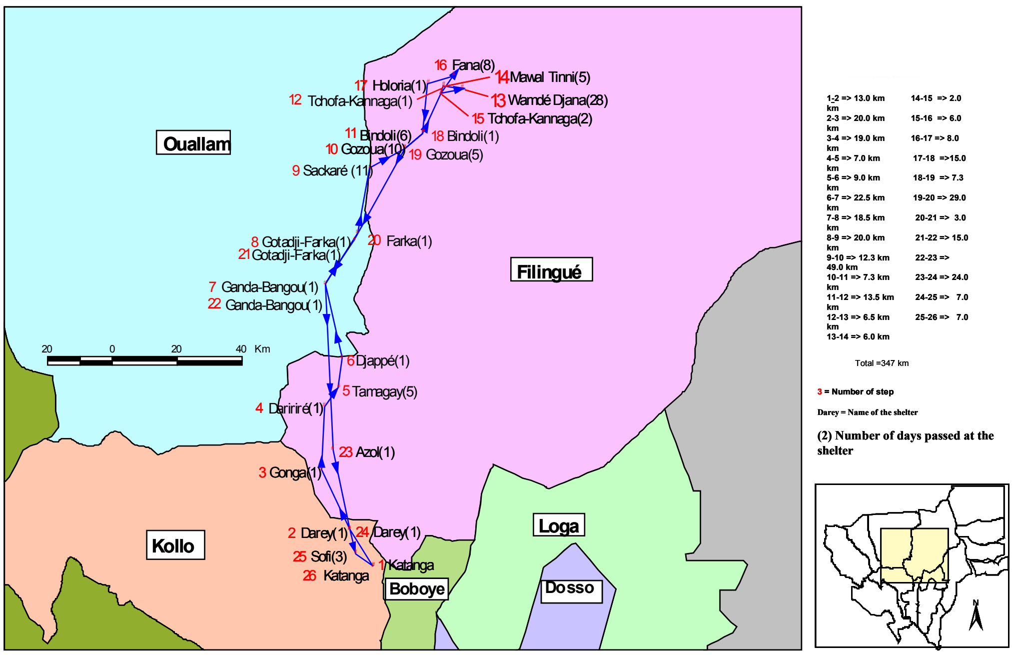

Figure 8. *Transhumance of a herd from Katanga to the pastoral zone during the rainy season of 1998.*

The experiments conducted in Toukounous showed that additional grazing time in the night is particularly important to cope with feed scarcity in the dry season. Night grazing provided the advantage of increased grazing time, which resulted in increased forage intake and better animal performance in terms of live weight gain (Ayantunde et al. 2001). The value of night grazing varies with environmental and pasture conditions and production objectives. Grazing exclusively in the night cannot be a substitute for day grazing. It complements day grazing and leads to better animal performance, especially in the late dry season.

Supplementation

Supplementing grazing ruminants in the study site is often limited to animals of high nutrient demand, such as those in lactation, mostly during the dry season when available forage is low and of poor quality. Use of feed supplements is common in fattening of sheep for the feast of 'Tabaski'. The experiment in Toukounous (Ayantunde et al. 2001) showed that the benefits of supplementation include increased digestible organic matter intake and better animal performance (Figure 9). Whereas the supplemented cattle gained body weight, the unsupplemented cattle recorded weight loss.

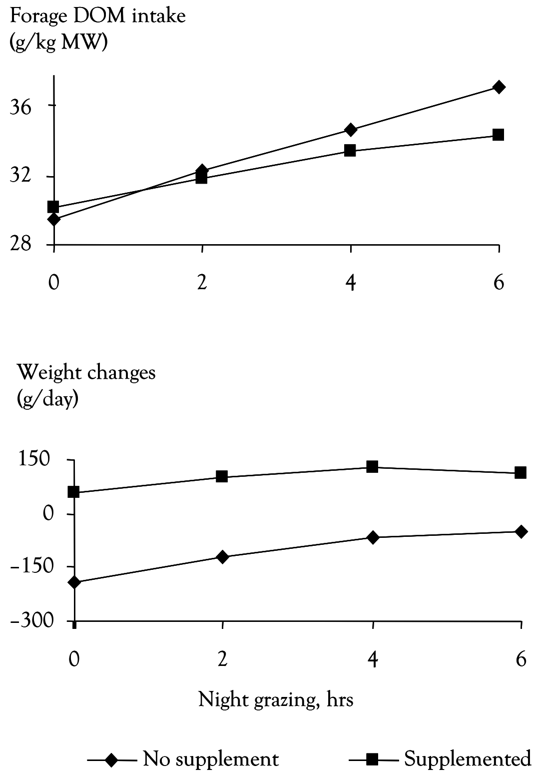

Figure 9. *Forage digestible organic matter intake and weight changes of supplemented and non-supplemented cattle grazing day and/or night.*

