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# A spatio-temporal analysis of forage availability and grazing and excretion behaviour of herded and free grazing cattle, sheep and goats in Western Niger

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**Abstract**

Grazing itineraries of herded and free grazing cattle ($n = 194$), goats ($n = 148$), and sheep ($n = 129$) were monitored in a village territory over a 1-year cycle by direct observation of grazing and excretion behaviour and by parallel animal tracking using a Global Positioning System. During the study period, standing and litter biomass of spontaneous vegetation and crop residues was measured repeatedly on sample plots of fields ($n = 16$), fallows ($n = 15$) and rangeland ($n = 8$). Based on a land use map, a Geographic Information System on forage availability was produced for the territory and overlaid with the livestock grazing itineraries. The animals' behaviour at pasture was related to the forage mass encountered along their daily itineraries in order to analyse the spatial variation in behaviour as influenced by season, livestock species and herd management mode.

Maximum daily itinerary lengths were 25 km in cattle, 20 km in goats and 21 km in sheep; itinerary length varied significantly between species, herd management modes and season. Animals spent between 456 and 625 min per day on pasture, the grazing day of cattle being longer than that of sheep and goats. Across seasons, all three species spent on average about 60% of the daily grazing time feeding, 20–26% walking and 12–20% resting. The forage mass encountered along the animals' itineraries was higher than the average amount of forage available in the area. Particularly during the late dry and the rainy season, herding increased the amount of forage on offer to grazing livestock. Throughout the year, 39% of the observed excretions occurred on cropland, 31% on rangeland, 20% on fallows and 10% in and around settlements; the spatial repartition of excreta deposits differed between herded and free grazing animals, with free grazing animals depositing a higher share of excretions on barren land.

The obtained information on the variation of grazing and excretion behaviour with respect to ruminant species, land use type, forage supply, season and herd management can be coupled with quantitative data on feed intake and excreta deposition, in order to compute livestock-mediated nutrient budgets for Sahelian agro-pastoral land use systems.


*Keywords:* Excretion frequency; Forage availability; GPS; Grazing behaviour; Herd management; Ruminants; Sahel

## 1. Introduction

Since the 1980s, research on livestock-mediated nutrient cycling in the mixed farming systems of sub-Saharan Africa concentrated particularly on the yield-enhancing effects of manure applied to pearl millet (*Pennisetum glaucum* L. R. Br.), sorghum (*Sorghum bicolor* L. Moench) and maize (*Zea mais* L.) (Dugué, 1998; Powell et al., 1998; Bationo and Mokwunye, 1991; Schlecht et al., 2004a). Although the limited availability of livestock manure for cropland fertilisation was a concern expressed regularly, respective model calculations based on the regional development of herd sizes, feed availability, feed intake and faecal excretion

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are scarce (Fernández-Rivera et al., 1995). The majority of Sahelian livestock graze freely or under the guidance of a herder within communally exploited grazing areas. Through the ingestion of feed organic matter and nutrients in one place and the subsequent excretion of the indigestible fractions of the diet – along with endogenous and microbial substances – in another place, livestock-mediated source–sink relationships between different fields, fallows and rangelands are building up within the grazed area. However, the dichotomy of individual livestock ownership and management as opposed to communal exploitation of grazing resources exacerbates the assessment of livestock-mediated nutrient flows. Consequently, the nutrient fluxes that evolve from the grazing activity of livestock are often ignored in modelling exercises that aim at assessing nutrient balances in African farming systems (Stroosnijder et al., 2001).

To be able to model these flows, the spatial distribution of grazing and excretion activities and the underlying driving forces must be known. Therefore, the present study analysed the seasonal variation in the repartition of grazing activities and faecal and urine excretions across different land use types as influenced by the accessibility of land units, the availability of forage and herd management.

## 2. Materials and methods

### 2.1. Site and agricultural system

The study was conducted between 1997 and 1999 in the village territory of Chikal (14°25′N, 3°26′E, 249 m a.s.l.), situated at the border of the semi-arid Southern Sahelian zone with the arid Northern Sahelian zone. The rainy season lasts from June to September and peaks in July and August. The long-term average rainfall is 361 mm $a^{-1}$ (S.D. 110.6), falling in 35 days (S.D. 10.5). Rainfall in 1997 was 235 mm (S.D. 23.2) distributed across 20 rainy days (S.D. 2.5); in 1998 348 mm (S.D. 51.4) of rain fell in 26 rainy days (S.D. 2.3). Rainfall was distributed more regular in 1998 than in 1997 (Chikal Meteorological Station). The mean annual temperature is 29 °C, monthly average temperatures were 24 °C in January and 33 °C in April, the coolest and the hottest month.

The 298 $km^2$ large study area is located at the edge of the 'Continental Terminal' sandstone plateau and the fossil river valley of the 'Dallol Bosso'. Its eastern part is dominated by a laterite plateau (2665 ha), which is covered by tiger bush vegetation. An EW oriented quaternary dune (2048 ha) prevails in the north-eastern part, while the western part lies in the fossil valley (15 509 ha). The plateau and the Dallol are separated by a band of NS oriented depressions (840 ha). Weakly inclined plains, so-called pediments (8668 ha) separate the plateau from the depressions and the dune. Except for the plateau, fields (in September 1997: 14 050 ha/ 47.3% of village land) are interspersed with fallows (6222 ha/20.9%), rangelands (9286 ha/31.2%) and settlements (172 ha/0.6%). Annual dicotyledons and grasses dominate the spontaneous herbaceous vegetation of fallows and rangelands. The ligneous vegetation is sparse and spatially concentrated. The majority of the sedentary Hausa farmers cultivate pearl millet and keep cattle, goats and sheep. After the crop harvest (October), livestock graze crop residues on fields as well as the mature herbaceous plants ('standing hay') left on fallows and rangelands. During the dry season, herds of mobile livestock keepers also enter the village territory to graze on crop residues. During most of the rainy season (July–September), these mobile herds and a considerable number of village cattle and sheep are taken to pastoral areas further north, while the animals remaining in the village territory are herded on rangeland and fallows to avoid crop damage. During the early dry season (October–December), the mid dry season (January–March) and the late dry season (April–June) animals are either herded or left to graze on their own.

### 2.2. Land use mapping

Aerial photographs of the village territory were taken in September 1997 and September 1998. As land clearing for cultivation usually occurs between March and June, these photographs reflect the land use of the periods July 1997–June 1998 and July 1998–June 1999, respectively. Photographs were taken with a 35 mm single lens reflex camera from an altitude of 2000 m above ground. Each photograph ($n$ = 144) covered 2060 m × 1380 m; adjacent photographs overlapped by 30%. DIN A4 colour prints of the photographs were georeferenced; polygons of different land use were delineated on the prints, vectorised, and joined into a land use map using ATLAS-GIS[1] software. The geomorphologic characterisation of land use types[2] was based on a SOTER soil and terrain digital database (Schlecht et al., 2001). The overlay of the 1997/1998 and 1998/1999 land use maps with the SOTER produced 6558 and 12 435 land units, all characterised in geomorphology and land use.

### 2.3. Vegetation monitoring

#### 2.3.1. Destructive vegetation sampling

Starting in 1997, the dry mass of standing herbaceous vegetation and of litter was determined in October, January, March/April, May/June and August until June 1999. On 15 fallow and 8 rangeland monitoring sites distributed across the four major geomorphologic units (Fig. 5a), a stratified random sampling technique was used (Hiernaux, 1995). The herbaceous layer was first stratified into facies defined by specific combinations of soil, topography and vegetation composition. Within each facies, the standing vegetation and the vegetation litter, respectively, were then classified into four strata of apparent herbaceous density (bare soil, low,

[1] GIS: Geographical Information System.

[2] Land use type: the fields, fallows or rangelands in general. Land unit: one clearly delimited field, fallow or rangeland.

medium, and high density) for every meter along a fixed transect line of 200 m length (400 m on more heterogeneous sites). For each facies total cover of standing plants and of litter were measured in twelve 1 $m^2$ plots distributed at random along the transect (three in high, six in medium and three in low density strata). All plant species (Hutchinson and Dalziel, 1954–1972) were listed and the three dominant ones per plot were ranked according to their contribution to total herbage mass. Standing herbage inside the quadrate was clipped at 1 cm above soil surface and collected into a cotton bag. Vegetation litter inside the quadrate was collected into a second bag. The harvested samples (per site and facies 12 of standing vegetation, 12 of litter) were oven-dried (70 °C) to constant weight and weighed (precision 1 g) to determine air dry mass (DM). The frequencies of the strata and facies were used to weight the values obtained for cover and dry mass. The frequencies were also used to weight the contribution of individual plant species to the mean herbage cover. For this, equivalence was established between the species' rank and their relative contribution to vegetation cover within each plot, based on established statistics (Hiernaux, 1995).

The mass of crop residues and weeds was determined on 16 fields in October, January, March/April and May/June. Estimation of standing millet stover mass accounted for the density of planting hills (pockets) and the number and height of tillers (<50, 50–150, >150 cm) per hill (Hiernaux and Ayantunde, 2004). The 10 pockets that were closest to a fixed 100 m transect were clipped above the first stem node and tillers were grouped into three samples according to height. Each sample was separated into leaves, leaf sheaths and stems. Litter of millet stover was quantitatively collected in ten 1 $m^2$ sampling plots every 10 m along the transect, pooled into one sample per site and separated into leaves, leaf sheaths and stems. Weeds were quantitatively harvested in the same 10 plots, with all species listed and the individual cover of the five species that contributed most to weed mass estimated. For each field, one pooled sample of standing weeds and of weed litter, respectively, was constituted. Air dry mass of the samples of weeds and millet stover was determined as described above.

