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The Influence of Farmer and Pastoralist Management Practices on Desertification Processes in the Sahel

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ABSTRACT

After a basic description of the ecological features of the Sahel, the history of its human population, and the diversity of existing agricultural production systems, an analysis of the ways in which natural resource management influence ecological changes in the Sahel is presented. The fundamental processes by which cropping, livestock husbandry, and forestry impact on the agro-ecosystem are first reviewed, distinguishing between short- and long-term impacts on productivity as well as diversity and resilience. These fundamental processes are combined at different scales to assess the influence of management options on the nature and magnitude of this impact. Contrasting situations were found along the Sahelian bioclimatic gradient: risks of environmental degradations are moderate and mainly climate-driven in pastoral systems at the drier edge, while they are serious and mainly management-driven in the crop-livestock systems of the southern Sahel. Finally, the major institutional and economic factors that influence resource management at the household and community levels are discussed. In conclusion, current trends are revisited and the role that national and international policies could play in promoting crop-livestock integration and agriculture intensification in order to alleviate poverty and desertification is considered.

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INTRODUCTION

The Sahel belt stretches across the southern edge of the Sahara desert, over 6000 km from the Atlantic coast of Senegal and Mauritania in the west to the Red Sea coast of Sudan in the east, with a North–South width of 400 to 600 km. The Sahel cuts across 10 nations, which are among the poorest in the world, and is home to about 50 million people, the majority of whom practice subsistence agriculture. After describing the basic ecological features of this region, we will consider the particular ways in which cropping and livestock grazing are involved in processes of ecological change. How crops and livestock are managed plays a major role in the nature and magnitude of environmental impact. We identify the major socioeconomic factors that influence resource management at the household and community levels. We conclude by revisiting current trends and considering the role that national and international policies could play in promoting crop-livestock integration and agriculture intensification in order to alleviate poverty and desertification.

ECOLOGICAL FEATURES OF THE SAHEL

Climate and Soils

The Sahel is primarily defined by a tropical arid to semi-arid climate. It actually encompasses a steep climatic gradient conventionally bracketed by the 100 and 600 mm yr^{-1} isohyets. However, transitions in the north with the Sahara desert, and in the south with the Sudanian savannas, are both gradual and have historically fluctuated. Rain falls in summer when days are long, ambient temperatures are elevated, and potential evapotranspiration is high. Rainfall distribution is strictly monomodal, centered in August, with rainy seasons lasting two months in the north to five in the south. While the rainfall distribution of the Sahel is often described as erratic, the seasonal pattern of this monsoonal system is actually very regular; however, the spatial and temporal distribution of rains during the rainy season is highly irregular and unpredictable. Annual rainfall at a given site varies from year to year with a coefficient of variation between 25% and 30%. Most of the rains come in squall lines or convective storms of high intensity. The high prevalence of intense rainfall events contributes to higher rates of soil crusting and runoff than would be expected from the sandy soils and limited relief that are typical of the Sahel (Casenave and Valentin 1989). With the exception of narrow coastal regions in Mauritania, Senegal, and Sudan, the long dry season is also characterized by extremely low air humidity (daily minima < 5%) for several months, along with high temperature and aerosol density.

Sahelian soils developed over a long history of alternating subhumid and hyper-arid climatic periods. Soils differ across different types of bedrock and topography but all tend to have low organic matter content and weak structure. Cation exchange capacity, varying in relation to what is generally a low clay content, is usually unsaturated. Most topsoils are acidic and poor in soluble nitrogen and phosphorus. Extensive research in the Sahel has confirmed that soil nutrient deficiency limits range and crop productivity (Penning de Vries and Djitèye 1982). Considering the water to nitrogen balance, Breman and de Ridder (1991) postulated that range production would become N-limited above 250 mm yr^{-1} of available soil moisture per year and established relationships to predict primary production from infiltrated rainfall and N availability, along with estimated N losses through grazing, volatilization, and leaching.