In the study in Boundou, supplementing cattle was shown to be beneficial not only to animals but also improved soil fertility (Sangaré et al. 2002a). These authors reported improvement in soil chemical properties (NH_4-N and soil pH) when associating mulching and corralling of supplemented cattle compared to the sole corralling. The effect of mulching and corralling on millet grain and stover yield was also higher when cattle were supplemented (67 and 50%) than when they were not supplemented (30 and 26%).

In the studies in Katanga and Gouro-Yena, it was observed that cows supplemented at the end of the dry season had lower weight gains during the rains than those that were not supplemented, and that supplemented cows had slightly better reproductive performance than those that were not supplemented (Fernández-Rivera et al. 2003). Therefore, analysis of profitability of use of supplements needs to consider the effects in the long term and include aspects such as mortality, reproductive performance and crop production if manure is used to fertilise the soil.

Influence of land use on livestock nutrition

Observational studies on the 10 herds showed that distance walked daily by grazing ruminants was longest during the wet season (Figure 10) when feed resources were plenty.

The reason for this is lack of access to grazing areas around the villages, since crops have to be protected from damage by the animals. More than 80% of the grazing time was spent on fallow and range land by the animals in wet season (Table 4). The associated energy cost in walking obviously increases the energy requirements of the animals.

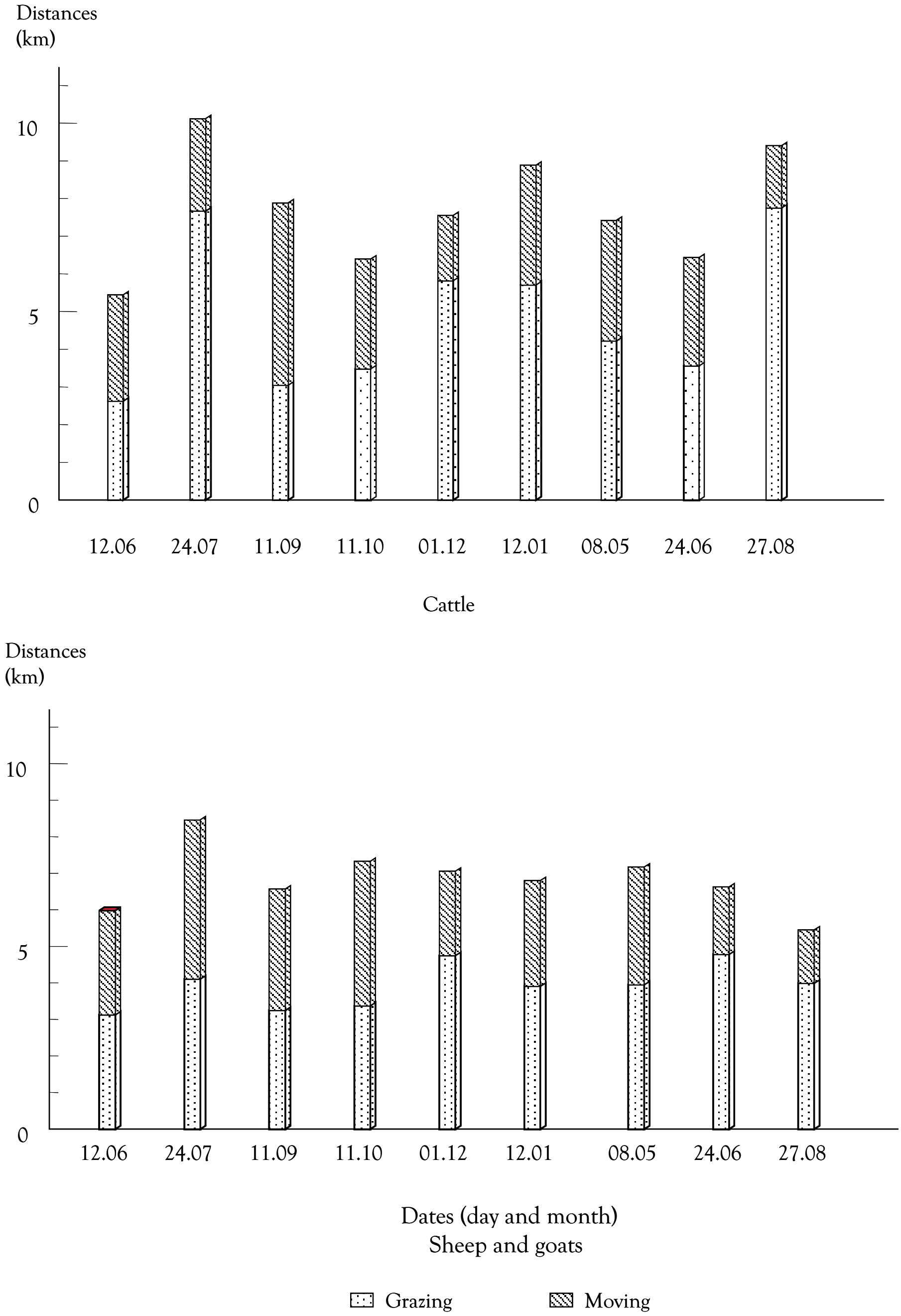

Figure 10. *Seasonal changes in distances walked daily by grazing cattle, sheep and goats in western Niger.*

Table 4. *Daily grazing time of cattle and small ruminants and its partition on activities and land units in two villages in south-western Niger.*

Season	Village	Herds (no.)	Grazing time (h/day)	Time (%) spent			Time (%) spent on	
				Eating	Walking	Resting	Cropland	Fallow/ range
Rainy	Banizoumbou	11	10.4	77.3	10.1	12.2	0.1	99.9
	Kodey	10	9.9	63.2	17.8	17.8	15.0	85.0
Early dry	Banizoumbou	12	9.7	78.1	6.3	14.6	59.6	40.4
	Kodey	14	10.9	62.0	15.6	21.2	80.4	19.6
Mid-dry	Banizoumbou	15	10.7	70.8	7.9	20.1	43.3	56.7