The portion of herbaceous plants and of millet stover palatable to ruminants was deduced from established palatability scores (Hiernaux, unpublished); these were weighted by the contribution of individual species (herbaceous plants) and plant parts (millet) to the overall biomass yield at each site. For litter, an additional weighting factor accounting for ease of ingestion was applied. Monthly values of millet stover and herbage mass yield per land unit for the period January–December 1998 were obtained through interpolation of the values measured throughout the yearly cycle, applying a monthly rate of dry season decay (October 1997–June 1998; October 1998–January 1999) and rainy season growth (July–October 1998) to standing plants and to litter, respectively.

### 2.3.2. *Upscaling of vegetation measurements*

In order to extrapolate the vegetation data measured on the 39 sites to the whole study region, the herbaceous vegetation on each land unit was assigned to cover classes that were established from interpretation of the 1997 images. Four land use categories were distinguished: fields, fallows, rangelands including thickets and human settlements. Fields were stratified according to relative soil cover, i.e. the density and diameter of the millet pockets (three cover classes: <0.05, 0.05–0.15, >0.15), and the apparent density of the weed layer (three classes: <50, 50–150, >150 kg DM $ha^{-1}$). Fallows were stratified according to the relative extent of bare soil patches (three classes: <0.10, 0.10–0.25, >0.25) and the apparent density of standing herbaceous plants on vegetated spots (three classes: <600, 600–1200, >1200 kg DM $ha^{-1}$). Stratification of rangelands and thickets was based on the relative extent of bare soil patches (four classes: <0.25, 0.25–0.50, >0.50–0.75, >0.75). The herbaceous layer in settlements was set to zero.

For units where the land use remained unchanged between September 1997 and September 1998, the classification was maintained for the whole study period. In case of land use change (conversion of field into fallow, conversion of fallow or rangeland into field), the classification for July 1998 onwards was deduced from the stratification of 1997 following a set of rules, which depended on the direction of the change.

The extrapolation of the results of the monitoring sites was based on the distribution of herbage mass measured in October 1997 and October 1998. For fallows, rangelands and for weeds on fields, the yields of vegetated areas were used. Here as well as in the case of millet stover, sites yielding a mass inferior to the mean of all respective sites minus one half of the standard deviation of this mean were attributed to the low mass stratum. Sites with yields superior to the mean of all respective sites plus one half of the standard deviation of that mean were attributed to the high mass stratum; sites with yields in between these two thresholds were attributed to the average mass stratum. Within these newly constituted strata, the average mass yield and the standard deviation were calculated. Under the hypothesis of normal distribution, these values were then used to define the range of yields per stratum, from which random values were attributed to each relevant land unit by using the function 'normal' (SAS, 2000). Trees (>4 m height) and shrubs (<4 m height) were also stratified within each land unit, based on visual estimates of crown cover from the 1997 photographs. Five classes of crown cover (%) were recognised (trees: 0, <0.5, 0.5–1.5, >1.5–4.5, >4.5; shrubs: 0, <5, 5–15, >15–45, >45). Based on data from similar Sahelian agro-ecosystems (Hiernaux and Ayantunde, 2004) it was assumed that the foliage mass of trees and shrubs equalled 37 and 27 g DM $m^{-2}$ of crown. The proportion of palatable foliage mass was defined according to a regional typology of the woody population (Hiernaux and Ayantunde, 2004).

### 2.4. Livestock tracking

The daily grazing itineraries of cattle, sheep and goats were visually observed and simultaneously tracked by a GPS[3] during three consecutive days every 5–6 weeks throughout January–December 1998, resulting in a total of 10 monitoring periods. Twelve cows (*Bos indicus*) of local breeds as well as six sheep and six goats of Sahelian type breeds were selected from three different locations within the study area (Fig. 5a) and monitored in a specified order. During the dry season, some of these animals were herded while others were left to graze freely. During the first month of the rainy season some cattle and small ruminants continued to graze on their own. Elevated contents of anti-nutritional compounds protect young millet plants from being grazed excessively, and animals grazing in fields during this period will mainly feed on weeds. However, the concentration of anti-nutritional compounds rapidly decreases as millet starts tillering; therefore all animals were herded during the mid and late rainy season. Decisions concerning herd management were left to the livestock owners.

In January 1998, the selected cows, sheep and goats weighed on average 300 kg (S.D. 35.1), 39 kg (S.D. 7.4) and 28 kg (S.D. 5.5). Live weight steadily decreased during mid and late dry season to 215 kg (S.D. 30.0), 29 kg (S.D. 8.0) and 22 kg (S.D. 3.4) in early July. During the rainy season and especially during the post-harvest period, the live weight increased again to 320 kg (S.D. 42.9) in cattle, 38 kg (S.D. 7.5) in sheep and 26 kg (S.D. 4.4) in goats until early November.

#### 2.4.1. Collection of spatial data

Four six-channel Trimble GeoExplorerII GPS receivers[4] with an external antenna of 7 cm diameter and 2.5 cm height were used for livestock tracking. The units weighed 0.4 kg and were powered by an external rechargeable 12 V 3 Ah battery, which allowed running the GPS for 8 h (sheep, goats) or 12 h (cattle). The latitude, longitude and altitude were recorded in line feature mode every 10 s for cattle and every 5 s for sheep and goats, along with the logging time. The rover position mode automatically changed from 3D to 2D mode if less than four satellites were tracked, using the last recorded altitude to calculate the position. The antenna elevation mask was set at 15°, the position dilution of precision (PDOP) mask was set at a value of 6 and the signal to noise ratio (SNR) mask at a value of 4. For differential ex post correction of the rover data, a Trimble Pathfinder Community Base Station consisting of an antenna (mounted 5 m above ground) and a 12-channel receiver connected to a laptop computer was installed 17 km NW of Chikal. The base station recorded positions at intervals of 1 s during 24 h $d^{-1}$ with both PDOP and SNR mask set at a value of 6. The GPS receivers were switched on when the animals set out for pasture in the morning. When the animals returned from pasture in the evening, the raw data files were downloaded and differentially corrected with the corresponding base station files. According to the manufacturer, positions logged with the described GPS setup are typically between 2 and 5 m off their true position after differential correction (Trimble, 2001).

To carry the equipment, animals were fitted with canvas backpacks (Schlecht et al., 2004b). The total weight load was equivalent to 2% and 8% of the average body mass of the selected cattle and small ruminants, respectively. Prior to the study, the animals were adapted to carrying the equipment. Negative effects of the equipment on the physical condition and the grazing behaviour of the animals were not observed.

#### 2.4.2. Observation and analysis of livestock behaviour at pasture

During GPS tracking, an observer followed each animal from its departure until its return to the night resting place. Every 5 min, the hushed signal of a clock synchronized with the GPS clock prompted the observer to record the animal's activity at that moment. Activities differentiated were feeding (grazing, browsing, walking between feeding stations), walking (directional movements), and resting (resting and/or ruminating, social activities and idling). Longer periods of feeding or walking (activity bouts) are sometimes interrupted by single observations of e.g. walking or resting. In order to reduce the effect of such isolated events, coherent activity bouts were produced by attributing the predominant behaviour to moving time windows of 15 min, equivalent to three observed activities. In the case of equal representation of feeding, walking and resting within these 15 min, it was assumed that the animal was predominantly feeding. To merge the behaviour recordings with the GPS data logged at 5 and 10 s intervals, the observed behaviour was interpolated to the respective points in time. Thereafter, the differentially corrected grazing itineraries were plotted on the land use maps of 1997 (itineraries from January to June 1998) and 1998 (itineraries from July to December 1998). This permitted to relate the animals' activity to the land units visited, the palatable mass of herbaceous and ligneous forage encountered and to patches of bare soil crossed. The daily grazing time was calculated from the start and end time of GPS logging. The length of the whole itinerary and of sections passed on different land units was calculated using ArcGIS 3.2. For each land use type the lengths of individual units crossed were added up to daily values. The speed of position change was calculated by dividing the distance covered by the duration of a feeding or a walking bout.

Drinking was always accounted for explicitly: even if it lasted for less than 5 min the start and end time of water consumption were recorded. Every time the animal excreted faeces or urine this was recorded. The spatial occurrence of drinking and excretion activities were determined by merging the information of time of occurrence with the

[3] GPS: Global Positioning System.
[4] Brand names are for the purpose of information only.

spatial information obtained from overlaying the animal's itinerary with the land use maps. The frequency of excretion of faeces and urine during feeding, walking and resting was calculated and compared to the excretion frequency obtained for the whole grazing day. Activity-specific excretion frequencies were also compared to the excretion frequencies calculated for the first 7.5, 13 and 22.5 min after the morning departure, the start of drinking and the end of a day resting period.

In Sahelian grazing systems, the animal's grazing area is determined by the location of the night resting place (camp) and the watering point. The mid-point between the camp and the watering point(s) was calculated for each itinerary and plotted on the land use map. A first circular buffer zone with a radius equal to the actual itinerary length divided by $\pi$ was assigned to this central point. The weighted average biomass on vegetated spots and the proportion of bare spots within this area, denominated 'actual grazing area' was calculated.