Natural Vegetation

The natural vegetation of the Sahel is adapted to its climate and soils, as well as to a fauna that until last century included abundant and diverse populations of large mammals, and to tens of thousands of years of human activities, including regular bush fires. Natural vegetation is composed of an herbaceous layer mainly made up of annual species, especially grasses, and a layer of scattered woody shrubs and trees. Unlike other arid ecosystems, perennial grasses and low shrubs are not common; their proportion increases at the southern transition to Sudanian savanna, and also at the northern transition to desert steppe. Succulents, although so emblematic of aridity in some deserts, are almost absent in the Sahel except for a few examples along its coastal edges. The causes of these particularities are a matter of controversy. Some authors explain them by the long history of human pressure on resources. However, the few perennial herbs and succulents present in the Sahel today are generally promoted by human disturbances (Hiernaux 1998). Moreover, the severity and long duration of the dry season inhibits perennials and succulents, while the seasonal regularity of the rains favors annuals with seeds that germinate actively with the first rains. As a consequence, the seed stock is transient, with only a few species producing seeds that remain viable over several rainy seasons. The transient nature of the seed stock causes the sharp changes in vegetation composition often witnessed in monitoring studies. In spite of the wide amplitude of these interannual changes in production and species composition, natural vegetation is remarkably resilient to droughts, as demonstrated by the spectacular spontaneous "regenerations" of northern Sahel rangelands following the drought crises in 1973–1974 and 1983–1984 in the Gourma region in Eastern Mali (Hiernaux 1995).

Woody plants have variable leaf size and a diverse phenology, ranging from ephemerals to evergreens. They compete with herbs for water and nutrients in the top meter of the soil profile where most of their root system is developed. However, a few taproots assure their access to percolated water and shallow water tables (Breman and Kessler 1995). This competition creates an equilibrium between herbaceous and woody plants, which, unlike other arid ecosystems, does not lead to bush encroachment. Only in the "brousse tigrées" (tiger brush), a patterned thicket common on very gently sloping hard pans in the Sahel, have woody plants won the competition thanks to a natural water harvesting system (d'Herbès et al. 1997). The monitoring of woody plant populations in Sahelian rangelands indicates active dynamics, although at a more extended time scale than for the herbaceous community, including drought-induced mass mortality of populations at some time lag after droughts, and occasional waves of regeneration (Couteron and Kokou 1997).

HUMAN POPULATION AND FARMING SYSTEMS

The Demographic Upsurge

During the first half of the 20^{th} century, human population growth in the Sahel was slow as the result of widespread famine, disease, and economic recession. Population growth accelerated in the mid-century with annual increases ranging from 2–4%. Cropped land generally expanded at similar rates, while livestock population grew less rapidly until the droughts of 1972–1973 and 1983–1984, which resulted in a drastic decline of livestock. Persistent population increase and local migration have resulted in the uneven distribution of the rural population in the Sahel, with hubs in densely populated areas, such as the groundnut belt of Senegal, the Mossi plateau in central Burkina Faso, and the Hausa land of Southern Niger and Northern Nigeria, separated by sparsely populated areas. As land scarcity, infrastructure development, and market relations have all intensified, rural production systems have evolved but still maintain some features distinctive from other arid regions. Rural land uses include livestock husbandry, cropping of staple cereals (largely millet) and limited cash crop production (groundnut, cowpea, cotton), and the gathering of wild plant materials for fuel, fiber, construction materials, medicine, grain, and condiments.

Evolving Production Systems

Historically, a certain degree of occupational specialization has existed, in either livestock husbandry ("pastoralists") or in crop agriculture. Despite these specializations, livestock has always been the major physical asset and wealth store for all rural groups in the Sahel, while human nutrition has always been cereal-based. Therefore, livestock owned by other groups were often managed by pastoralists who obtained grain from agriculturalists through a range of voluntary to coercive mechanisms.

