

The Distribution of Grazing Pressure in Relation to Vegetation Resources in Semi-arid West Africa: The Role of Herding

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ABSTRACT

In semi-arid West Africa, livestock are increasingly managed by sedentary producers in close proximity to expanding cropped lands. To evaluate the agricultural and environmental implications of this trend, a study was conducted to investigate the effect of grazing management on the spatial distribution of grazing pressure, the forage provided animals during the grazing period, and local herd-forage ratios across three agropastoral landscapes characterized by varying cultivation pressure. During the 19-month study period, data on herbaceous vegetation, livestock populations, and grazing itineraries were collected. These data were referenced to land units averaging 70 ha in area. Using this approach, each of 3,819 grazing itineraries was characterized as to: 1. the sum of the products of the palatable forage mass of a particular land unit and the time spent grazing by the herd within that unit (FAT, expressed in kg-hours ha⁻¹); and 2. the average palatable herbaceous forage mass

encountered by livestock across the itinerary weighted by the time spent in the land units crossed (FA, expressed in kg ha⁻¹). The spatial dispersion of livestock grazing around human settlements was found to decline with a reduction in herding labor investment (herded>herd-release>free pasture). Multiple regression analyses of itinerary data demonstrate that both FAT and FA also decline with a reduction in herding labor investment. Herded and herd-release managed livestock were offered more palatable forage and grazed areas of higher forage availability than free-pastured animals. This supports arguments that as the investment of time and effort into herding declines, feed supply to livestock will decline and the potential for grazing-induced environmental change will increase.

Key words: agropastoralism; cultivation pressure; forage availability; environmental monitoring; GIS; livestock management; Niger.

INTRODUCTION

In semi-arid West Africa, livestock are increasingly managed within agricultural zones on a year-round basis. This trend has been driven in part by a shift in livestock ownership to farmers, merchants, and

government officials from traditional livestock-rearing peoples, who now rely increasingly on crop agriculture for subsistence. Increased reliance on cropping and a decline in self-owned stock within herds have resulted in the diversion by many agropastoral households of labor away from herding resulting in labor commitments below those required to maintain wider patterns of livestock mobility (Bonfiglioli 1990; Turner 1999). As a

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result of these changes, a greater share of regional livestock remains in agricultural areas throughout the year (Bourn and Wint 1994). In certain areas of very high cropping pressure, the expansion of fields effectively blocks even local movements of livestock during the cropping season so that livestock have become increasingly managed near particular human settlements year-round (Hellemans and Compere 1990; van Driel 1997).

There is considerable debate about the implications of this trend for sustained agricultural productivity in agropastoral areas. Some have emphasized the manuring benefits associated with the increased year-long proximity of livestock to cropped fields (Bosma and others 1999; Bourn and Wint 1994; Pieri 1992). Others, evaluating this trend at broader spatiotemporal scales, have argued that manuring benefits will decline as cropping densities increase and that any decreases in livestock dispersion and mobility will lead to grazing-induced environmental change (Powell and others 1996; van Keulen and Breman 1990). A major uncertainty that underlies widely divergent predictions of the economic and environmental futures of the agropastoral zone of semi-arid Africa is the changing spatiotemporal distribution of livestock as cropping pressures increase and labor is diverted away from grazing management (Turner 1995). Changes in grazing management would be expected in agropastoral areas as local pasture availability declines; nontraditional livestock owners take over grazing management responsibility for their livestock; and the traditional livestock managers ("pastoralists") divert household labor away from herding to other pursuits, crop farming in particular. Some studies point to large variations between and within villages with respect to how the grazing of livestock is managed (Faugère and others 1990; Koyate 1987; Moulin 1993; Schlecht and others 2001; Turner 1995). Grazing management, by affecting the location of animals' activities, affects the spatiotemporal distribution of manure deposition and grazing pressure with respect to cropped and vegetated patches across the agropastoral landscape (Niamir-Fuller 1999; Scoones 1994).

THE EFFECT OF GRAZING MANAGEMENT ON SUSTAINED LIVESTOCK PRODUCTIVITY IN THE SAHEL

In the Sahel, as in many agropastoral areas of the world (Galaty and Johnson 1990), domestic livestock graze unfenced common pastures. Although the rate and distance of movements between

encampment points varies across the nomadic to sedentary continuum, village- or encampment-based animals follow similar daily grazing movements. One or two times a day, animals move away from resting points at pastoral encampments, hamlets or villages, to graze and return at the end of the grazing period. These daily grazing movements determine the patterns of grazing pressure and manure deposition within a grazing radius (around 5–7 km) of the resting point. The degree of human management of these movements is variable and reflects the degree to which the managing family invests labor into herding. To evaluate the agroecological implications of growing scarcities of herding labor and pasture in the agropastoral zone of West Africa, empirical analyses of the effects of grazing management (in response to these constraints) on local patterns of grazing pressure and livestock productivity are needed.

Such empirical work has been hampered by methodological difficulties. The livestock population that grazes a common pasture is made up of many separate herds with independent movement patterns. Most prior work has considered the relationship between management and livestock productivity with little attention directed to livestock movements or the spatiotemporal distribution of grazing with respect to palatable forage (Amanor 1995; Colin de Verdière 1995; Faugère and others 1990; Killanga and others 1989; Turner 1999; Wilson 1986). Other studies have focused on the role of human management on livestock movements and mobility by characterizing grazing itineraries by their length, time duration, or spatial dispersion, but do not relate these movements to the changing distribution of forage resources nor consider their implications for livestock productivity (Coppolillo 2000; Guerin and others 1986; Turner 1999). To understand the ecological and economic implications of changes in grazing management in agropastoral areas such as the Sudano-Saharan region, spatially-explicit work on grazing management's effect on livestock distribution that relates livestock distribution to the vegetation resource is needed.

MATERIALS AND METHODS

To accomplish this task, we developed a GIS-based approach that relates grazing management decisions, herd movements, livestock distribution, and vegetation in a spatially-explicit fashion. This approach relies on the tracking of herds and explicitly ties the geographies of herd movements to the seasonal geographies of forage availabilities.