A second buffer zone, denominated 'theoretical grazing area', was calculated under the assumption that the animal could have grazed for 10 h (36 000 s) per day. The respective buffer zone was drawn around the same central point, but the radius was calculated as follows: $r\,(\text{km}) = 0.5 \times (36\,000\,(\text{s}) \times (v_{\text{feed}} \times \text{pr}_{\text{feed}} + v_{\text{walk}} \times \text{pr}_{\text{walk}}))/1000$ where $v$ is the speed of an activity (m $\text{s}^{-1}$) and pr is the proportion of daily grazing time spent per activity. For $v$ and pr, values specific for animal species and season were taken.

### 2.5. Statistical analysis

As the length and the spatial orientation of daily grazing itineraries of individual animals varied considerably during each 3-day monitoring period, each itinerary was addressed as an independent observation. All statistical tests were performed with SAS 8.1 (SAS, 2000). Multivariate analysis of variance (Proc GLM) was carried out to determine the effect of animal species (cattle, goats, sheep) and season (early dry, mid dry, late dry and rainy) on the different dependent variables. From the nonparametric Spearman correlation analysis (Proc FREQ; test scorr) it resulted that herd management (herded and free grazing) was significantly correlated to season; herd management was therefore treated as a nested parameter in the analysis of variance. For the comparison of means, the Student–Newman–Keuls multiple range test was applied. To determine the correlation between parametric variables, single and multiple linear regression analysis was carried out (Proc REG/selection = stepwise for multiple regression).

## 3. Results

Among a total of 342 GPS-tracked cattle itineraries, 77 itineraries, followed in the months of January to June, occurred during night. Since behaviour recording during night grazing was difficult, only itineraries that were followed during the day were considered here. Additionally, for all animal species, only those itineraries were considered for which at least 67% of the distance covered fell within the mapped area and which were monitored for >4 h; typically, night grazing itineraries of cattle were less than 4 h long. A number of 471 itineraries (cattle: 194, goats: 148, sheep: 129) met these criteria; however, due to incomplete parameter recording during short time intervals, 12 itineraries per species had to be excluded from some of the analyses.

In the following, the characteristics of the grazing day and the grazing itinerary are presented. The 'grazing day' comprises the time from the moment the animal leaves its night resting place until its return to this point (which is not necessarily at a fixed geographical position). The term refers to the temporal aspects of grazing, while the term 'grazing itinerary' refers to the spatial aspects. Grazing and excretion behaviour refer to activity patterns, whereby 'grazing behaviour' comprises feeding, walking, resting and drinking.

### 3.1. Characteristics of the grazing day

Forty percent of the animals set out for pasture before 07:00 h and 48% departed until 09:00 h. While differences in morning departure were small between species ($P > 0.05$), the influence of season and herd management were significant ($P < 0.001$). Evening return varied significantly between seasons, species and management modes ($P < 0.001$), although the majority of the animals (87%) returned from pasture between 16:00 and 19:00 h, and only 12% returned before 16:00 h. The average duration of the grazing day varied between 7.6 h (456 min) and 10.4 h (625 min) across seasons, species and herd management modes (Table 1). Across the year, herded livestock set out for pasture 1.5 h later but also returned to the night resting place one hour later than free grazing animals. In general, the grazing day of cattle was longer than that of sheep and goats. In 19% (goats), 29% (sheep) and 44% (cattle) of the itineraries, watering occurred either before morning departure or after evening return. In 63% (goats), 51% (sheep) and 41% (cattle) of the itineraries, one single watering occurred during the grazing day, while 18% (goats), 20% (sheep) and 15% (cattle) of the grazing days were interrupted by two watering events. The timing of watering was not influenced by season ($P > 0.05$) but was weakly correlated with animal species ($R = 0.20$, $P < 0.001$). The frequency of watering was weakly related to herd management, with free grazing animals being watered more often than herded animals ($R = 0.15$, $P < 0.001$).

The average number of activity bouts per day varied between 3.3–7.3 feeding bouts, 2.3–5.7 resting bouts and 1.4–4.8 walking bouts. The number of feeding, resting and walking bouts was not correlated to the duration of the grazing day in any of the three species but varied significantly across seasons ($P < 0.001$): walking bouts

Table 1
Duration of the grazing day of cattle, sheep and goats and distances walked per day, as influenced by season and herd management

| Season (months in 1998) | Herded | Number of observations | | | Duration of grazing day (min $d^{-1}$) | | | Length of grazing itinerary (km $d^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Cattle | Goats | Sheep | Cattle | Goats | Sheep | Cattle | Goats | Sheep |
| Mid dry (January–March) | Yes | 42 | | 24 | 551 | | 468 | 12.7 | | 10.1 |
| | No | 28 | 52 | 18 | 580 | 548 | 570 | 10.7 | 7.3 | 6.8 |
| Late dry (April–June) | Yes | 9 | | 7 | 625 | | 496 | 12.2 | | 10.1 |
| | No | 29 | 30 | 21 | 556 | 553 | 495 | 7.1 | 6.2 | 5.9 |
| Rainy (July–September) | Yes | 33 | 33 | 30 | 546 | 491 | 492 | 13.1 | 11.8 | 12.5 |
| | No | 21 | 9 | 6 | 501 | 535 | 465 | 8.4 | 8.3 | 10.3 |
| Early dry (October–December) | Yes | 29 | 20 | 20 | 482 | 461 | 456 | 13.9 | 10.8 | 11.2 |
| | No | 3 | 4 | 3 | 593 | 468 | 533 | 12.1 | 7.1 | 7.1 |
| S.E.M.[a] | | | | | | 9.25 | | | 0.68 | |

| Parameter | d.f. | $P > F$[b] (duration of grazing day) | $P > F$[b] (length of grazing itinerary) |
|---|---|---|---|
| Managament[c] | 4 | 0.05 | 0.001 |
| Species | 2 | 0.001 | 0.001 |
| Season | 3 | 0.02 | 0.03 |
| Species × season | 6 | n.s. | n.s. |

[a] Standard error of the means.
[b] Probability of a parameter effect.
[c] Nested in season.

were most frequent in the rainy and the early dry season and resting bouts were most frequent in the late dry season.

The daily number of walking and resting bouts also varied between species ($P < 0.05$) and between herd management modes ($P < 0.01$), with free grazing animals resting more frequently than herded animals. Across species, the average duration of a feeding bout ranged from 64 min in the late dry season to 80 min in the mid dry and the rainy season.

Resting bouts were shortest in the early dry season (22 min) and longest in the late dry season (50 min). The average duration of walking bouts did not vary across seasons (15–24 min), but was longer with herded than with free grazing animals, while the opposite was true for the resting bouts.

Across the whole year, all three species spent on average close to 60% of the daily grazing time on feeding, between 20–26% on walking and 12–20% on resting (Fig. 1). For each of the three activities, differences were significant between seasons ($P < 0.001$), species ($P < 0.01$) and herd management modes ($P < 0.01$); the interaction of season and species was significant for the proportion of time spent feeding ($P < 0.05$) and resting ($P < 0.01$).

### 3.2. Characteristics of the grazing itinerary

As illustrated in Table 1, herded animals walked longer distances than free grazing animals and cattle walked longer distances than sheep and goats. The length of the grazing itinerary varied independently of the duration of the grazing day, with the exception of herded sheep and cattle, for which a correlation between the duration of the grazing day and the length of the itinerary was found ($R \geq 0.60$). In all seasons herded cattle walked about 13 km during daytime, while free grazing cattle walked 7–8 km in the late dry and in the rainy season and 11–12 km in the early dry and the mid dry season. Free grazing sheep and goats covered the longest distances in the rainy season and the shortest distances in the late dry season. The maximum itinerary length was 25 km $d^{-1}$ in cattle (herded, mid dry season), 20 km $d^{-1}$ in goats (herded, rainy season) and 21 km $d^{-1}$ in sheep (herded, mid dry and rainy season).