Pastoralists

Today, households that are exclusively pastoral (supplemented by gathering activities) are in the minority and are confined to the drier areas. The increasing majority of households are now actively involved in both cropping and livestock husbandry. Since the droughts of the early 1970s, livestock-poor pastoralists are increasingly farming on land that is usually leased to them by farmers holding agricultural usufruct. The settled pastoralist household often finds it difficult to respond adequately to the competing labor demands of crop management and livestock mobility maintenance during the rainy season. Over the past 25 years, livestock ownership has shifted partially to richer farmers, merchants, and civil servants (Moorehead 1991). While these groups continue to rely on livestock specialists to manage their livestock (increasingly through wage contracts), poorer agricultural households tend to manage their livestock themselves; former livestock entrustment contracts with livestock specialists have eroded following the decline of the historic patterns of pastoralists' movements. To a greater degree than the classical herd and family movements of the nomads (Bonfiglioli 1990; Schareika et al. 2000), pastoral movements in the Sahel were and remain dominated by the South–North fluctuations of the herds guided by individual herders or shepherds. Herds move toward arid rangelands at the onset of the wet season, returning progressively to semi-arid or subhumid zones or to riverside areas where they spend the rest of the dry season, sometimes following another round of transhumance (Benoit 1979; Schlecht et al. 2001). During both seasons these movements aim to provide the best quality feed to the herds. The movements are controlled by water availability (Thébaud 1999) but they are increasingly constrained by the reduction and fragmentation of grazing land areas in semi-arid zones and in flood plains (Moorehead 1991; Turner 1999).

Crop-Livestock Farmers

Access to cultivatable land varies between Sahelian communities, reflecting soil agronomic potential and population density. In Western Niger, average land cropped is less than 5 ha per household and less than 1 ha per adult equivalent in the densely populated Dallol Bosso (Beauvilain 1977), while in villages of the less densely populated Fakara, lying immediately to the west, these values increase to 13.2 ha per household and 2.3 ha per adult equivalent (Table 8.1). Such averages, in turn, conceal significant variation among members of the same community. For example, the Djerma's historical claim to land in the Fakara is reflected in their greater access to cropland compared to that of more recent arrivals such as the Fulani. Among each of these social groups, the land cultivated per household varies significantly due to differences in effective access to land and labor, which reflects not only household size but also wealth status of the family. Moreover, land access rights are generally restricted to adult men in spite of the large involvement of women in crop management. Conversely, livestock ownership is most often individual and does not exclude either women or children. Hence livestock is the major form of wealth storage in this area. The differences in livestock wealth are even greater than those in land cropped both within and across communities in the region.

Farming Systems and Natural Resource Management

A household's resource endowment in land, labor, and livestock plays an important role in determining the nature of its crop and livestock management. Labor-rich households are more likely to farm a larger fraction of their cropland, self-manage their livestock, and commit greater amounts of labor to soil management—particularly to the efficient capture and incorporation of livestock manure into their fields. Land-rich households, on the other hand, are more likely to depend on fallowing to maintain soil fertility. While the particular mix of household endowments helps shape an individual household's strategy for resource management, resources held by the community, whose use is regulated by community institutions, are also important. This is particularly evident in the case of communal and cross-communal

Table 8.1 Averages of labor force (adult equivalent), area of land cropped and owned (traditional land right), and livestock managed by Djerma and Fulani farmers in villages of the district of Dantiandou (Western Niger).