Grazing itineraries followed by herds within three contiguous agropastoral territories with varying proportions of grazing lands were characterized as to their grazing management; the numbers of animals in the herd; the time spent in each land unit; and the amount of palatable fodder of each land unit crossed. These data provide the basis for evaluating the effect of grazing management, under conditions of increasing but variable pasture scarcity, on feed supply to livestock and on ecologically-relevant grazing pressure.

Study Area

The study was conducted within the Fakara region of western Niger, an area of narrow plateaus separated by shallow valleys that lies between the Niger River to the west and the Dallol Boboye (Bosso), a fossil tributary of the Niger, to the east (Figure 1). Rain falls during a single rainy season from May to October with long-term annual rainfall averaging 575 mm (1921–1990 mean rainfall for Niamey located 80 km to the west). Soils in the area are largely sandy (90–95%), weakly structured, low in organic matter content (0.15–0.2% organic C) and acidic (pH water 4.6–5.0). They generally have very low cation exchange capacity (1–1.5 meq/100 mg), low base saturation (25–50%) and significant levels of exchangeable aluminum (20–35%) in the top 50 cm.

The Fakara has historically been sparsely populated (Beauvilain 1977; Gado 1980). Since the early colonial period, its resident population has been composed largely of Djerma farmers cultivating mainly millet. Large transhumant herds managed by FulBe pastoralists typically moved through the area from the Dallol at the beginning of the rains and after the harvest during the dry season (Beauvilain 1977). Persistent drought since the early 1970s has encouraged FulBe to settle and farm on plots of land loaned to them by Djerma landowners in the Fakara. In addition, land shortage within the Dallol itself has led to a seasonal movement of farming peoples to the Fakara during the cropping season. As a result, there has been a large increase in cultivated area in the Fakara, especially toward the Dallol to the east and in those areas where water is more available during the rainy season from wells or ephemeral pans.

Grazing pressure, which historically was especially high at the beginning of the rainy and dry seasons, has become more persistent across seasons. Only a portion of resident livestock in the Fakara leaves for pastures to the north during the cropping season. Paid by Animal head, resident

FulBe are often the day-to-day managers of the Djerma-owned livestock (cattle, sheep, and goats) during the cropping season. After harvest, fields become open to livestock grazing and many livestock owners, especially those that pay for grazing services, will take back their animals and allow animals to freely roam (without a herder) during daily grazing periods (free pasture). Even for herded livestock, we have observed a wide variation in the degree to which animals' grazing is managed. One major distinction is between those livestock that are herded throughout the grazing period (herded) and those that are herded to a destination, left, and then recovered and led back to the village or homestead by the herder at the end of the day (herd-release).

Land use, herbaceous vegetation, livestock populations, grazing management, and livestock movements were monitored in three agropastoral territories over a 19-month period. Each of the three agropastoral territories includes one or more villages and FulBe hamlets, their cropped lands and the fallowed lands, and rangelands utilized for grazing the livestock managed by the territory's residents and by outside pastoralists. The three territories are found along an east-west axis within a 500 km² study area lying just west of the Dallol (Figure 1). Similar to the region, the three agropastoral territories have experienced a rapid increase in cropping pressure over the past thirty years (Table 1). Of the FulBe residents in these three territories, 46% report first settling in the area since 1970. Despite their shared history and similar ethnic composition, rainfall, and edaphic conditions, the three agropastoral territories of this study show persistent differences in cropping pressure (Table 1).

GIS Development

A geographic information system (GIS), covering the 500 km² study area, was constructed using georeferenced interpretations of 1:20000 and 1:25000 photographs from two aerial surveys conducted during the immediate post-harvest season (November – December) of 1992. Photointerpretations delineated major hydromorphic features (ephemeral water courses and pans), topographic classes, human point and line features (including wells, foot paths, cattle paths, villages, and FulBe camps), and land uses such as manured fields, cropped fields (rainy season of 1992), non-bushy fallows (recent), bushy fallows (less recent), and uncultivable land (mostly plateau). Interpretations of subsequent aerial photography over the study