The movement between individual feeding stations of animals at pasture occurs at a lower speed than directional long distance movements (walking). The average speed when feeding was 0.29 m $s^{-1}$ (S.D. 0.12) in cattle, 0.33 m $s^{-1}$ (S.D. 0.12) in sheep and 0.28 m $s^{-1}$ (S.D. 0.11) in goats ($P < 0.001$). The speed of walking was 0.77 m $s^{-1}$ (S.D. 0.13) in cattle, 0.8 m $s^{-1}$ (S.D. 0.16) in sheep and 0.71 m $s^{-1}$ (S.D. 0.19) in goats ($P < 0.001$). Seasonal differences in the speed of walking and of feeding ($P < 0.01$ in both cases) were observed across species ($P < 0.01$ for species × season). However, these findings must be interpreted with care, as differentiation between small-scale and large-scale movements is not always easy with a spontaneous observation of behaviour. Moreover, faulty GPS recordings (obtrusion of satellite signals, unfavourable satellite geometry) can result in a rather high or low speed calculated for a given activity. In order to partly account for these possible errors, movements of animals above a speed of 1.5 m $s^{-1}$ were excluded from the analysis. From a spatial point of view, the allocated proportion of daily grazing time (Fig. 2) varied between land use types ($P < 0.001$), seasons ($P < 0.001$) and species ($P < 0.05$), with small ruminants spending a higher proportion of time in

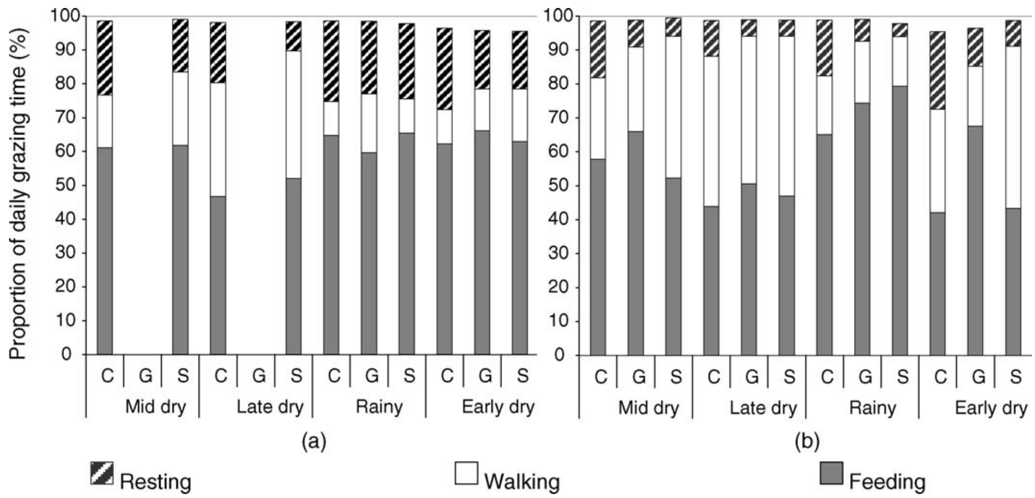


Fig. 1. Allocation of the daily grazing time of (a) herded and (b) free grazing cattle (C), goats (G) and sheep (S) to resting, walking and feeding during the early dry, mid dry, late dry and rainy season. Differences to 100% are due to missing recordings of the observer or the GPS.

and around settlements than cattle. Throughout the dry season and across the three species, fields represented the most frequently visited land use type. Significant interactions between season and species for the proportion of time spent on fields ($P < 0.01$) were due to the fact that fields were also visited frequently by free grazing sheep and goats during the first month of the rainy season. Across the year, herd management influenced the proportion of time spent on fields and on rangelands ($P < 0.001$) but not the time spent on fallows. The proportion of time spent either feeding or resting on each of the four land use types (Fig. 3) differed between species ($P < 0.05$) and herd management modes ($P < 0.05$), with small ruminants spending a higher share of feeding time on fields than cattle, especially when animals were free grazing. Seasonal differences in the spatial allocation of feeding and resting time differed at $P < 0.001$, with interactions between species and season being significant for the proportion of resting time spent on fields ($P < 0.001$).

### 3.3. Excretion behaviour

Across species and seasons, the average number of observed excretions (defecations and urinations) varied from 6–15 per grazing day (Table 2). The frequency of defecation differed between species ($P < 0.001$), the frequency of urination differed between species ($P < 0.001$) and between seasons ($P < 0.05$). The hourly number of excretions voided by cattle, sheep and goats during the grazing day (Table 2) was 0.8 (S.D. 0.38), 1.7 (S.D. 0.60) and 1.6 (S.D. 0.73). Similar to controlled feeding trials (Schlecht et al., 1998) where the number of excretions was not equally distributed between faeces and urine (0.57/0.43), more defecations than urinations were observed in the present study (cattle 0.59/0.41; goats 0.54/0.46; sheep 0.62/0.38). Throughout the year, 39% of the observed excretions occurred on cropland (Fig. 4), 31% on rangeland, 20% on fallows and 10% in and around settlements. The proportion of excretions deposited on fallows varied across seasons ($P < 0.001$), the proportion

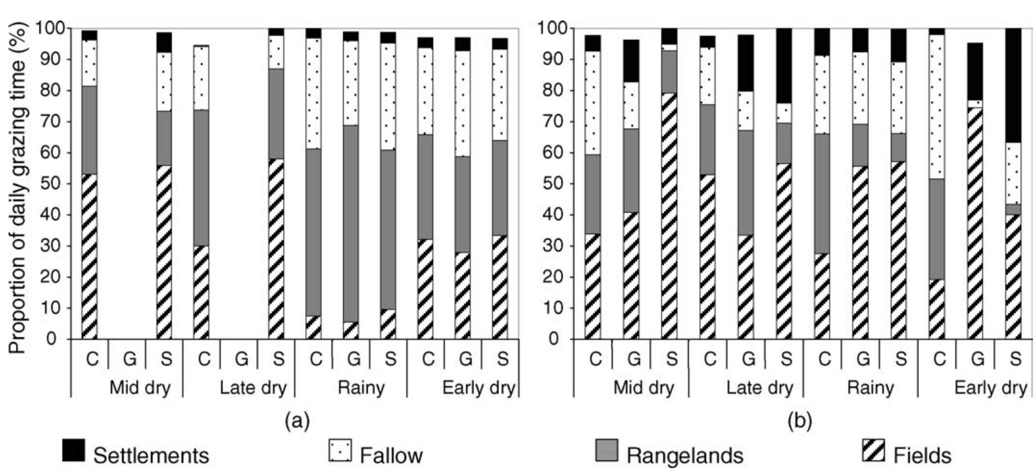


Fig. 2. Proportion of the daily grazing time of (a) herded and (b) free grazing cattle (C), goats (G) and sheep (S) spent on different land use types during the early dry, mid dry, late dry and rainy season. Differences to 100% are due to missing recordings of the observer or the GPS.

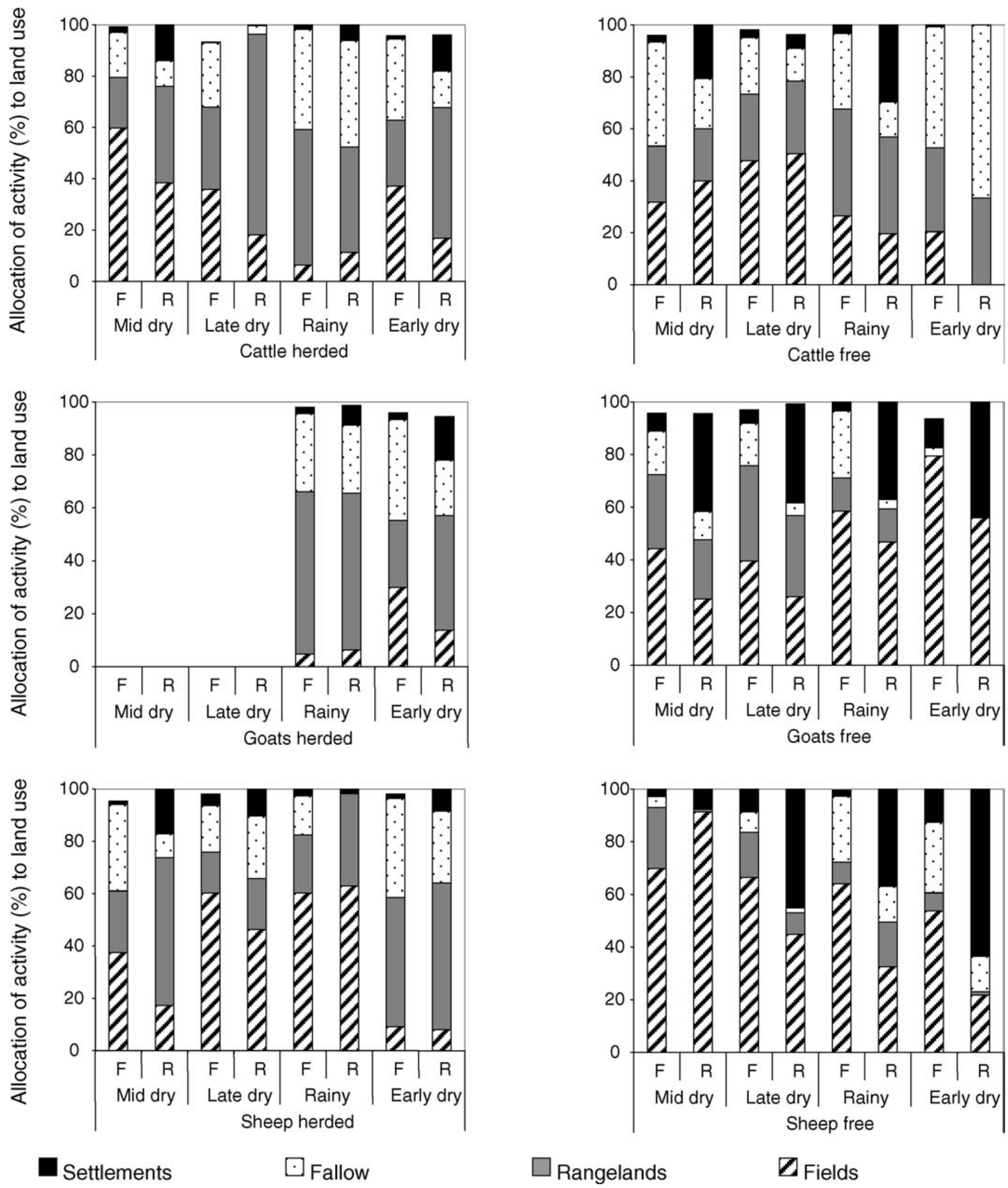


Fig. 3. Proportion of the daily feeding (F) and resting time (R) of herded and free grazing cattle, goats and sheep allocated to different land use types during the early dry, mid dry, late dry and rainy season. Differences to 100% are due to missing recordings of the observer or the GPS.

of excretions deposited on fields and rangelands differed across seasons ($P < 0.001$), species ($P < 0.01$) and herd management modes ($P < 0.001$). Due to weed grazing in fields by small ruminants in the early rainy season and the inaccessibility of the fields during two-thirds of the rainy season, interactions between species and season ($P < 0.05$) were observed for the proportion of excretions deposited on this land use type. When considering only the dry season where all land use types were equally accessible for livestock, the proportion of observed excretions changed considerably for fields (47%) and rangelands (25%) but not for fallows and settlements (18%, 11%).