Farm Type	Wealth Ranking	# of Farms	Labor[1]	Cropped Land		Livestock (number)			
				area (ha)	owned (%)	cattle	sheep	goats	donkey
Djerma	Low	213	4.9	9.1	61.4	1.1	1.0	1.0	0.2
village	Medium	126	4.5	21.4	59.5	0.7	1.1	1.4	0.2
farms	High	27	8.4	25.2	56.9	12.7	5.1	4.1	0.8
Fulani	Low	92	5.8	8.7	3.5	4.5	4.6	11.9	1.5
camp farms	High	74	5.4	12.7	9.7	15.4	13.1	22.5	2.0
All	All	532	5.2	13.2	43.5	4.7	3.9	7.0	0.7

[1] adult equivalent

grazing resources such as water points, salt licks, rangelands, fallow lands, and even crop residues left in the fields. Their communal management facilitates the seasonal mobility of livestock, which is a major way to adjust the feed demand to diverse and fluctuating feed resources. Livestock grazing is regulated by herding, an activity that seeks to match the feed demand of managed animals to feed availability. While pastoral access rights are set through communal institutions, herding is an individual strategy, the efficacy of which depends on the availability of labor and pastoral skills in the household. Technical and social skills are required to decide on the timing and direction of livestock itineraries for day and night grazing periods, in relation with the location of the water points and camps, as well as to decide on the grouping of animals in separate herds or whether individual animals should be entrusted to other herders (Bonfiglioli 1990; Schareika et al. 2000). Successful herding often requires the herd to be split into different management units on a seasonal basis (based on age, sex, and species), a practice which is variably pursued, depending on herd size and herding labor availability. Compared with less labor-intensive grazing strategies, herding also increases livestock wealth security and lowers the risk of crop damage by grazing animals. Conflicts caused by encroaching livestock are more frequent where livestock-rich but labor-poor agropastoralists live among sedentary farmers, especially if the two groups are ethnically different.

IMPACT OF NATURAL RESOURCE MANAGEMENT ON THE AGRO-ECOSYSTEM

The biological productivity of the Sahelian ecosystem is constrained by low soil fertility and sparse rainfall. The high spatiotemporal variability of rainfall interacts with the relative importance of the various land-use ecological processes, which work at different spatiotemporal scales, in affecting biological potential. In response to this dynamic system, agriculturalists and pastoralists have developed production strategies that are spatially broad and temporally diverse. Researchers' understanding of the human and ecological complexity of this region has been constrained by the dominance of descriptive (including remote sensing) over process-oriented research traditions, the short-term nature of most research, and static equilibrium-based concepts and methods brought to the social and ecological study of this area. An unfortunate legacy of this is that, despite a long history of research directed at the problem of desertification in the Sahel, there remains a paucity of work that explicitly considers the complex relationship between specific characteristics of land use and ecological change.

Since the 1970s, the debate has focused around whether climate or human activities are the more important factors behind land degradation, variously defined. Clearly, the interactive effects of climatic variations and land-use changes on production ecology are so strong that such an either/or approach is not justified. What is needed is more process-oriented ecological research that untangles "grazing impact" or "cropping impact" into their constituent biophysical processes — working on different spatiotemporal scales and differentially influenced by rainfall variability. Such process-oriented work can, in turn, form a stronger basis for investigating how, by shaping the seasonality and intensity of particular ecologically relevant actions, different resource management strategies may reduce or increase environmental stresses. Following the outline of such an approach, we present in this section some of the main fundamental processes of a Sahelian land-use ecology and consider the role of resource management at the household and community scales in influencing the relative importance of these processes.