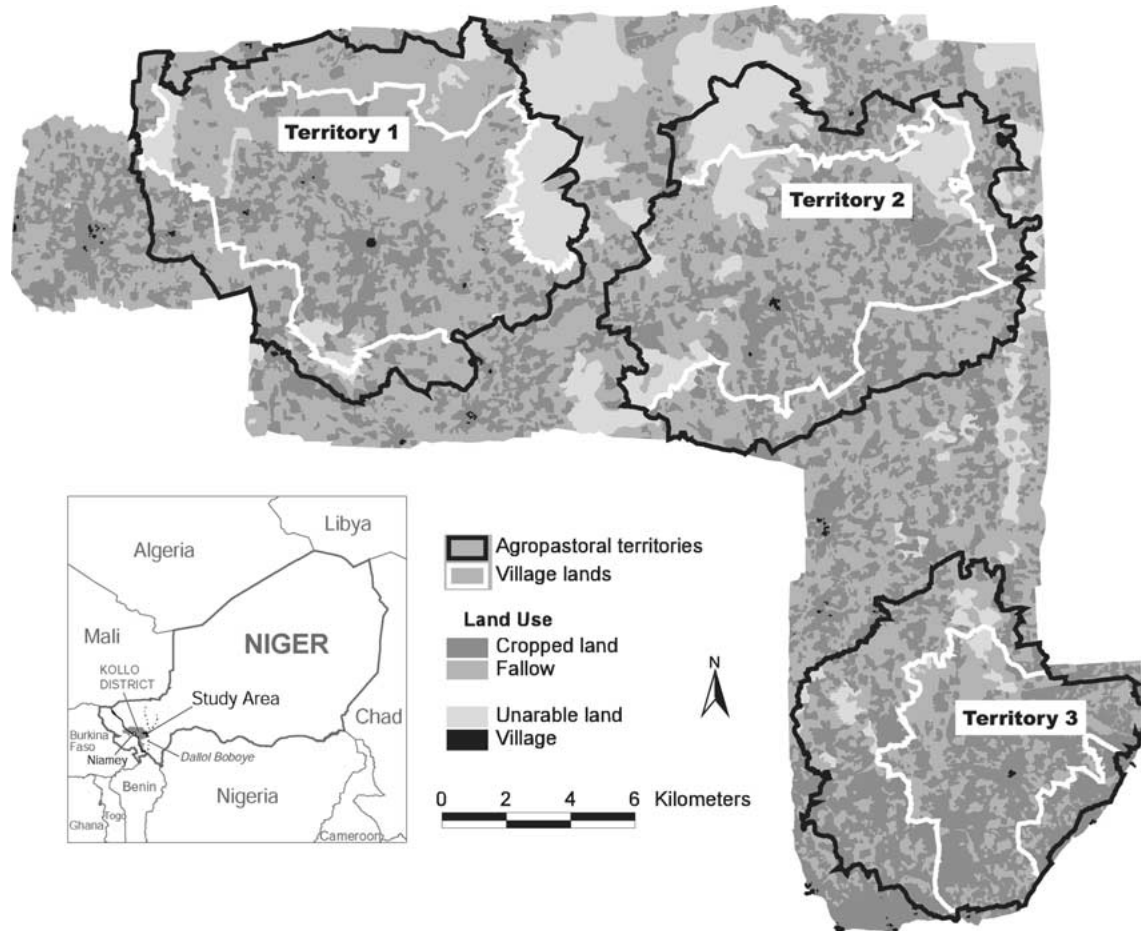


Figure 1. Map of the 500 km² study area in western Niger showing the locations of the three agropastoral territories (black borders) and village agricultural lands (white borders) in relation to major land uses in 1992 (cropped, fallow, nonarable, and village).

area in 1994–1996 provided consistent land-use classifications for each year of the study. The GIS coverage was divided into 694 land units, averaging 70 ha in area, using boundaries clearly distinguishable on the ground. Local place names were gathered and incorporated into field maps that were used to facilitate the delineation of grazing itineraries through interviews of herders.

Vegetation Monitoring

A double-sampling approach was used to estimate the average species composition (percentage of total herbage cover) and dry standing herbage mass (HM, kg dry matter ha⁻¹) within each land unit at the onset (early October), middle (late February), and end (early June) of the dry season across the 19-month study period. Each land unit was visited and these vegetation parameters were visually estimated using different procedures for cultivated and uncultivated lands. Uncultivated

land was divided into major herbaceous vegetation types, characterized by three dominant species from 1 to 3. For each vegetation type or “facies”, the percentage cover (by deciles) of predetermined standing mass classes (0–62.5, 62.5–125, 125–250, 250–500, 500–1000, 1000–2000, 2000–4000, 4000–8000 kg DM ha⁻¹) was monitored. Land unit values for these parameters were estimated as the weighted average of facies coverage. The species composition and HM of natural vegetation (weeds) within cultivated areas of each land unit were estimated in a similar fashion. Millet fields were first stratified into four classes: fields with or without manure application, and in the latter case with low, medium or high crop residue mass. Standing crop mass was estimated accounting for hill density and the number and height of tillers per hill. Visual estimates of herbage and crop residue mass were also performed at 24 uncultivated and 24 cultivated (that is, millet fields) sites located across the study area

Table 1. Characteristics of the Three Agropastoral Territories Found within the Study Area in the Fakara Region in Western Niger

Agropastoral Territory	Area (km ²)	Year (19..)	Managers ^a	Itineraries ^b	Land-use Fractions		
					Range	Fallow	Crop
1	122	50			0.90	0.06	0.04
		75			0.40	0.40	0.20
		94	45	141	0.15	0.57	0.26
		95	54	957	0.16	0.60	0.24
		96	62	409	0.17	0.54	0.29
		50			0.89	0.08	0.03
2	111	75			0.37	0.49	0.13
		94	47	164	0.15	0.45	0.40
		95	69	1055	0.14	0.49	0.37
		96	63	478	0.15	0.50	0.35
		50			0.53	0.26	0.22
3	75	75			0.08	0.53	0.38
		94	16	45	0.05	0.31	0.64
		95	59	456	0.05	0.29	0.66
		96	48	231	0.08	0.25	0.67
		50					

^aNumber of herd managers monitored.

^bNumber of grazing itineraries enumerated over the study period.

^cMean land-use fractions as determined through aerial photointerpretation for five separate crop-cycle years: 1950, 1975 and the three years of study period (1994–1996).

and within the main soil/land-use combinations. Species composition and HM were determined through clipping, drying and weighing of herbaceous vegetation samples collected along 100-meter and 200-meter transects at the cultivated and uncultivated sites, respectively. Visual estimates were regressed on estimates derived from the destructive sampling and regression equations, developed for each sampling period. These equations were used to correct the visual land-unit estimates of HM and to attribute the proportion of HM to each of the dominant species in relation to dominance rank. Coefficients of determination varied between 0.83–0.92 and 0.53–0.89 for HM estimates on uncultivated and cultivated sites respectively. The palatable herbage mass (PHM) was estimated in two steps: 1. multiplying the species contribution to the herbage mass of a particular facies by a season-specific palatable fraction; and 2. weighting the resulting estimates by the relative area of each facies of natural vegetation and of cropped area as determined by interpretation of aerial photography for the particular crop-cycle year.

Herd Monitoring

All livestock managed within each of the three agropastoral territories were censused at approximately three-week intervals throughout the monitoring period. The number of animals managed by

each household was quantified through a combination of interviews and direct counts. Each census categorized animals with respect to species (cattle, sheep, goats), sex and the major way in which the animal's grazing was presently managed (free pasture, herd-release, herded). These data provide exhaustive accounting of the number of animals managed within each territory by species and management type throughout the study period.

All livestock managers, defined here as those persons who actively manage the grazing of their own or entrusted animals (herded or herd-release) during at least a portion of the year, were visited at approximately three-week intervals. A subset of their herds, chosen to span the range of herd size, management type, and livestock species, was followed by research assistants throughout a grazing period (tracked). Routes were described on the basis of land units with entry and exit times and the major activities of animals (walking, eating, resting, drinking) monitored systematically every 5 min for one animal of each herd. For the purposes of this paper, the total time spent walking and eating will be referred to as grazing time, which is equal to the total time spent by livestock following the grazing itinerary (daily time on pasture) minus resting and watering time. The vast majority of herds were not tracked but the grazing itineraries each herd had followed over the 24 h prior to the interview were reconstructed through detailed, map-based interviews of livestock managers every three weeks. As

with the tracked herds, these itineraries were described by an ordered list of land units with the major activities of animals (grazing, resting, drinking) noted for each. The times at which the herd left to graze, returned from grazing, watered and rested were recorded during interviews as well. The majority of these interview-derived grazing itineraries were registered to land units throughout the grazing period, that is, they were "complete." Itineraries for which the informant could not recall the location (land unit) of the herd for some portion of the grazing period are considered "incomplete."