Simple linear regression analysis showed that the proportional distribution of excretion events was strongly correlated to the proportion of total grazing time spent per land use type. Hereby it was assumed that excretions can only occur in places where animals spend at least 5 min and the intercept was set at zero. The analysis was performed on the whole set of data (1252 observations of visited land use types × observed excretions) as well as on the data sets obtained per species and per species and season. The resulting *x*-coefficients varied between a minimum of 0.90 and a maximum of 1.04, the correlation coefficients varied between $R = 0.90$ and 0.96 with $P < 0.001$ in all cases. Correlations of both the proportion and the number of excretion events per land use type with the actual amount of time spent there were less close. The influence of the activity (daily proportion of walking, feeding and resting time)

Table 2
The number of faecal and urine excretions observed during the grazing day of cattle, goats and sheep[a], the hourly excretion rates of faeces and urine during the grazing day, and during feeding, resting, walking and drinking, and excretion rates within the first 7.5 min after morning departure, start of drinking and end of a resting period

| | Observed excretions during the grazing day ($n$) | | | | Hourly excretion rate ($n$, $h^{-1}$) | | | | | Hourly excretion rate ($n$, $h^{-1}$) within 7.5 min after | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mid dry | Late dry | Rainy | Early dry | Whole day | Feeding | Resting | Walking | Drinking | Morning departure | Start of drinking | End of resting |
| Faeces | | | | | | | | | | | | |
| Cattle | 3.8 | 3.4 | 4.6 | 5.7 | 0.49 | 0.42 | 0.76 | 0.46 | 0.80 | 2.89 | 1.21 | 0.66 |
| Goats | 7.4 | 7.5 | 7.0 | 6.6 | 0.84 | 0.80 | 0.77 | 1.22 | 0.45 | 3.85 | 0.78 | 1.17 |
| Sheep | 9.2 | 7.7 | 8.2 | 9.3 | 1.08 | 0.96 | 1.24 | 1.43 | 1.36 | 4.71 | 1.37 | 1.42 |
| S.E.M.[b] | | | 0.61 | | 0.078 | 0.073 | 0.105 | 0.145 | 0.162 | 0.400 | 0.145 | 0.126 |
| Parameter | d.f. | | | | | | $P > F$[c] | | | | | |
| Species | 2 | | 0.001 | | 0.001 | 0.001 | 0.001 | 0.001 | 0.02 | n.s. | n.s. | 0.001 |
| Season | 3 | | n.s. | | 0.02 | n.s. | 0.001 | n.s. | 0.02 | 0.02 | n.s. | n.s. |
| Species × season | 6 | | n.s. | | n.s | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Urine | | | | | | | | | | | | |
| Cattle | 2.7 | 2.2 | 3.2 | 3.9 | 0.33 | 0.29 | 0.45 | 0.31 | 0.59 | 1.60 | 0.64 | 0.51 |
| Goats | 7.9 | 5.7 | 4.9 | 4.7 | 0.72 | 0.67 | 0.64 | 0.94 | 0.71 | 2.31 | 1.14 | 0.90 |
| Sheep | 5.8 | 4.2 | 4.6 | 5.9 | 0.64 | 0.58 | 0.63 | 0.64 | 0.76 | 2.71 | 0.76 | 0.78 |
| S.E.M.[b] | | | 0.52 | | 0.060 | 0.056 | 0.061 | 0.086 | 0.123 | 0.238 | 0.156 | 0.113 |
| Parameter | d.f. | | | | | | $P > F$[c] | | | | | |
| Species | 2 | | 0.001 | | 0.001 | 0.001 | n.s. | 0.001 | n.s. | n.s. | n.s. | 0.05 |
| Season | 3 | | 0.001 | | 0.01 | n.s. | 0.03 | n.s. | 0.03 | n.s. | 0.01 | 0.03 |
| Species × season | 6 | | 0.001 | | 0.001 | 0.01 | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |

[a] Number of observations are given in Table 1.
[b] Standard error of the means.
[c] Probability of a parameter effect.

observed per land use type on the proportion of excretions deposited there was tested by stepwise multiple linear regression. Across seasons and livestock species, the proportion of feeding time allocated to a land use type explained 81% of the variation in the proportion of deposited excretions ($P < 0.001$, $n = 1175$), while the proportion of resting time explained 3% and the proportion of walking time explained only 1% of this variation. Analysing the data separately for each animal species, the proportion of feeding time explained 88% (goats; $P < 0.001$, $n = 373$), 85% (sheep; $P < 0.001$, $n = 334$) and 73% (cattle; $P < 0.001$; $n = 468$) of the variation in the proportion of excretions deposited, while the other two activities explained 5% (cattle) or less (sheep, goats) of that variation. Since activity patterns per land use type differed between seasons, the analysis was also run on the data sets obtained per species and season. Here, two major deviations from the general picture were observed: in the late dry season, the proportion of resting and feeding time per land use type explained 67% and 12% of the variation in the proportion of excretions deposited by cattle and 14% and 76% of that variation in sheep.

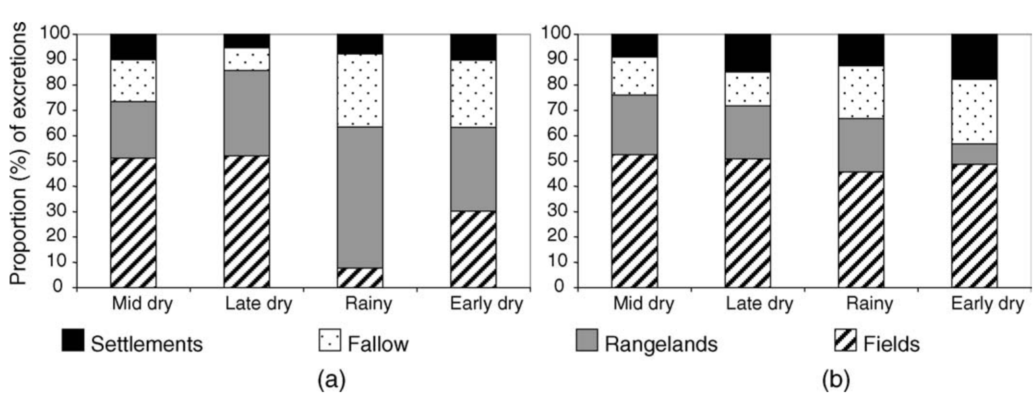


Fig. 4. Proportional allocation of excretions of (a) herded and (b) free grazing ruminant livestock (urine and faeces; observed events) to different land use types during the grazing day.

Table 3
Total biomass of crop residues and weeds on fields and of herbaceous vegetation on fallows, rangelands and thickets as determined by destructive sampling in October 1997 and October 1998, and coefficients used to calculate monthly offer of total and palatable forage for different land use types

| Month | Parameter | Crop residues | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Millet planting density | | | Weeds | Herbaceous vegetation | | |
| | | Low | Average | High | | Fallow | Rangelands | Thickets[a] |
| October 1997 | Mass (kg DM $ha^{-1}$) | 1063 | 2084 | 3253 | 95 | 578 | 124 | 837 |
| | S.D. | 279.6 | 253.0 | 1205.8 | 20.9 | 268.8 | 70.6 | 1056.5 |
| | Palatable fraction | 0.70 | 0.66 | 0.65 | 0.59 | 0.85 | 0.88 | 0.82 |
| January 1998 | Mass relative to October 1997 | 0.86 | 0.92 | 0.79 | 0.19 | 0.35 | 0.52 | 0.52 |
| February 1998 | | 0.82 | 0.74 | 0.43 | 0.22 | 0.23 | 0.41 | 0.41 |
| March 1998 | | 0.79 | 0.60 | 0.23 | 0.25 | 0.11 | 0.31 | 0.31 |
| April 1998 | | 0.67 | 0.51 | 0.21 | 0.22 | 0.09 | 0.25 | 0.25 |
| May 1998 | | 0.57 | 0.44 | 0.19 | 0.19 | 0.07 | 0.19 | 0.19 |
| June 1998 | | 0.48 | 0.38 | 0.17 | 0.17 | 0.06 | 0.12 | 0.12 |
| October 1998 | Mass (kg DM $ha^{-1}$) | 1087 | 2351 | 4549 | 299 | 1268 | 266 | 1400 |
| | S.D. | 507.3 | 196.2 | 677.0 | 76.1 | 587.5 | 132.9 | 233.8 |
| | Palatable fraction | 0.70 | 0.67 | 0.69 | 0.55 | 0.79 | 0.85 | 0.75 |
| July 1998 | Mass relative to October 1998 | n.a. | n.a. | n.a. | n.a. | 0.14 | 0.02 | 0.02 |
| August 1998 | | n.a. | n.a. | n.a. | n.a. | 0.28 | 0.04 | 0.04 |
| September 1998 | | n.a. | n.a. | n.a. | n.a. | 0.53 | 0.20 | 0.20 |
| October 1998 | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| November 1998 | | 0.98 | 0.85 | 0.84 | 0.82 | 0.93 | 0.87 | 0.87 |
| December 1998 | | 0.95 | 0.72 | 0.95 | 0.68 | 0.86 | 0.75 | 0.75 |

[a] Used for the calculation of biomass offered on individual land units; in the text and in Fig. 5, thickets are subsumed under rangelands.