The Fundamental Impact Processes

Cropping

Sahelian cropping systems are dominated by a staple cereal (mainly millet and some sorghum) aimed at subsistence, associated with a range of secondary crops, either dual purpose legumes (cowpea, bambara nut, groundnut) or cash crops (sesame, sorrel). Depending on soil texture, tillage ranges from very extensive no-till practices on sandy soils to ridging or plowing in finer-textured soils. The bottleneck of cereal cropping is often the time–labor required for weeding, the efficiency of which is as low as 0.15 ha per adult per day for manual weeding in Western Niger. Low inputs and poor inherent fertility of the soils generally limits yields and explains the periodic fallowing traditionally practiced to restore soil fertility. Clearing pristine vegetation or a fallow for cropping severely affects woody plant populations, which will be persistently modified. Most of the woody plants are cut during clearing, and the coppices will be cut again once or twice a year; a few trees, selected for their useful products, are spared and often benefit from the reduced competition. In the long run, this form of management promotes the "park" landscape characteristic of old agrarian civilizations in Africa. In addition, no matter what technique is used to prepare the land (no-till, hoeing, plowing), cropping exposes much of the soil surface at least during the early stages of crop growth, and this promotes wind as well as water erosion (Buerkert et al. 1996). It also increases soil temperature and accelerates the rate of mineralization of the soil organic matter, which then rapidly decreases during the crop cycle, especially when the crop residues are not returned to the soil. Indeed, the main impact of cropping on the ecosystem is the gradual mining of nutrients, especially nitrogen and phosphorus (Piéri 1989; Stoorvogel and Smaling 1994). For example, very extensive millet cropping in Western Niger annually exports 15 kg N, 2 kg P, and 15 kg K per hectare per year through grains (Hiernaux et al. 1997). These exports are seldom balanced by fertilizer inputs, except on the restricted areas that benefit from livestock manure.

Livestock Grazing

Grazing affects the agro-ecosystem through defoliation, trampling, and the deposition of excreta, which all have short- and long-term effects on vegetation and soils. Defoliation varies greatly from one vegetation patch to another (at < 20 meter scale). In the short term, plant defoliation lowers herbaceous vegetation cover and aboveground mass, but the net effect on production differs with the season of defoliation. Grazing during the wet season affects herbage growth in ways that depend on the timing, frequency, and intensity of the defoliations. When grasses are defoliated at an early stage of development, the increase in tiller number compensates, and sometimes overcompensates, the initial reduction in herbage mass (Hiernaux and Turner 1996). At later stages, additional tillers and regrowth do not compensate the loss in production, which reaches a maximum when defoliation occurs at heading. Growth response is negatively related to defoliation frequency, with up to 50% reduction in total yield for severe defoliations repeated every two weeks. The nutrient content of regrowth remains higher than in ungrazed plants, so that total nutrient uptake by repeatedly defoliated plants almost equals nutrient uptake by ungrazed plants, despite their lesser production. Grazing during the dry season does not affect plant growth but accelerates decay of standing hay into litter, litter decomposition, and organic matter mineralization. The removal of the standing hay and litter aggravates soil erosion but helps germination and seedling establishment at the start of the next rainy season.

In the long term, grazing influences species composition at spatial scales circumscribed by a typical daily grazing radius (3–6 km). Except for the large sand dunes systems at the northern fringe of the Sahel, the distribution of waterpoints during the wet season is sufficiently scattered to allow temporary access to most range resources. Consequently, concentration of grazing pressure is avoided when the herbaceous layer is most sensitive to grazing. However, as the dry season progresses, livestock have to concentrate around more permanent large surface water points or unevenly distributed wells and boreholes. In the regions endowed with a continuous and exploitable water table, the promotion of a web of regularly spaced waterpoints, such as in the Ferlo region of Northern Senegal (Barral 1982) or in Eastern Niger (Thébaud 1999), facilitates a full exploitation of fodder resources — this runs the risk of aggravating feed shortages in dry years. When grazing pressure is maintained throughout the rainy season, seed production can be substantially disrupted, threatening the propagation of the species. Preferred species are replaced either by less palatable ones or by species that better cope with defoliation pressure, often because of their short growing cycle. Less palatable species tend to give high yields in material that is largely returned to soils, while short-cycle annuals yield less because of the short duration of their growth. Both responses result in a diminution of livestock feed resources. The long-term impact of livestock on the vegetation also results from the effect of the vegetation removal and trampling on the soil physical properties, runoff, and erosion processes. Trampling by grazing animals (especially during rainy season) increases bulk density and decreases water infiltration rates in fine-textured soils but may improve water infiltration of sandy soils by breaking thin structural crusts and speeding up litter decomposition (Hiernaux et al. 1999). However, decreased vegetation cover and broken soil crusts may enhance wind erosion.