Seventeen percent of all itineraries exceeded the boundaries of the GIS coverage. These itineraries were excluded from subsequent analyses because no vegetation data were available outside of the GIS coverage. Eighty-seven percent of these excluded itineraries originated in territory 3. As described in more detail by Turner and Hiernaux (2002), the tracking data were used to generate algorithms that were used to process interview derived itinerary data: 1. estimate the unknown entry times for units crossed along the itinerary from the major livestock activity in the unit and the shortest-path-distance connecting the midpoints of the unit's common borders with adjoining units in the itinerary; and 2. the units crossed during unregistered time periods of incomplete itineraries.

Data Analysis

Herd census data provide a good basis to subdivide the livestock population by management mode (herded, herd-release, free pasture) across the study period. Given that the three territories are subject to varying cultivation pressures (Table 1), these data are used to evaluate how pasture availability affects herd management as evidenced by the seasonality of livestock presence (how many animals are sent out of the territory during the cropping season) and how animals are managed by season.

The land-use, herd monitoring and vegetation data are required to characterize the implications of variation in herd management for the amount of forage made available to livestock. The procedure followed was to spatially relate livestock grazing time to seasonal averages of PHM on offer within land units traversed by livestock itineraries. Seasonal averages of PHM were calculated differently from vegetation and land-use data according to season. During the cropping season (CS, 15 June to 15 October) when animals are excluded from fields, the estimate was set equal to one-half of the

palatable herbage mass of noncropped areas in October times the noncropped fraction per land unit (as determined by interpretation of aerial photography). The dry season (DS) was divided into two parts: 15 October to 1 March (DS1) and 1 March to 15 June (DS2). PHM available in DS1 was calculated as the average of palatable herbage mass determined at the beginning (early October) and end (late February) of the period, and for DS2, the average of PHM determined in late February and early June (end of DS, start of CS) was taken. In cases where vegetation data were missing for a land unit during a particular season, data from an adjoining unit of similar soil type and topographic position were utilized. Such assessments account for 5% of the total grazing time enumerated in this study.

The herd monitoring data were used to estimate the time spent grazing, resting, and drinking within each of the land units crossed by each itinerary. To evaluate the effect of management on livestock feed supply, a measure called "forage availability time" was used. Forage availability time (FAT) is defined as the sum across the time on pasture of the products of the grazing time (excluding resting and drinking time) spent by a herd within each land unit crossed (hours) and that unit's seasonal average PHM (kg ha^{-1}). This index (kg-hrs ha^{-1}) is a measure of the forage offered to livestock over the grazing day. An increase in either the duration of grazing or in the palatable fodder availability within land units crossed will result in an increase in FAT. FAT divided by the time spent grazing (hours) represents the weighted-average amount of palatable forage offered the herd across the grazing period (FA). Grazing management that results in higher values of FA leads livestock to locations with higher palatable vegetation availability. FA is used here to measure the influence of grazing management on the spatial distribution of managed livestock in relation to heterogeneously distributed PHM. For a given herd size, itineraries with lower values of FA produce higher ratios of livestock to palatable herbage mass and are therefore more likely to contribute to grazing-induced changes in vegetation and soil parameters (higher herd-to-forage ratios). In this way, FA is a measure of the effect of management on livestock distributions in relation to the changing locations of palatable vegetation resources.

The FAT and FA indices were calculated for 3,819 itineraries followed by herds in the three agropastoral territories during the 19-month study period. The effects of management mode (herded, herd-release, free pasture), agropastoral territory (1, 2,

3), and season (CS, DS1, DS2) were evaluated through multiple regression, after controlling for data type – that is, the way in which data were acquired (tracking , interviews) and the way interview data were processed (complete and incomplete interview data). Table 2 presents the coding for the dummy independent variables introduced into the model. Only regression models that do not violate the following criteria were accepted: insignificant autocorrelation between independent variables, constancy of residual variance, and normal residual distributions. Because most resident livestock are herded during the rainy season to avoid crop damage, grazing management mode and season are autocorrelated (Pearson chi-square = 850, $P < 10^{-15}$). Rainy season data ($n = 1751$) and dry season (DS1 and DS2) data ($n = 2068$) were therefore analyzed separately. Due to the small numbers of itineraries managed in free pasture or herd-release modes during the rainy season and the fact that these were followed only during the very beginning of the rainy season before field closure, regression analyses of rainy season data only considered data type and agropastoral territory as independent factors.

RESULTS

The data collection, processing, and analytic procedures described above produce results with respect to: 1. the spatiotemporal variation in the dry mass of palatable herbaceous vegetation in the study area; 2. the variation in grazing management of livestock within the study area; and 3. by relating #2 to #1, how the variation in grazing management affects feed availability to livestock and herd-forage balances, controlling for season, agropastoral territory, and data type.

Palatable Herbaceous Mass

The mass of palatable herbaceous forage (PHM) reaches its peak at the end of the rainy season (September–October) and declines first rapidly (October–December) and then more slowly during the dry season (January–May). The study period encompasses two growing seasons. Table 3 presents the average PHM for each of the three agropastoral territories at the end of each cropping season (October). In 1995, rainfall in territory 1 was poorer in terms of amount and distribution, than in the other two territories. This explains the low PHM value for that year. Except for this low value, average peak PHM is very similar across the three village territories. Figure 2 is a plot of Octo-

ber 1996 vs October 1995 PHM at the level of the land unit. Unit-level peak PHM varies from 55 to 2060 kg ha⁻¹ with most of this heterogeneity at spatial scales that fall within the agropastoral territory. Areas of high PHM in the study area tend to be low-lying areas that receive rainfall runoff whereas areas of low PHM tend to be areas of shallow soils on slopes that are major sources of runoff. Unit-level PHM did not vary significantly across agropastoral territory in 1996. In 1995, unit-level PHMs in territory 1 were significantly lower ($P < 10^{-6}$) than in the other two territories but agropastoral territory only explained 7% of the 1995 unit-level PHM. A significant fraction of this unit-level heterogeneity in PHM was found to be persistent from 1995 to 1996. Coefficients of determination associated with territory-specific regressions of 1996 on 1995 PHM range from 0.58 to 0.68. The steeper slope of the regression line for territory 1 is due to its low PHM values in 1995. As would be expected, interannual variation in PHM was found to be higher at intermediate levels of PHM (600–1000 kg ha⁻¹) where PHM is most influenced by variation in rainfall pattern and quantity.