	Kodey	8	10.6	55.6	14.0	29.0	79.0	21.0
Late dry	Banizoumbou	4	11.2	65.1	6.1	27.7	47.2	52.8
	Kodey	7	11.1	54.6	14.5	29.2	88.8	11.2

Grazing time increased as the season progressed from wet to dry (Table 4). Eating time as a proportion of daily grazing time decreased from wet to dry season as the animals spent more time in search of food and for resting due to high ambient temperatures (>40°C) in the late dry season. Thus, where and when animals are allowed to graze should be taken into consideration in devising strategies to cope with feed scarcity.

Socio-economic and policy constraints on livestock nutrition

The use of feed resources in the study area, and in general in the Sahel, is limited by various socio-economic, institutional and policy issues. Rangelands, uncultivable lands and fallow fields in most part of the Sahel are common pool resources used simultaneously or sequentially by members of a community or a group of communities. Communities that possess primary use rights may allocate rights of access to subsidiary groups. For example sedentary farmers may give concurrent or sequential rights to grazing on village lands to transhumant pastoralists. These rights may shift over time leading to re-negotiating access rights or conflicts. Lack of clarity in access and use rights represents a major constraint to feed availability, especially for transhumant pastoralists in the Sahel. Even where use rights are clearly specified, the heterogeneity of users and multiple uses to which common pool resources are put suggest that co-operative action will be required to ensure equitable access to feeds by all farmers and to promote sustainable management of rangelands and fallow fields.

Demographic changes also have a substantial effect on feed availability from the range. Arable land expansion, partly due to high population growth, results in reduced rangeland area and seasonal inaccessibility to remaining pastures due to fragmentation caused by cropping low-lying areas previously used for dry season grazing. The net effect is a reduction in feed availability from the rangelands and the concentration of increasing numbers of livestock on smaller areas, which destroys pasture vegetation and contributes to range degradation. Land tenure and use policies are needed to facilitate herd mobility.