During the first 7.5 min following (i) the morning departure, (ii) the start of drinking or (iii) the end of a day resting period, excretion rates were significantly higher than the average rate observed for the three major activities and for the grazing day as a whole (Table 2). The excretion frequencies observed during 13 and 22.5 min after the aforementioned activity changes were lower than the respective average values, demonstrating that these activity changes immediately triggered excretions. Across species, the morning departure triggered the highest number of defecations, followed in cattle by the start of drinking and the end of resting. In small ruminants the end of resting triggered defecations more frequently than the start of drinking. A similar picture was observed for urinations. The morning departure had the highest impact on urination frequency, followed in cattle and goats by the start of drinking and the end of resting, while in sheep urinations were observed more frequently at the end of resting than at the start of drinking.

### 3.4. Forage availability along the grazing itinerary

Across the territory, the ligneous strata was dominated by the trees *Acacia nilotica* (L.) Willd. ex Del., *Balanites aegyptiaca* (L). Del., *Combretum glutinosum* Perr. ex DC., *Faidherbia albida* (Del.) A.Chev. and the shrub *Guiera senegalensis* J.F.Gmel. Species such as *Combretum micranthum* G.Don, *Boscia angustifolia* A.Rich., *Piliostigma reticulatum* (DC.) Hochst., *Prosopis africana* (Guill. et Perr.) Taub., and *Sclerocarya birrea* (A.Rich.) Hochst. were also present. In settlements and their surroundings the planted species *Azadirachta indica* A. Juss, *Hyphaene thebaica* (L.) Mart. and *Prosopis juliflora* (Sw.) DC. were found. The herbaceous vegetation of fallows and rangelands was dominated by the grasses *Cenchrus biflorus* Roxb., *Eragrostis tremula* Hochst. ex Steud., *Pennisetum pedicellatum* Trin., *Panicum laetum* Kunth, *Schoenefeldia gracilis* Kunth, *Schizachyrium exile* (Hochst.) Pilger and *Aristida sieberiana* Trin., and by the dicotyledonous species *Alysicarpus ovalius* (Schum. &. Thonn.) J. Léonard, *Mitracarpus scaber* Zucc., *Zornia glochidiata* Reichb. ex DC., *Sesamum alatum* Thonn., *Jacquemontia tamnifolia* (L.) Griseb., *Tribulus terrestris* L. and *Sida cordifolia* L. Millet crop residue yield was higher in October 1998 than in October 1997, especially on fields with high planting densities (Table 3). Likewise, at 299 kg DM $ha^{-1}$ the weed biomass available in millet fields after the 1998 harvest was three times higher than the values determined in October 1997. At 1268 and 266 kg DM $ha^{-1}$ in October 1998, fallows and rangelands supplied approximately twice the amount of herbaceous feed than in October 1997. While biomass disappearance during the 1997/1998 dry season was relatively rapid on fallows and medium and high yielding millet fields, biomass disappearance was much slower on the rangelands and on low yielding millet fields. The spatial distribution of all feed resources, namely browse, palatable millet crop residues and herbaceous biomass is illustrated in Fig. 5a and b.

The seasonal variation in forage mass encountered on vegetated patches along the animals' itineraries and the proportion of bare soil patches crossed (including settlements)

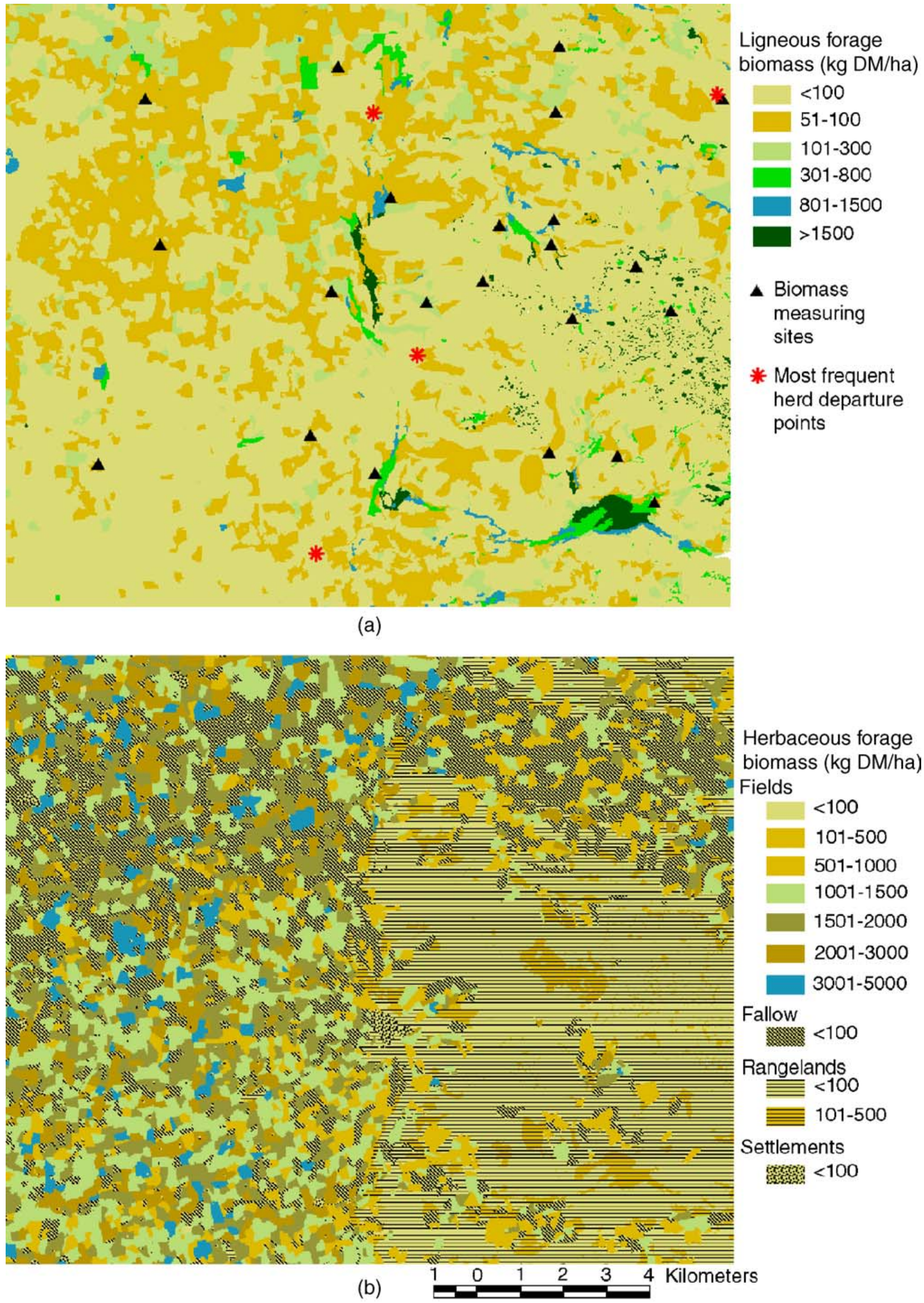


Fig. 5. Spatial repartition of (a) ligneous and (b) herbaceous forage resources (total foliar and herbaceous mass) in the territory of Chikal, Western Niger, as determined through interpretation of aerial photographs taken in September 1997 in combination with destructive biomass sampling in October 1997.

is given in Table 4. For the example of the mid dry season, herded cattle encountered on average 387 kg DM $ha^{-1}$ (equivalent to 38.7 g DM $m^{-2}$) of palatable herbaceous forage including millet crop residues on the vegetated patches along their itinerary. However, 56% of the itinerary led through bare soil. These values translate to 16.9 g DM $m^{-2}$ of herbaceous forage on offer along every meter of the itinerary if the vegetation was distributed homogenously. Availability of herbaceous vegetation along the itinerary was highest after millet harvest (early dry season), followed by the mid dry and the late dry season, while the lowest values were determined in the rainy season. Herded cattle generally encountered a higher mass of palatable herbaceous forage on vegetated patches than free grazing cattle, while this picture was much less pronounced in small ruminants. Especially when accounting for the bare soil patches, the marked differences in forage encountered by free grazing as opposed to herded sheep and goats (>300 kg DM $ha^{-1}$) were reduced to