Livestock Populations and Their Management

Figure 3 presents the numbers of animals (expressed as tropical livestock units or TLU) by management category (herded, herd-release, and free pasture) found within the three agropastoral territories from May 1995 through November 1996. The number of animals fixed at the homestead is negligible and mostly made up of stall-fed small stock (sheep or goats) fattened for religious celebrations and social events. In all three territories, grazing management varies significantly with season. During the cropping season, animals are primarily herded to avoid crop damage. The exact dates of field closure and opening depend on the development of the millet crop which in turn is strongly influenced by rainfall regime. After crop harvest, animals are variously managed in their grazing activities. Those owners of small stock that pay others to herd their livestock during the cropping season (most Djerma within the study area) are likely to take back their animals during the dry season and allow them to pasture freely. Cattle are less likely to be managed in this way – either they are herded throughout the day or herded and released. Livestock managers, as defined above, are more likely to herd their livestock throughout the year.

Table 2. Definition of Independent Variables used in Multiple Regression Analysis of Forage Availability Indices

Variable	Definition
Territory 1	1 if herd is based in agropastoral territory 1 (Banizoumbou), 0 otherwise
Territory 2	1 if herd is based in agropastoral territory 2 (Tigo-Tegui), 0 otherwise
Data: tracked	1 if data on itinerary was collected by physically following the herd (that is, not through interviews), 0 otherwise
Data: interview incomplete	1 if data on itinerary was collected by interview resulting in an incomplete characterization of the location of herd during the grazing period, 0 otherwise
Management: herded	1 if herd was herded throughout its grazing period, 0 otherwise
Management: herd-release	1 if herd was herded and then left on its own (released) during its grazing period, 0 otherwise
Season: DS1	1 if itinerary was followed during the early dry season (15 October – 1 March), 0 otherwise
Season: DS2	1 if itinerary was followed during the late dry season (1 March – 15 June), 0 otherwise

The local availability of pastures affects livestock management. One major difference among the three territories is the wide variation in livestock populations within territory 3 compared to territories 1 and 2. This variation is caused by sharp declines in resident livestock populations during the cropping season, when part of the livestock population is taken either on long-distance transhumance to the north or moved more locally to areas where pasture availability is higher. This practice, although evident in all three territories, is especially prevalent in territory 3. Livestock managers in territory 3 cite the lack of quality pasture as the major reason they send their animals out of the territory during the cropping season. As shown in Table 4, self-reported dependence on extra-territory movements of livestock (transhumance) and the prevalence of intra-territorial encampment moves (moves) are higher in territory 3.

The Effect of Grazing Management on Grazing Patterns and Forage Offered Livestock

The spatial distribution of livestock grazing time produced by the three management modes across the three agropastoral territories is depicted in Figure 4. To facilitate comparison, unit-level grazing density is expressed as a fraction of total grazing time (TLU-hours) produced by the particular management mode within the territory divided by the unit's area in hectares. Units that are more darkly shaded experienced a higher fraction of the management mode's grazing time. For all three

Table 3. Average Palatable Herbaceous Mass (PHM expressed in kg dry matter ha⁻¹) In Three Agropastoral Territories at the End of the Study Period's Two Cropping Seasons (October 1995 and 1996)*

Time of Measurement	Agropastoral Territory		
	1	2	3
October 1995	649	729	805
October 1996	872	796	851

*Palatable herbaceous mass includes palatable portions of millet stalks and weeds in croplands and the palatable portions of herbaceous vegetation in rangelands and fallows. These are weighted averages (by surface area) of land-unit data for those land units within each agropastoral territory that vegetation data were available in both years. These land units cover 89, 96 and 96 percent of territories 1, 2, and 3 respectively.

territories, grazing distribution becomes less dispersed and more concentrated around human settlements with a shift from the "herded" to "herd-release" to "free pasture" management modes.

Table 5 presents the mean values of shortest-path distance, FAT and FA for itineraries followed by herds for the twenty-seven combinations of season, agropastoral territory, and management mode. Across all combinations of territories and seasons, the mean shortest path distances increase from free pasture to herd-release to herded management mode. Shortest path distance varies less strongly across season and territory although distances tend to be longer for territory 2 and increase as one moves from CS to DS1 to DS2 for territories 1 and 3. The longer distances covered in territory 2

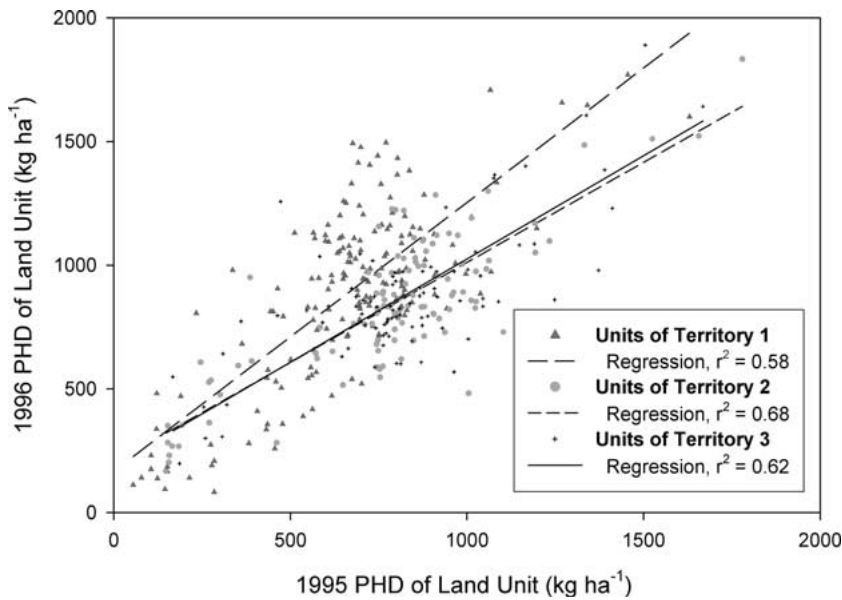


Figure 2. Average palatable herbaceous dry mass (PHM) of land units within three agropastoral territories at the end of the cropping season in 1996 plotted against those of 1995. Linear regression best-fit lines that relate 1996 to 1995 values are plotted for each territory.

are most likely due to its more dispersed watering point geography. Increased distances covered across the seasons result from the longer distances traveled as the average availability of palatable forage declines.