Through fecal excretion, livestock recycle about 50% of organic matter ingested, 48% of N, and 85% of P intake. Another 40–50% of the N intake is also returned through urine, but most of this is then lost through volatilization. About half of these returns is deposited by the animals while grazing, while the other half is deposited while animals are resting. Resting places could be a barn or a backyard shelter, an individual or collective paddock, or an area of the fields on which the animals are corralled. If animals are not corralled directly on fields, the manure that accumulates at resting places is collected, transported, and applied to the fields. The other half of feces and urine produced are deposited along the grazing itinerary wherever the animals are sent to graze. As a result, livestock mediate a spatial transfer of organic matter and nutrients from the grazed rangelands to the manured fields. This may lead to discernable differences in soil fertility at spatial scales associated with 3 to 6 km daily grazing radii (Turner 1998).

Gathering and Forestry

The effect of gathering natural products is highly variable depending on the nature of the product harvested, as well as the frequency and intensity of removal. Historically, over much of the Sahelian region, the impact of fuelwood collection by rural populations was minor because it only involved dead wood (Benjaminsen 1993). However, as a result of the rapid increase of both fuel and building material needs, especially in the vicinity of growing towns, an increasing number of trees and shrubs are cut, from crop fields at clearing but also from the forest and savannas of marginal lands (Peltier et al. 1995).

How Does Management Influence Impact?

Land Tenure and Other Institutions

Crop-management decisions, such as those concerning crop and variety choice, soil preparation, reseeding, fertilizer and insecticide use, weeding, and the fate of weeds and crop residues, are largely made within households and are influenced by many socioeconomic factors, among which market opportunities and labor availability are of key importance. Land tenure laws and regulations differ between countries (some of which have recently adopted land titling laws), but access to land for cropping is generally based on customary rights across the Sahel. Primary rights are generally shared by the families who trace their ancestors through lineages of the community founders. These rights are limited to the usufruct of crops and of selected natural products (trees). Secondary rights are obtained through contracts with owners of the primary rights; these rights are often restricted to the crop products. Other natural products such as trees are not included, which is a disincentive for agroforestry management. These contracts, which do not systematically include a payment (generally provided in kind on an annual basis), establish a social link between the contractors. Unless secured by mortgages, secondary rights are revocable, thus providing no incentive to make durable investments in the land.

The flexibility of this land-tenure system has allowed the rapid expansion of cropped land to the detriment of fallows and rangelands (Bourn and Wint 1994; Mortimore and Tiffen 1995). In terms of area, fallowing is the major technique used to restore soil fertility in crop lands. In classical shifting cultivation systems, five years of cropping is alternated with 15 to 30 years of fallowing. This fallow duration was sufficient to restore the topsoil's organic matter and nutrient content, as well as its woody plant community structure. At the same time, fallows provided livestock with forage during the cropping season. The expansion of cropped areas has directly affected the practice of fallowing, reducing both fallow area and duration. In the present short-fallow system of Western Niger, five years of cropping alternate with three years of fallow. This duration is not sufficient to assure reconstitution of the woody plant population nor soil organic matter content, and the herbaceous layer of fallows are dominated by crop weeds. Fertilizer inputs, which could provide an alternative way to maintain soil fertility, require cash income, which is only commonly available in areas that can support cash crops such as cotton and groundnut.

The Contrast between the Southern and Northern Sahel

Management influences the impact of grazing differently in the Southern Sahel, where livestock husbandry is more associated with cropping, than in the Northern Sahel, where pastoral activity is dominant.