Table 4
Fraction of bare soil patches crossed and forage availability along the daily grazing itinerary of cattle, goats and sheep[a] as influenced by season and herd management

| Season | Herded | Fraction of bare soil crossed | | | Availability of palatable forage mass (kg DM ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Herbaceous plants | | | Browse | | |
| | | Cattle | Goats | Sheep | Cattle | Goats | Sheep | Cattle | Goats | Sheep |
| Mid dry | Yes | 0.56 | | 0.54 | 387 | | 401 | 28 | | 20 |
| | No | 0.47 | 0.57 | 0.63 | 277 | 330 | 753 | 41 | 39 | 7 |
| Late dry | Yes | 0.44 | | 0.60 | 99 | | 209 | 75 | | 37 |
| | No | 0.53 | 0.58 | 0.70 | 175 | 94 | 170 | 23 | 86 | 12 |
| Rainy | Yes | 0.53 | 0.55 | 0.53 | 88 | 64 | 82 | 40 | 39 | 35 |
| | No | 0.47 | 0.56 | 0.55 | 37 | 28 | 29 | 64 | 39 | 19 |
| Early dry | Yes | 0.53 | 0.49 | 0.49 | 599 | 670 | 658 | 26 | 30 | 28 |
| | No | 0.45 | 0.68 | 0.65 | 493 | 1202 | 1015 | 60 | 8 | 22 |
| S.E.M.[b] | | | 0.012 | | | 60.2 | | | 4.2 | |
| Parameter | d.f. | | | | | $P > F$[c] | | | | |
| Managament[d] | 4 | | 0.03 | | | 0.01 | | | 0.03 | |
| Species | 2 | | 0.01 | | | 0.01 | | | 0.001 | |
| Season | 3 | | n.s. | | | 0.001 | | | 0.001 | |
| Species × season | 6 | | 0.01 | | | 0.001 | | | 0.001 | |

[a] Number of observations are given in Table 1.
[b] Standard error of the means.
[c] Probability of a parameter effect.
[d] Management: nested in season.

differences of less than 50 kg DM ha$^{-1}$ in the early dry season. For the offer of palatable browse along the itinerary the picture was less clear than for the annual plants, probably due to the different leaf growing cycles of the various ligneous species (Von Maydell, 1990). Considerable amounts of browse were however encountered during the late dry season and the rainy season.

To determine whether differences existed in the amount of forage encountered during feeding as compared to walking and resting, indices were calculated that related the accumulated forage mass encountered per activity to the average forage mass encountered during the grazing day. Indices >1.0 suggest that the particular activity generally took place on patches offering more than the average amount of forage, while indices <1.0 imply the contrary. Across seasons, herded animals of any species always fed on patches offering more than the average amount of palatable herbaceous forage (indices >1.1), while indices of 0.7–0.9 were found for resting and walking ($P < 0.001$). In free grazing goats and sheep, indices of 1.0 and 1.2, respectively, were obtained for feeding as compared to 0.9 for free grazing cattle ($P < 0.05$). For resting, indices >1.0 were obtained in free grazing cattle and sheep (goats: 0.6). For walking, an index of 1.2 was calculated for goats and cattle and an index of 0.9 for sheep. For the mass of palatable browse encountered, indices for feeding were >1 across species and herd management modes. Indices for resting of 1.1–1.4 and indices for walking of <1.0 were calculated for herded animals. For free grazing animals, indices obtained for resting and walking varied between 0.8 and 1.0.

To test whether the grazing itinerary chosen by the animals or their herders maximised the forage availability, the average palatable plant mass on vegetated patches along itineraries was compared to that of vegetated patches in the actual grazing area and in the potential grazing area, respectively (for definitions see Section 2.4.2). The exercise was carried out for the mid and the late dry season. Within the theoretical choices the herder or the animal had, the itinerary actually chosen presented the highest amount of forage to herded cattle and sheep as well as to free grazing sheep. In free grazing goats the opposite was observed as far as the herbaceous forage mass was concerned, while the amount of browse encountered along their itineraries was higher than the weighted average amount available in both the actual and the potential grazing area, and the same was observed for free grazing cattle. Except for free grazing sheep, the proportion of bare soil crossed by the animals' itineraries was always lower than the weighted average of bare soil patches within the actual and the potential grazing area (Table 5).

## 4. Discussion

The response of grazing cattle to the spatio-temporal variability of vegetation resources was studied by Dicko (1983) in the rice-perimeters of Central Mali, by Turner (1998) in the Inner Delta of the river Niger and by Scoones (1995) in a savannah system in southern Africa. Likewise, studies on grazing behaviour and feed intake mostly

Table 5
Fraction of bare soil patches crossed and forage availability along the daily grazing itinerary of cattle, goats and sheep as compared to the fraction of bare soil and forage availability in the actual and potential grazing area[a]. The data covers the mid and late dry season (January–June 1998)

| | Cattle, herded | | Goats, herded | | Sheep, herded | |
|---|---|---|---|---|---|---|
| | Yes ($n = 15$) | No ($n = 36$) | Yes | No ($n = 39$) | Yes ($n = 11$) | No ($n = 21$) |
| Fraction of bare soil patches | | | | | | |
| Itinerary | 0.57 | 0.47 | | 0.54 | 0.55 | 0.67 |
| Actual area | 0.63 | 0.54 | | 0.59 | 0.6 | 0.55 |
| Potential area | 0.63 | 0.56 | | 0.59 | 0.62 | 0.55 |
| S.E.M.[b] | 0.019 | 0.028 | | 0.015 | 0.019 | 0.038 |
| Parameter (d.f. = 2) | | | $P > F$[c] | | | |
| Grazing area (I, A, P) | 0.05 | 0.01 | | 0.01 | 0.05 | 0.001 |
| Availability of palatable herbaceous vegetation (kg DM $ha^{-1}$) | | | | | | |
| Itinerary | 396 | 222 | | 160 | 396 | 467 |
| Actual area | 245 | 237 | | 232 | 279 | 224 |
| Potential area | 255 | 223 | | 238 | 279 | 231 |
| S.E.M.[b] | 49.1 | 5.0 | | 25.3 | 39.5 | 80.3 |
| Parameter (d.f. = 2) | | | $P > F$[c] | | | |
| Grazing area (I, A, P) | 0.001 | n.s. | | 0.01 | n.s. | 0.05 |
| Availability of palatable browse (kg DM $ha^{-1}$) | | | | | | |
| Itinerary | 23 | 30 | | 84 | 16 | 10 |
| Actual area | 20 | 22 | | 24 | 18 | 24 |
| Potential area | 20 | 23 | | 23 | 20 | 27 |
| S.E.M.[b] | 1.0 | 2.3 | | 20.4 | 1.0 | 5.4 |
| Parameter (d.f. = 2) | | | $P > F$[c] | | | |
| Grazing area (I, A, P) | n.s. | n.s. | | 0.001 | n.s. | 0.001 |

[a] For calculation of actual and potential grazing area see Section 2.
[b] Standard error of the means.
[c] Probability of a parameter effect; ANOVA was done for each species separately.

focussed on cattle (Dicko, 1983; Mahler, 1991; Ayantunde et al., 1999; Ickowicz et al., 1999; Rath, 1999; Schlecht et al., 1999a), despite the considerable general interest in the livestock component of the agro-pastoral and pastoral Sahelian production systems (e.g., Colin de Verdière, 1995; Thébaud, 1999; Schareika et al., 2000; Slingerland, 2000). Rather than quantifying the intake and excretion of organic matter and nutrients by grazing livestock (Ickowicz et al., 1999; Schlecht et al., 2004a), the present study tried to elicit the spatial and temporal variability of grazing and excretion behaviour of cattle, sheep and goats within communally exploited grazing areas of the Sahelian zone.

### 4.1. Major aspects of grazing and excretion behaviour

The spatial occurrence of grazing reflects the animals' or the herders' response to landscape heterogeneity and to the accessibility, quantitative offer and quality or palatability of forage (Scoones, 1995). The amount of forage available to grazing animals depends primarily on the season, but is also influenced by the land use patterns. Depending on the area of land cropped, a sometimes very important portion of the dry season grazing area is not accessible for livestock during the rainy season. This limits the amount of forage to what is available on fallows and rangelands. In addition, rainy season access to fallows that are encircled by fields may be impossible if livestock paths or tracking corridors are lacking or have been usurped by fields (Tielkes et al., 2001). However, the ongoing replacement of fallows and rangelands by expanding cropland (Wezel and Haigis, 2002) does not imply a reduction in the quantity and quality of dry season livestock feed, as dry herbaceous fallow vegetation and millet crop residues are similar in their nutritional value (Schlecht et al., 1998). The obtained results on biomass yields also indicate that the mass of livestock forage per hectare is mostly higher with millet crop residues than with the annual herbaceous vegetation on fallows and rangelands, which is supported by the data of Turner et al. (2005). Independent of the type of land use and biomass yield, forage supply diminishes as the dry season progresses, which increasingly limits forage intake of grazing animals (Ayantunde et al., 1999; Rath, 1999; Schlecht et al., 1999a). In the present study, free grazing sheep and goats responded to this by a reduction of the length of their daily itineraries by approximately 1 km in the late dry season as compared to the early and mid dry season, and free grazing cattle reduced their day grazing itineraries by 5 km. Since night grazing was not accounted for in the present study, it is however probable that some of these cattle added a night grazing period of 3–4 h to the day grazing period, during which they might have walked additional 4–5 km (Ayantunde et al., 2000; Schlecht et al., 2003). Herders, on the other hand, maintained itinerary lengths of 10–13 km $d^{-1}$ across species and across the whole year. From a nutritional point of view, both strategies present advantages. Walking long distances might allow the animal to gain access to less exploited pasture areas and maintain a certain level of feed intake. Reducing itinerary length on the other hand may also be a reasonable strategy at times when the energy requirement for walking, feed intake and maintenance of body functions exceeds the amount of metabolizable energy gained from the ingested feed, as is the case in the late dry season (Schlecht et al., 1999b). Considering the energy requirements for maintenance and walking of Nigerien breeds of zebu cattle (Rometsch, 1995), a free grazing cow of 250 kg live weight would need additional 200 g DM of dry season feed if it increased its late dry season itinerary by 5 km $d^{-1}$ (Schlecht et al., 2003). While herders are informed about areas where feed might still be more abundant and can guide their herds accordingly, free grazing animals have to learn about these areas first. The chance for this decreases with increasing distance of the pasture from the animals' night resting place (Dumont and Gordon, 2003), which partly explains why free grazing animals reduced their grazing itineraries.