Mean values for FAT and FA show a marked variation across seasons. Given that cultivated lands are considered off-limits for grazing and excluded from the calculation of PHM during the cropping season, both FAT and FA are lower in CS than in DS1 when fields become open to grazing. With the progression of the dry season, PHM declines on both cultivated and uncultivated lands resulting in a decline in FAT and FA for itineraries during DS2. Across all management modes, FA and FAT during the rainy season are lower in territory 3 than the other territories. The high cultivation pressure in this territory results in a higher fraction of pastures located on uncultivable marginal lands during the cropping season. Variation across management modes is less marked during the dry season although herded and herd-release modes tend to have higher FA and FAT than the free pasture management mode.

The results of the multiple regression analyses of the dry-season data are shown in Table 6. Data type, agropastoral territory, management mode, and season together account for 70 and 76% of the variation in FAT and FA, respectively. Both vary most by season, with FA declining as the dry season progresses. Itineraries described through tracking and incomplete interview data have, respectively, significantly lower and higher FATs compared to the complete interview data, reflecting the higher and lower resting time estimates associated with

these data types. Once controlled for data type, agropastoral territory, and season, the analysis shows that the mode by which herds are managed significantly affects the amount of palatable forage offered livestock during the grazing period. Both herded and herd-release management modes result in greater FAT and FA values than free pasture with forage availabilities higher for herded animals than those herded and then released.

Multiple regression analyses of the cropping-season data (excluding management mode variables), show that FAT and FA are both significantly lower in territory 3 ($P < 10^{-15}$) due to its high cultivation pressures there and itineraries derived from tracking data have significantly lower FATs ($P < 10^{-4}$). Coefficients of determination for the FA and FAT regressions are both 0.29.

DISCUSSION

The climate and social dynamics in dryland regions of West Africa have combined to produce a situation where livestock are owned and managed by sedentary producers (either “farmers” or settled “pastoralists”) within heavily cropped areas. Moreover, the grazing of livestock in the region is increasingly managed by people who are less able to allocate time and effort to such management. How livestock are managed under these new conditions is an important question for a number of reasons. First, livestock production remains a key sector in the regional economy. Declines in livestock productivity would seriously affect both the economic security of livestock managers and owners and the national accounts of Sahelian

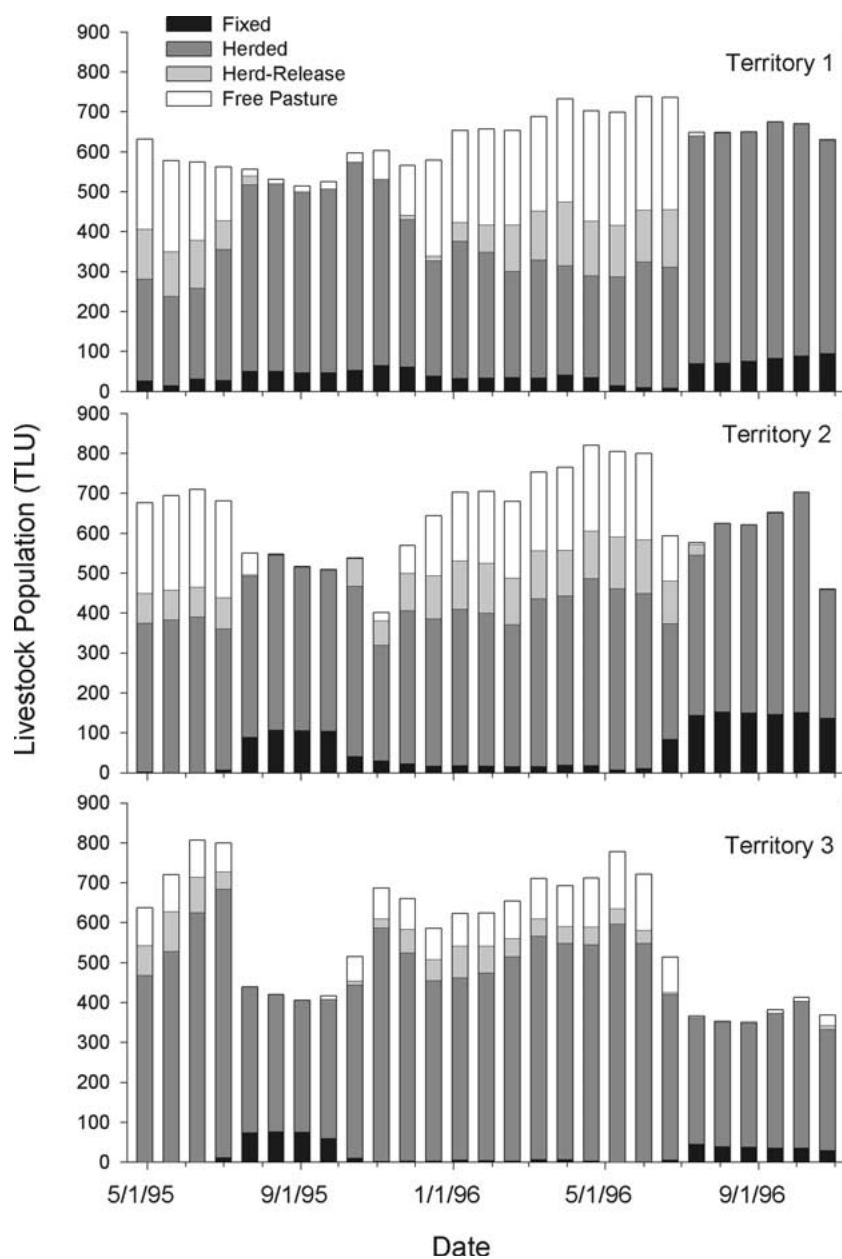


Figure 3. The number of livestock expressed in tropical livestock units (TLU) managed in fixed, herded, herd-release, and free pasture modes within the three agropastoral territories as estimated at three week intervals from April, 1995 through November, 1996. TLU is a measure of tropical ruminant forage demand with an adult cow, sheep, and goat equal to 0.7, 0.1 and 0.08 tropical livestock units, respectively. Juvenile animals (weaned animals less than one and 2.5 years for small ruminants and cattle, respectively) were equal to one-half of the adult TLU value.