Land tenure security is also vital to investing in land-improving inputs, such as manure, if the productivity of both cropland and rangeland are to improve (Gavian and Fafchamps 1996).

The reduction in feed availability from range has been partly offset by increased availability of crop residues. In contrast to the wide variety of feeds available from the range, crop residues are seasonally produced. They become available only after grain harvest. Farmers use various methods to feed crop residues to their animals. Arranged in increasing order of labour requirements, these methods include: (1) open access to whole residues on harvested fields; (2) harvest and removal of stalks, with subsequent open access to stubble on harvested fields; (3) harvest and removal of stalks, with subsequent restricted access to stubble on harvested fields; (4) transport and storage for feed or sale; and (5) harvest of thinnings from cultivated fields for selective feeding before the main harvest (McIntire et al. 1992).

The pattern of crop residue use is often dictated by population density, crop residue value, herd management practices and level of transport and marketing infrastructure. Open access to residues occurs in areas with low population densities and where animals are herded communally. In densely populated and heavily stocked areas, farmers restrict access to crop residues. The availability of labour, large livestock populations and easy access to markets encourage the removal of crop residues from fields. Direct grazing, through either open or restricted access, allows farmers to use residues as feed without incurring storage and processing costs. This method of feeding results in low utilisation rates due to trampling and spoilage, but allows for the consumption of most nutritious plant parts and return of nutrients to the soil. Methods of residue feeding that involve harvesting (i.e. cut-and-carry systems) are more demanding in terms of labour, transport and storage facilities. The returns to these methods have to be reasonably high before they appeal to farmers. This is why in the region where the study site is located they are mostly used for high value crop residues such as cowpea and groundnut hay and for fattening animals or dairy cows raised in peri-urban areas with ready access to markets.

Apart from the socio-economic factors discussed above, there are other limitations to the use of local feeds in the Sahel. In the 1970s and 1980s, inappropriate pricing policies and overvalued exchange rates encouraged the use of imported grains and concentrates at the expense of locally produced feeds. After implementing economic policy reforms and liberalising the exchange rate markets in late 1980s and early 1990s, exporting agricultural products became profitable again. This has encouraged the export of agro-industrial by-products, such as cottonseed cake and groundnut cake, to the detriment of the livestock sector in most countries. The low availability and high cost of these supplements prevents their use at large scale. However, in the study area feed supplements derived from the daily processing of grains for human consumption are widely used and sold in local markets.

General discussion

Causes, mechanisms and effects of undernutrition

Nutrition of grazing ruminants in the millet–cowpea–livestock farming system of the Sahel is related to numerous factors. We argue that in this system, poor soil fertility and low rainfall, characterised by a high inter-annual variation and recurrent droughts (Hiernaux 1994), are the chief causes of poor nutrition of livestock. They limit the primary production of range and cropland and lead to drastic seasonal fluctuations in feed supply. The effects of feed scarcity and seasonality are exacerbated by poor feed quality, including the presence of anti-nutritional factors, which results in low feed use by the animal.

A key mediating mechanism that leads to poor productive performance is low forage intake. Low feed availability increases grazing time and, below certain levels of aboveground mass, reduces forage intake. Some herd management practices decrease grazing time and consequently limit forage intake. Other management practices increase energy expenditure in walking, further compromising the nutrition of grazing animals. Expansion of cropping lands at the expense of rangeland may result in higher overall feed yields but limits availability and access to other grazing lands during the rainy season. Land tenure and use rights also constrain the nutrition of livestock through limiting access to grazing lands and water and often lead to conflicts among users of these resources. A poor capital base and limited access to markets prevent the wide use of purchased supplements.

Seasonal variations in forage intake and quality and the higher energy expenditure due to long walking distances result in low availability and imbalances of nutrients at the animal, tissue and cell levels. From the mid dry season to the early rainy season, lack of feed is the overriding factor. It leads to low availability of all nutrients, primarily those yielding energy and protein. Nutrient imbalances are likely manifested as protein deficiencies from the peak of forage biomass and crop residues to early in the dry season, when fodder is still abundant and nutritional quality is decreasing. Late in the dry season insufficient levels of nitrogen and soluble carbohydrates in the herbaceous layer and the presence of anti-nutritional factors in browses impair rumen function and limit the ability of the animal to extract nutrients from the available feed. Minerals, especially salt and phosphorus, appear also to constrain the nutrition of grazing ruminants in the study zone. Sangaré et al. (2002b) observed a response to supplementation with phosphorus in growing lambs. The provision of water for livestock also constrains livestock nutrition in the system, especially during the late dry season. Issues related to water–livestock interactions in the study site are addressed in a separate paper.