In pastoral zones, animal diversification, splitting livestock into specialized herds, and livestock mobility are the main strategies to avoid risks and to optimize the tracking of fluctuating and heterogeneous resources (Scoones 1995). Livestock mobility flattens peaks in grazing pressure and allows the use of feed resources that are only periodically available, like crop residues in Southern Sahel or wetland pastures. The flattening of grazing pressure is easier during the wet season, when water resources do not limit mobility. Thus, with annual stocking rates (Tropical Livestock Unit, TLU) of 25 to 50 kg of livestock ha^{-1} (5 to 10 TLU km^{-2}) and an average herbage yield (dry matter, DM) of 0.5 t DM ha^{-1}, direct removal rates of standing biomass equate to 5–10% in the wet and 15–30% in the dry season, or 20–40% over the entire year (de Leeuw et al. 1999). These rates are lower in good rainfall years, higher in poor ones, and may become excessive in drought years, at least locally. As a result, the Northern Sahel rangelands appear to be very resilient to grazing pressure. Variation of herbaceous yield observed across 25 range sites during 10 years in Northern Mali is best explained by rainfall (magnitude and distribution), soil type, and topography rather than by grazing history (Hiernaux 1995). The influence of grazing history on species composition was conspicuous in situations of extreme livestock pressure, in the vicinity of camps, watering points, and other livestock resting and concentration points. Elsewhere, the influence of grazing on the species composition was partly masked by the strong effect of the distribution of early rains on the germination and establishment of annual species (Cissé 1986). The influence of grazing history on species composition is also obscured by the similarities in adaptive traits of annual plants to drought and grazing — such as the advantages of a short growing cycle, a large investment in seed production, and a high tillering ability of grasses under conditions of high defoliation pressure or recurrent drought.

In the crop-livestock systems of the Southern Sahel, land-tenure institutions do not generally impede cropland expansion, except in some key pastoral areas such as around livestock paths and waterpoints that may be protected. Crop expansion does not systematically lead to a reduction in the livestock feed produced on the land; however, it does cause feed shortages during the wet season when livestock are not allowed access to cropped land. As crops expand, local rangelands are subjected to increasing grazing pressure during the wet season. For example, grazing pressure exerted during the first month of the wet season on the rangelands and fallows of village territories in Western Niger reached 68 to 160 TLU days per tonne of forage, while the average grazing pressure over the year's cycle was only 7 to 12 TLU km^{-2} (Hiernaux et al. 1997). A high grazing pressure exerted just when the herbaceous vegetation is most sensitive to grazing can lead to rapid degradation, either through severe reduction of the herbaceous cover and production (rangeland with *Zornia glochidiata* and *Microchloa indica* on shallow soils) or through encroachment of an unpalatable weed (*Sida cordifolia* on deeper or more fertile soils). Livestock management that sends herds on transhumance to the Northern Sahel can reduce grazing pressure in the agropastoral south during the wet season (Table 8.2).

After crop harvest, livestock are allowed back on to cropped lands. The feed value of millet or sorghum stalks and weeds at this time assures, at best, the maintenance of livestock weight. However, increasing quantities of crop residues are harvested by farmers to feed selected animals or to sell, and thus are neither available for grazing nor returned to crop soils (de Leeuw 1997). The privatization and commodification of crop residues is an important phenomenon in many areas, particularly those experiencing high population pressures. This

Table 8.2 The practice of wet-season transhumance in three village communities of the district of Dantiandou (Western Niger) depending on the relative area cropped in 1995.

Villages	**Land cropped** (%)	**# Households**			**# Livestock in transhumance during the 1995 wet season**		
		Total #	Managing herd	Practicing transhumance	cattle	sheep	goats
Banizoumbou	30	172	53	17	314	217	117
Tigo Tegui	36	166	57	33	731	825	521
Kodey	62	110	59	48	1338	542	923

trend not only affects the availability of local fodder resources, but has significant nutrient cycling implications for Sahelian croplands, by lowering the attractiveness of the area for grazing.