Table 4. Mobility Characteristics of Livestock Management in Three Agropastoral Territories in the *Fakara* Region of Western Niger

Territory	Livestock managers		
	Practicing Transhumance (%) ^a	Moving Camps ^b	
		(%)	Avg
1	38	22	1.4
2	77	55	1.9
3	90	61	3.4

^aPercentage of livestock managers reporting sending at least some of their livestock out of the study area during a portion of the year.

^bPercentage (%) of all managers who report moving the locations of their camp at least once during the study period and average number of moves (Avg) made by managers whose camp location moved at least once during the study period.

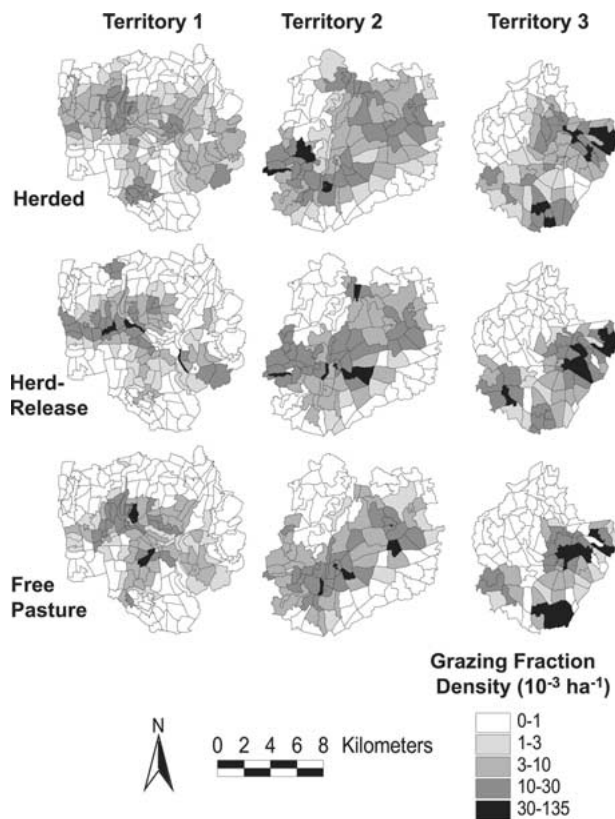


Figure 4. Spatial densities (ha^{-1}) of the average fraction of the total grazing time (TLU-hours) for each agropastoral territory and management mode experienced by land units over the study period.

countries. Second, cropland fertility has historically been maintained through livestock manuring (Harris 1998; Prudencio 1993). The efficiency of fertility maintenance is affected by forage intake by livestock and the location of animals across the agropastoral landscape (Hiernaux and others 1997; Powell and others 1996; Turner 1995). Third, improper management of livestock can lead to local livestock/forage imbalances and grazing-induced environmental change (Scoones 1994; Turner 1999). Hence, the sustained agricultural productivity of dryland regions is likely to be influenced by the way the grazing of livestock is managed within agropastoral areas experiencing cropland expansion.

The study area has experienced the same trends as that described for the region. Since the droughts of the early 1970s, there has been an influx of FulBe pastoralists who have settled in the area to farm. Cultivated area has expanded to the detriment of rangeland (Table 1). Due to its proximity to the Dallol and the valley of Dantiandou (Figure 1), territory 3 has experienced an earlier and more extensive expansion of cultivated area.

Livestock are owned by both Djerma and FulBe, while the latter remain the primary grazing managers. The distribution of palatable forage within the study area displays both interannual persistence and variability (Figure 2) which suggests that variation in human management may affect both forage availability to grazing animals and the grazing pressure locally exerted on herbage mass. In response to increasing land-use pressures and labor constraints, livestock owners and managers have modified grazing management in a wide variety of ways. This is particularly evident after harvest when avoiding of crop damage is no longer a reason for livestock herding.

Major environmental and productivity implications of the responses of settled livestock managers to these new pressures and constraints are, that grazing management effort declines, leading to a decrease in the average length of grazing itineraries and the spatial dispersion of livestock. This is consistent with previous work in the region (Moulin 1993; Turner 1999) but differs from the findings of other studies (Coppolillo 2000). Taking FAT as a measure of the amount of palatable forage availability to livestock during the grazing period, it is not surprising that the season has a dominant influence on this parameter, due to the high seasonality of standing dry herbage mass in dryland areas. Management mode also has a significant, although smaller, effect on FAT, which increases as herding effort increases. Therefore, if feed intake is limited by the time that animals have access to forage, herding effort does have a positive influence on animal nutrition. Previous research has found forage availability to increasingly limit forage intake as the dry season progresses (Rath 1999; Schlecht and others 1999).

Management modes resulting in itineraries with low FA produce higher grazing pressures (TLU per kg palatable forage) than management modes resulting in itineraries with higher FA, and will more likely lead to grazing-induced changes in soil and vegetative parameters. As with FAT, FA was found to increase with herding effort. Herds that are managed in free pasture mode are more likely to lead to higher grazing pressures relative to forage availability than herds that are herded. Although this finding suggests that grazing-induced environmental change is more likely to result from free-pastured rather than herded livestock, this research has uncovered little evidence of reduced vegetative production resulting from changes in grazing management or pasture shortage. In fact, the productivity of herbaceous vegetation, which is strongly influenced by variations in edaphic con-

Table 5. Monitored Grazing Itineraries by Agropastoral Territory (1–3), Season (CS, DS1, DS2), and Management Mode (Herded, Herd-Release and Free Pasture) over the Study Period