The low availability and imbalances of nutrients lead to poor animal performance. Depending on the animal physiological status, nutrient deficiencies and imbalances result in growth retardation, reproductive wastage, low milk yield, increased susceptibility to disease, lower ability to perform work and lower amounts of manure. These effects on the animal negatively impact the ability of farmers to benefit fully from their herds. The ultimate consequence of poor livestock nutrition is lower income due to productivity losses and lesser sales of products; losses of assets and increased vulnerability to risk due to animal mortality; food insecurity resulting from lower farm productivity; and less sustainable farming due to a lower ability of farmers to recycle soil nutrients efficiently (Figure 11).

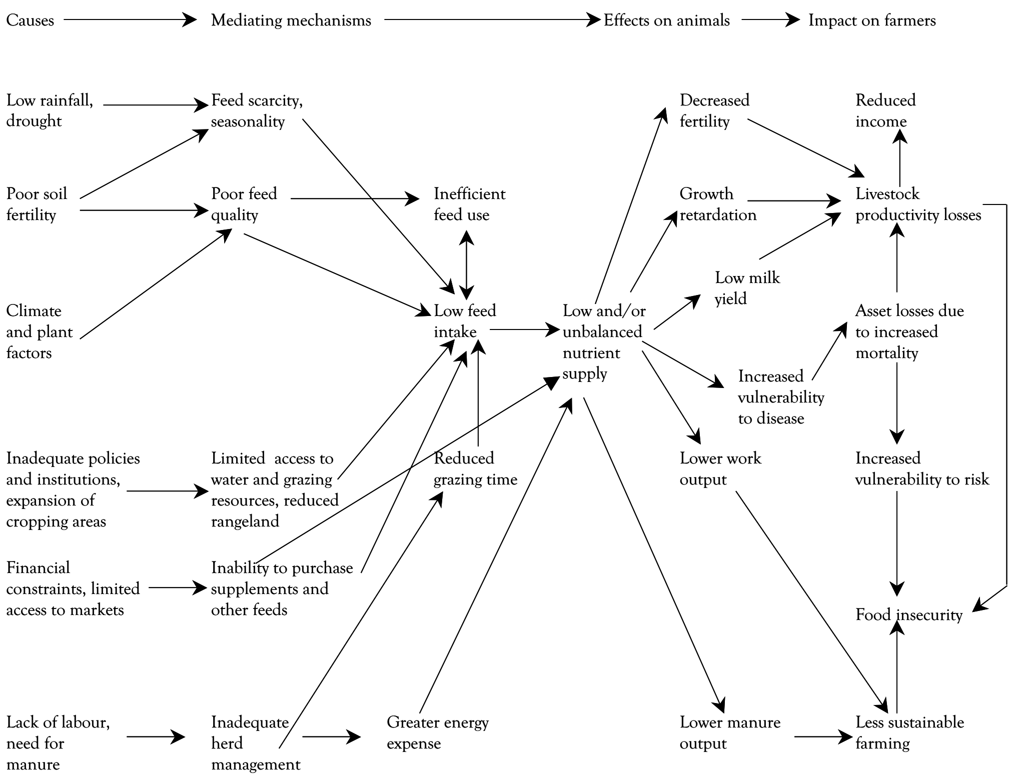

Figure 11. *Underlying causes, mediating mechanisms and effects of undernutrition of livestock at the animal and farm level in the millet–cowpea–livestock system of the Sahel.*

Most studies on undernutrition of livestock have focused on the effects of lack of feed on the physiology and production of the animal, but have failed to distinguish the underlying causes from their mechanisms and effects. This paper attempts to establish this distinction and examine how causes relate to mediating mechanisms and these lead to productivity losses, ultimately impacting on farmers' livelihoods.

