Soil Fertility Management in West African Land Use Systems
G. Renard, A. Neef, K. Becker and M. von Oppen (Editors); Niamey, Niger, 4-8 March 1997

ISBN 3-8236-1272-7

44

Effects of livestock on soil fertility in West Africa

J.M. Powell[1] and C. Valentin[2]

1. USDA-ARS Dairy Forage Research Center, 1925 Linden Dr. West, Madison, WI 53706, U.S.A.
2. ORSTOM, BP 11416, Niamey, Niger

ABSTRACT

Livestock have long been an integral part of West African farming systems. Although the communal and extensive grazing of natural pastures continues to be the predominant feeding strategy, drought and demographic pressures are confining livestock to smaller land areas and farmers are more intensively using pastures and crop residues to feed their herds. These changes accentuate livestock impacts on soil fertility. The passage of biomass through livestock accelerates nutrient cycling. Nutrient losses due to livestock result principally via volatilisation of urea nitrogen (N). In grazing systems, livestock are principal vectors of nutrient redistribution across the landscape. Manure and urine excretions and livestock effects on soil physical properties are concentrated around watering points, along paths of livestock movement and in resting areas. Most studies indicate that livestock-induced changes to pastures appear to be short-term and limited to small areas. Livestock have little impact on soil nutrient balances of pastures as opposed to cropland. During dry seasons, farmers corral livestock overnight on fields to manure cropland. This practice returns both manure and urine to soil and conserves nutrients. Urine increases the availability of soil phosphorus (P) and crop yields. Manure-P mineralises faster in soil than biomass-P. Increases in soil-P availability due to livestock could be considered of benefit to crop production in West Africa where soils are inherently more P than N deficient. A particular challenge facing farmers in West Africa having limited access to external nutrient sources, is to minimise nutrient losses through good management. Improved feed production, quality, availability and more efficient feeding systems; new ways to capture and conserve nutrients excreted by livestock; improved manure spreading techniques; cropping systems that reduce nutrient losses and a more widespread use of fertilisers can improve livestock impacts on the soil environment. Any technology or management aimed at reducing the negative impacts of livestock on soil fertility need to be integrated and assessed in relation to the primary goal of sustainable increases in agricultural production.
Key words: Livestock, nutrient cycling, manure, trampling, soil erosion

RESUME

Impact de l'élevage sur la fertilité des sols en Afrique de l'Ouest

L'élevage a longtemps été une partie intégrante des systèmes de production ouest-africains. Bien que l'exploitation communautaire et extensive des pâturages naturels demeure la stratégie fourragère prédominante, les sécheresses et la pression démographique repousse l'élevage dans de plus petites superficies et les agriculteurs utilisent les pâturages et les résidus de récolte de façon plus *intensive pour nourrir leurs troupeaux. Ces changements accentuent l'impact de l'élevage sur la fertilité du sol. Le passage de la biomasse à travers les animaux accélère le cycle des éléments nutritifs. Les pertes en éléments nutritifs dues aux animaux sont principalement occassionnées par la volatilisation de l'azote (N) dans l'urée. Dans les systèmes de pâturage, l'élevage est le vecteur principal de redistribution des éléments nutritifs dans l'environnement. Les excrétions fécales et urinaires et les effets de l'élevage sur les propriétés physiques du sol sont concentrées autour des points d'eau, les couloirs de passage et dans les zones de parcage. Beaucoup d'études indiquent que les changements induits par l'élevage dans les pâtures semblent être à court terme et limités aux petites superficies. L'élevage a peu d'impact sur le bilan nutritif des pâturages. En saison sèche, les paysans maintiennent les animaux sur les champs pendant la nuit pour fertiliser les terres agricoles. Cette pratique permet de retourner les féces et l'urine au sol et de conserver ainsi les éléments nutritifs. L'urine augmente la disponibilité du phosphore (P) du sol et les rendements agricoles. Le phosphore dans la fumure minéralise plus rapidement dans le sol que P dans la biomasse. Des augmentations de disponibilité en P dues aux animaux sont très bénéfiques pour les sols ouest-africains qui sont plus déficitaires en P qu'en N. Le défi posé aux agriculteurs d'Afrique de l'Ouest, dont l'accès aux sources extérieures en éléments nutritifs est limité, consiste à diminuer les pertes en éléments nutritifs en assurant une bonne gestion. L'impact de l'élevage sur la fertilité du sol peut être amélioré par une production fourragère améliorée, la qualité et la disponibilité de systèmes fourragers plus efficaces; de nouvelles façons de récupérer et conserver les éléments nutritifs excrétés par les animaux; des techniques améliorées d'épandage du fumier; des systèmes de cultures qui réduisent les pertes en éléments nutritifs et une utilisation plus répandue des engrais. La recherche de solutions aux problèmes de l'impact négatif de l'élevage sur la fertilité des sols doit être intégrée et évaluée en fonction d'une production améliorée et d'un impact réduit sur l'environnement.*