The allocation of the daily grazing time to different land units varied considerably between animal species, seasons and herd management modes. Comparing the proportion of time spent per land use type with the overall share of that land use type in the territory revealed that free grazing animals, and especially small ruminants, spent a disproportionately high share of time in and around settlements. In herded animals, the patterns of grazing time allocation to land use types were much more regular across livestock species and across seasons. However, neither the proportional share of land use types within the territory nor the total forage mass present on the different land use types would have permitted an acceptable prediction of the actual allocation of time to different land use types. For this parameter, factors such as the botanical composition of the vegetation on offer, the location of the night resting place and the watering point(s) are of great influence (Turner and Hiernaux, 2002). Figs. 2 and 3 show that once the share of feeding and resting time in the daily grazing time are known, the spatial repartition of both activities can be estimated reasonably well from the spatial repartition of the daily grazing time, a finding that might be of use for the assessment of the spatial distribution of grazing activities in similar studies.

The spatial distribution of faecal and urinary excretions across the different land use types was closely related to the proportion of time spent there. The excretion frequencies per activity or during the grazing day as a whole that were obtained in the present study can be used to predict the proportional repartition of excretion events across landscapes, if the allocation of grazing time to land units or land use types is known. The values can however not be directly translated into information on the amount of faeces or urine excreted per unit or per type of land. Controlled feeding trials demonstrated that the amount of faeces excreted during the day is lower than the amount of faeces excreted during the night, pointing to diurnal variation in the hourly excretion rates of faecal mass (Schlecht et al., 1998). Although addressed as continuous process in digesta flow models (e.g. Huhtanen and Kukkonen, 1995), the excretion of faeces – and of urine alike – is triggered by activity, especially when changing from an inactive (resting) phase to an active phase, as is the case at morning departure (end of the night resting period) and when resuming feeding or walking after a period of day rest. This was for example reflected by the high proportion of excretions voided on unproductive land, where especially free grazing small ruminants spent a considerable share of their resting time. When aiming at reducing the amount of nutrients excreted on these lands (e.g. settlements, barren land surrounding watering points), the livestock manager has to take care that resting is spatially targeted to, e.g. cropland, which implies that animals must be herded. However, only when practiced over a certain time span and by a sufficiently large number of animals, the amount of manure deposited will be sufficient to substantially improve the soil fertility of the targeted sites.

### 4.2. Forage supply along itineraries and in potential grazing areas

For the amount of ligneous forage encountered along the animals' itineraries no clear seasonal variation was determined. Rather, the values depended on the livestock management and on the species-specific behaviour at pasture. Especially goats, known for the high share of browse feed in their diet (Van Soest, 1994) selected itineraries encountering a high amount of trees and shrubs. But free grazing cattle also encountered a high share of browse along their pathways—the calculated selection indices suggest that the animals actively fed on the ligneous plants rather than rested in their shade.

The availability of total and of palatable herbaceous forage along the animals itineraries varied considerably with season. The lowest forage availability was encountered in the rainy season, due to the vegetation cycle of annual plants but also due to the reduced availability of land units that are accessible for grazing at that time of the year. Evaluated on the purely quantitative basis of forage offered per square meter, the rainy season is thus a very crucial period to animal nutrition in the agro-pastoral territories of the Sahel. Especially for cattle, which on a per animal basis need to ingest much more feed than small ruminants, this situation can lead to problems of quantitative undernutrition (Klein, 1981). But even in small ruminants the amount of feed available per animal can be severely restricted if an elevated number of animals remains in the territory during the rainy season. Therefore the practice of large-scale rainy season transhumance is crucial to adequate livestock nutrition as cropping intensity in the agro-pastoral Sahelian zone increases (Turner et al., 2005).

Comparing the amount of forage offered and of bare soil patches crossed along the animals' grazing itineraries with the respective average weighted values calculated for the actual and potential grazing area, it emerged that in most cases the path the animal or the herder chose offered more than an average amount of forage. The evaluation of the weighted average amount of forage encountered per hectare or square meter is however incomplete unless the length of the grazing itinerary is taken into account. The length of the daily itinerary was not determined by the time the animals spent walking; in general, a larger distance was covered during feeding than during walking. This can be ascribed to the relatively low density of the herbaceous vegetation, which is reflected in the high fraction of bare soil patches crossed. In most cases, these patches represent a few square meters of bare soil alternating with similar sized vegetated patches. To cover the distances between adjacent vegetated patches, walking between feeding stations is an inherent part of feeding in this system, resulting in the relatively high average speed of feeding of 0.3 m $s^{-1}$ obtained across the three livestock species.

Multiplying the weighted average amount of palatable forage per square meter with itinerary length results in the total amount of forage encountered during the grazing day, from which the animal can select and ingest. When calculating this value for example for cattle during the rainy season, it appeared that herded animals encountered 544 kg DM of palatable herbaceous vegetation along their daily itinerary as compared to 165 kg DM encountered by free grazing cattle. An equally contrasted picture was obtained for herded and free grazing sheep in the rainy season but also in the late dry season. These findings demonstrate the clear superiority of herding in terms of feed made available to the grazing animal, especially in the aforementioned periods of acute feed scarcity or inaccessibility. Although the effect of season clearly dominates among the factors determining feed availability to livestock, herding can greatly increase the amount of forage offered to livestock within the set margins and improve their possibility to select and ingest feed. In addition, herding distributes grazing pressure more homogeneously across a given area and thus reduces the danger of unfavourable changes in vegetation parameters through overgrazing (Turner et al., 2005). By changing livestock management from herding to free grazing, a higher proportion of grazing time concentrates on fewer land units, especially in the vicinity of the animals' night resting place and of settlements (Turner et al., 2005). In the present study this trend was indicated by the reduced grazing radius of free grazing animals with declining forage availability. It certainly depends on the individual land use patterns, the species composition of the livestock herd and the overall livestock density of individual village territories along with the annual forage supply whether grazing has to be spread across land units or can be more concentrated, especially on cropland. Therefore recommendations concerning herd management can only be contextual and have to be fine-tuned regularly.

### 4.3. Using GPS and GIS in grazing studies

Until present the application of GIS tools to questions of resource management remains poorly developed in semi-arid Africa (Turner, 2003). The use of GIS can provide a broader spatial context for the verification and extrapolation (upscaling) of principles and relationships observed by localized fieldwork (Turner, 2003; Schlecht and Hiernaux, 2004). As demonstrated in the present study, the combined use of GPS and GIS tools enables a spatially explicit analysis of the grazing and excretion behaviour of livestock across vast and heterogeneous areas. The integration of spatially explicit data on vegetation parameters such as palatable forage mass (which incorporates information about species composition) and on the expansion of bare soil patches within land units allows for a refined analysis of an animal's behaviour at pasture. The human component, which determines land use and herd management, is implicitly integrated in such an approach (Turner, 2003) and can be made more explicit where needed. Although the amount of information and the level of detail required to yield more than a visualisation of the spatial distribution of resources and livestock pathways must not be underestimated, the approach provides an excellent basis for the spatio-temporal modelling of livestock–resource interactions at the scale of a defined pasture of several hectares (Ganskopp et al., 2000), a village territory of several hundred square kilometres (Schlecht et al., 2004a; Turner et al., 2005) or a whole region exploited by mobile livestock herds (Schareika et al., 2000).

## 5. Conclusion

GPS/GIS-based analysis of the spatial repartition of grazing and excretion activities in relation to forage availability showed that herding has the potential to greatly improve livestock nutrition by increasing forage availability and distributing grazing pressure more homogeneously across a given territory, thereby reducing the danger of unfavourable changes in vegetation parameters. At the present expansion of cropland and marked increase in numbers of small ruminants over that of cattle (FAO, 2004), Sahelian farmers should be averted to increase their labour investments in herding. Herding can also enhance manure return to cropland when accounting for the increased defecation frequency at the morning departure and after periods of day rest, especially when the animals' time on barren land is reduced concomitantly.

On a broader level, the present information on the variation of grazing and excretion behaviour with respect to ruminant species, land use type, forage supply, season and herd management can be coupled with quantitative data on the daily or hourly amount of feed ingested and urine and faeces excreted. In this way, the data can be used to generate estimates of livestock-mediated nutrient budgets for land units and land use types within the agro-pastoral Sahelian landscapes (Schlecht et al., 2004a) and help identify possibilities for a judicious use of those resources that are determinant for these processes, namely forage and livestock manure.

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