Seasonal variation in the nature of nutritional constraints and opportunities to improve nutrition

The causes of undernutrition in livestock, and therefore the options to improve nutrition, vary seasonally. Late in the dry season lack of feed is the overriding factor and low protein content, especially in cattle, limits the efficient use of the feed available. The problem is compounded as the rains start due to spoilage of the remaining roughage, and occasionally, due to the direct effects of rains on animals. The main option during the late dry season and early rains, before the herds leave on transhumance, consists in providing supplementary feeding with crop residues, bush hay and/or grain by-products. If the amount of roughage available aboveground is extremely low, the rate of intake is very low and the animals spend more energy walking. Under these situations an alternative is to keep the animals tethered or in camps with survival feeding. Supplementary feeding with roughage will be determined by availability of labour and cost of transport, whereas use of concentrates will be a function of availability and cost of grain by-products.

As the rains continue, the forage starts to grow and the crops develop. At this stage the quality of the forage available is very high and the main constraint is herd mobility. Grazing and moving herds to watering points during this season may lead to crop damage and thus to conflicts between herders and farmers. The main option to improve nutrition and prevent conflicts in this season is the establishment or strengthening of local institutions to facilitate herd movements through corridors for herds to access range and watering points.

Except some trees that continue growing after the rainy season ends, all range forage and crops residues are produced during the rainy season. Attempts to increase fodder production on rangeland and/or cropland must be targeted during this season. Heavy continuous grazing during this season leads to undesirable changes in vegetation and lowers range productivity (Fernández-Rivera et al. 1995). There are opportunities for controlling the intensity and timing of grazing using short duration rotational grazing strategies by organising herders. Increasing the quantity and quality of fodder with food–feed crops is possible through precision manuring and applying fertilisers and possibly through variety selection. This option is less attractive if the residues are grazed communally, as is the case of millet stover. However, harvesting millet residues is becoming a common practice in the more densely populated areas. Cowpea hay is harvested and highly priced in local markets. It can be an option to supplement animals with higher protein requirements, such as lactating cows. However, because of the high demand for rams to slaughter in religious festivals, a more profitable use of cowpea may be for fattening sheep. Conserving crop residues and bush hay under cut-and-carry strategies may reduce spoilage and provide feed late in the dry season. Most of the growth, especially in cattle, occurs between June and December, from grazing on range and crop residues. During this period supplementation is not required. In on-station studies it was observed that growing sheep grazing on millet residues responded to supplementation with rumen undegradable protein (Salla and Fernández-Rivera, unpublished data). However, by-products of animal origin (e.g. blood and bone meal) are expensive and due to food safety concerns their use is increasingly restricted. Thus this option does not appear to be practical or economical.

In the early to mid dry season herd management appears the most practical option to improve nutrition. Calving generally occurs throughout the year and about 50% of the calves are born between April and July. It is common that calves older than 6–9 months continue suckling through the dry season. With demand for animals for fattening in the cultivated zone these calves could be weaned and sold along with cull animals before they lose weight. This would result in lower nutritional stress of otherwise lactating cows at the end of the dry season and in less pressure on the range during the rains. However, this strategy faces the conflict between the perceived advantages of increasing offtake and the need for storing wealth. Its application requires incentives and options acceptable to livestock keepers for investing the proceeds from selling animals. Night grazing can also be practised to improve nutrition during the early and mid dry season. Allowing animals to graze at night increases feed intake but reduces the amounts of manure collected.

As the dry season progresses, aboveground forage mass decreases. Animals require longer grazing times and spend more energy walking. Up to some point, the decrease in forage availability is compensated with longer grazing times. However, when forage availability is extremely low, such compensation is no longer possible. At this stage, if harvested crop residues or bush hay are available, it is advantageous to restrict walking by keeping animals on fields scheduled for manuring and feed these roughages or other supplements. The feed refusals are incorporated into the soil along with the manure and urine and contribute to improving soil fertility and increasing millet yields. As explained above, these options depend on the availability of labour for harvesting crop residues and bush hay, options to transport and store these roughages and on the cost of supplement feeds. In peri-urban areas with easy access to markets these supplements are increasingly being used to improve livestock nutrition.

This study points to the need for quantitative assessments of the impact of undernutrition of livestock on income, food security and assets at the household level. Such assessments would help identify priorities among the options for intervention described above, so as to better inform livestock development efforts in the millet–cowpea–livestock system of the region.

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