	Season	Management Mode								
		Herded			Herd-Release			Free Pasture		
		T1	T2	T3	T1	T2	T3	T1	T2	T3
N ^a	CS	569	570	427	20	35	13	41	66	10
	DS1	236	295	65	31	66	33	126	116	23
	DS2	159	196	52	81	69	27	240	211	42
Dist ^b	CS	6.98	10.10	7.78	6.43	9.35	6.39	5.82	6.58	3.22
	DS1	8.40	9.14	7.10	7.24	7.74	6.87	5.51	5.46	4.50
	DS2	9.12	8.96	8.75	7.85	8.51	7.40	6.02	6.42	5.43
FA ^c	CS	212	204	116	202	201	55	200	189	58
	DS1	560	654	648	542	618	618	547	598	683
	DS2	274	282	216	290	266	189	257	255	221
FAT ^d	CS	2025	2020	1080	2139	2191	516	2090	1906	555
	DS1	4996	5887	5562	4865	5645	5993	4892	5374	5993
	DS2	2562	2615	1974	2801	2607	1819	2555	2332	2181

^aNumber of monitored itineraries.

^bAverage of the sum of the shortest-path distance (km) across land units named within grazing itineraries.

^cAverage of itineraries' weighted-average forage availability (kg ha⁻¹).

^dAverage of the sum of the products of unit-level forage availability by grazing time across itineraries (kg-hrs ha⁻¹).

Table 6. Coefficients (b), Standard Errors (SE), Standardized Coefficients (β) and Significance Levels (p) of Multiple-regression Models Used to Estimate Forage Availability Time or FAT (kg-hrs ha⁻¹) and the Forage Availability or FA (kg ha⁻¹) of Grazing Itineraries followed by Herds during Dry Season ($n = 2068$)*

Independent Variables	Forage Availability Time (FAT)				Forage Availability (FA)			
	b	SE	β	p	b	SE	β	p
Constant	2138	86	0.00	<10 ⁻¹⁵	237.8	8.5	0.00	<10 ⁻¹⁵
Territory 1	-104	71	-0.03	10 ⁻¹	-12.7	7.0	-0.03	7 × 10 ⁻²
Territory 2	193	70	0.05	6 × 10 ⁻³	23.8	6.9	0.06	10 ⁻³
Data: tracked	-351	70	-0.06	5 × 10 ⁻⁷	19.3	6.9	0.03	5 × 10 ⁻³
Data: interview incomplete	373	68	0.10	4 × 10 ⁻⁸	9.1	6.7	0.02	2 × 10 ⁻¹
Management: herded	429	66	0.12	10 ⁻¹⁰	28.7	6.5	0.07	10 ⁻⁵
Management: herd-release	143	67	0.03	3 × 10 ⁻²	13.5	6.6	0.02	4 × 10 ⁻²
Season: DS1	2889	44	0.81	<10 ⁻¹⁵	335.9	4.3	0.85	<10 ⁻¹⁵

*Independent variables are defined in Table 2. The coefficient of determination (R^2) for the FAT and FA models are 0.70 and 0.77 respectively.

dition and in the amount and distribution of rainfall, was found to vary at finer scales than those of the agropastoral territory or grazing radius. The production of herbaceous forage in territory 3, which has experienced earlier and greater pasture shortages (Table 1) did not differ significantly from that of the other two territories (Table 3).

Not only are rural producers' responses to the new opportunities and constraints of livestock ownership highly variable but their choices with respect to grazing management have important economic and environmental implications. When

considering the economic and environmental futures of semi-arid areas undergoing increased sedentarization of livestock production, cropland expansion and population increase, many researchers have focused on the benefits to sustained agricultural productivity through greater integration of livestock and cropland husbandry. The results reported here suggest that the labor and forage demands of livestock grazing may limit the benefits gained from the greater proximity of livestock and croplands. Labor demands of grazing management do not decline but may actually in-

crease in cropped areas. Without purchased feed supplements, a diversion of labor away from herding is likely to reduce livestock and manure production and increase the risk of grazing-induced environmental change.

The results of this study also provide empirical support to arguments that there are biophysical limits to the benefits derived from greater crop/livestock integration (Powell and others 1996; van Keulen and Breman 1990). Livestock managers in territory 3 are faced with much higher cultivation pressure than those in the other two agropastoral territories, which is associated with higher rates of both transhumance and movement of pastoral camps within the territory during the cropping season. Both can be seen as a response to pasture scarcity: managers send their livestock out of the area to gain access to forage, and encampment locations shift to maintain access to livestock paths through cropped areas. Therefore, the evolution of livestock management under increased cropping pressure is more complex than is commonly depicted (for example, Bosma and others 1999; Bourn and Wint 1994; Pieri 1992). The decline of livestock mobility in agricultural areas is primarily driven by cultural and labor constraints as sedentary farmers gain a greater share of livestock wealth and newly sedentary pastoralists divert herding labor to cropping pursuits. Without purchased feed supplements, this trend is likely to reverse itself as forage scarcity increases and livestock managers will find that they must move livestock to feed them (Bonfiglioli 1990; de Haan and others 1990; Lericollais and Faye 1994; Lhoste 1987).

CONCLUSIONS

The importance of proper grazing management is often ignored by the development and conservation communities. This is a major omission because livestock remain the major store of wealth for rural peoples in dryland regions. This study has shown that grazing management decisions affect the distribution of grazing with respect to forage resources which, in turn, may affect the sustained productivity of the agropastoral landscape. In the common-pasture situations prevalent in dryland Africa, investing time and effort into livestock herding results in higher forage availability to livestock across the grazing period and more evenly distributes livestock with respect to palatable forage density. Therefore, the herding profession should not be seen as some archaic feature of the past but as an important contributor to the sustained productivity of both rangeland and cropland. In areas where

cropland expansion is rapid, efforts should be made to protect regional and local livestock corridors. Moreover, the labor requirements of herding need to be taken seriously. Pooling of livestock during the rainy season is a simple way of maintaining proper grazing management despite serious labor constraints. Although often ignored by outside conservation/development initiatives, simple measures could be taken at the local level to facilitate livestock mobility and reduce herding labor bottlenecks (Tielkes and others 2001). This paper demonstrates that increased attention to grazing management will have small but measurable benefits to the overall production of agropastoral systems in semi-arid West Africa.

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