Livestock play an important role in Sahelian agriculture. The use of animal power can alleviate labor shortages, improve the quality and timeliness of farming operations, and increase farm productivity (Williams 1997). Another important role of livestock in the agro-ecosystem is to transfer organic matter and nutrients from grazed areas to locations such as village paddocks, waterpoints, or fields where animals are corralled, through the feces and urine deposited during their resting time. In Western Niger villages, livestock management led to the concentration of manure on selected fields by a factor of 5 to 13 × compared to the average field within the village territory (Hiernaux et al. 1997). The average annual rate of manure deposition on field-based corrals was 12.7 t DM ha^{-1} for cattle and 6.8 t DM ha^{-1} for small ruminants. Because of these high rates, the aggregated corral area was only 0.5–1.2% of village cropped land. However, the effects of such high rates are expected to last four to five years. If one includes fields that receive manure and organic wastes collected in livestock paddocks, barns, or backyards, an estimated 3–8% of the cropped lands benefit from manure application in any given year.

Reflecting the strong variation seen among households with respect to access to land, labor, and livestock, there are large differences in households' manured cropland area. At the average manuring rates prevalent in the area, six cattle (12 t DM ha^{-1} yr^{-1}) or 12 small ruminants (6 t DM ha^{-1} yr^{-1}) are required to manure (year-round) one hectare. As a result, some farmers (e.g., the wealthy Fulani in Table 8.1) have the option of manuring all the land they crop while others can manure less than 5% of their fields. These rates of manure application increase millet grain yields by about 2/3 over four years, but also stover yields by about 80%. Therefore, the inter-household distribution of manure is highly uneven with significant implications for soil fertility maintenance at the landscape level. Customary contracts, such as manure spreading and livestock entrustment contracts, have played a historical role in providing a way for livestock-poor households to gain access to manure. Unfortunately, the prevalence of these contacts has declined significantly in many areas of the Sahel (Turner 1992). Institutional innovations that increase the security of customary contracts are needed for their reinvigoration.

PERSPECTIVES AND OPTIONS FOR FUTURE DEVELOPMENT

Population increase, shifts in livestock ownership, labor emigration by young men, and the growing privatization of natural resources are major social trends in the Sahel with important implications for natural resource management in rural areas. Growing land scarcity in many areas of the southern Sahel will increase the incentives for greater investments of labor and capital into the farming. In the southern Sahel, the tighter integration of crop and livestock activities is one option to increase input per unit area of land through animal traction, crop residues, and manure management. However, these incentives are countered by ecological constraints, seasonal labor scarcities, household differentiation in labor and livestock endowments, and the erosion of the institutions that have worked to facilitate accessing of the resources held by others. Therefore, the situation deviates from a Boserupian simplicity: a range of local responses to land scarcity are possible, each of which has significant environmental implications. The more detailed consideration of the processes by which changing land uses affect the environmental potential reveals that there is a strong seasonal aspect to this scarcity and to ecological sensitivity to human land uses. It is during the rainy season when land scarcities have their largest social and ecological effect. Labor demands are the highest, and the grazing resources most limited. Vegetation and soils are most sensitive to defoliation during the rainy season. Because of the strong seasonality of the social and ecological impact of scarcity, intensification in the Sahelian region must incorporate strategies to reduce the environmental stresses caused by land scarcity and agriculture intensification. Without significant livestock feed supplements, intensification is only sustainable if it is associated with regional integration with pastoral systems of northern Sahel (wet season transhumance, reproduction), and with N and P inorganic fertilizer inputs (to provide an overall increase in productivity). Identification of suitable cash crops, and crop diversification, will help, but neither the farmers nor the nations can finance the required global increase in fertilizer inputs. This calls for major political decisions (Breman et al. 1990). Better integration of livestock production between crop-livestock systems in the south Sahel and pastoral systems in the north Sahel also requires political action to set up the appropriate institutions that can ensure livestock mobility, thereby optimizing the use of pastoral resources and minimizing degradation risks.

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