Mots-clés: *Elevage, cycle des éléments nutritifs, fumure, piétinement, érosion du sol*

INTRODUCTION

Over the past several centuries, livestock (cattle, sheep and goats) production in West Africa has followed a fairly generalised formula based on transhumance and extensive grazing. However, livestock populations, distributions and husbandry, and their concomitant impacts on soil fertility and the environment have changed dramatically over the past few decades. The aim of this paper is to provide an overview of key biophysical and management factors that influence livestock-soil fertility linkages and identify possible pathways for improving livestock environmental impacts in West African farming systems.

Drought, a common occurrence in West Africa, has had tremendous impact on livestock numbers and the type of livestock farmers keep. During drought, approximately half of the livestock in arid and semi-arid areas may be lost (de Leeuw *et al.* 1993; IEMVT 1989). Small ruminants, particularly goats, have a higher survival rate than cattle (Arnal and Garcia 1974; Dahl and Hjort 1976). Also, the rapid reproduction and growth rates of small ruminants allow these flocks to be reconstituted much faster than cattle herds. Livestock numbers increase dramatically after drought (Gallais 1979).

Drought and demographic pressures have considerably altered the annual cycle of herd transhumance whereby livestock trek from arid and semi-arid areas during the dry season to more humid locations further south. Livestock are increasingly restricted to smaller land areas, especially during wet seasons when a high percentage of land is cultivated, and during dry seasons when herds congregate on fields to graze crop residues, and around watering points. The continuous cultivation of low-lying areas normally used for dry-season pasture have cut off many traditional paths of livestock movement. The expansion of cropping has reduced tsetse fly populations in sub-humid and humid regions allowing livestock production on a permanent basis. The alternate periods of soil use by livestock followed by rest have been shortened or abandoned completely in many location of West Africa.

Today, most livestock in West Africa are integrated into mixed farming systems involving the integration of cattle, sheep and goats with crop production. Livestock feeding continues to be based on grazing, although confinement feeding is gaining in importance, especially around urban areas (Winrock 1992). Millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) are the principal crops in semi-arid regions and maize (*Zea mays*) and rice (*Oryza spp.*) are important in the more humid areas. Livestock concentrations are highest in the semi-arid zone where herds range from a few to hundreds of head per household with varying ratios of cattle, sheep and goats (Swinton 1988; Wilson 1986). Livestock holdings of individual households are not the main culprits of environmental degradation. It is the communal grazing of grouped herds at stocking densities in excess of carrying capacity that can rapidly lead to overgrazing and loss of soil fertility via nutrient depletion, soil erosion, etc.

West African farmers have limited access to external nutrient inputs. Low rural incomes and the high cost of inorganic fertilisers, among other factors, prevent their widespread use. Most farmers continue to rely on organic matter recycling for maintaining soil fertility. Livestock have long played a key role in these processes (McCown *et al.* 1979; McIntire *et al.* 1992; Powell and Williams 1993). The cycling of biomass through livestock and the use of manure and urine to fertilise the soil have long been an important linkage between livestock and soil fertility in West Africa. Whereas biophysical processes such as nutrient acquisition, metabolism and excretion by livestock, nutrient recycling through soils, etc. are modelled to describe nutrient flows in farmers' fields, farmer management is often the major determinant of overall livestock impacts on soil fertility and the environment.

LIVESTOCK IMPACTS ON NUTRIENT CYCLING

West African soils are inherently low in organic matter (Kowal and Kassam 1978; Pieri 1989), nitrogen (N) and especially phosphorus (P) (Breman and de Wit 1983). The ability of soils to maintain their productive capacities depends on the amount of nutrients removed as grain and forage and nutrient losses (leaching, erosion, etc.) *vs.* nutrient returns via feed refusals, trampled biomass, roots and various natural inputs (Fig. 1). Up to 95% of the total nutrients consumed by livestock are excreted. Whereas N is voided in both urine and faeces, most P is voided in faeces (CAB 1984; Ternouth 1989). Approximately equal amounts of N are excreted in faeces and urine, although this proportion and forms of faecal-N are highly influenced by animal diet (Powell *et al.* 1994; Somda *et al.* 1995).

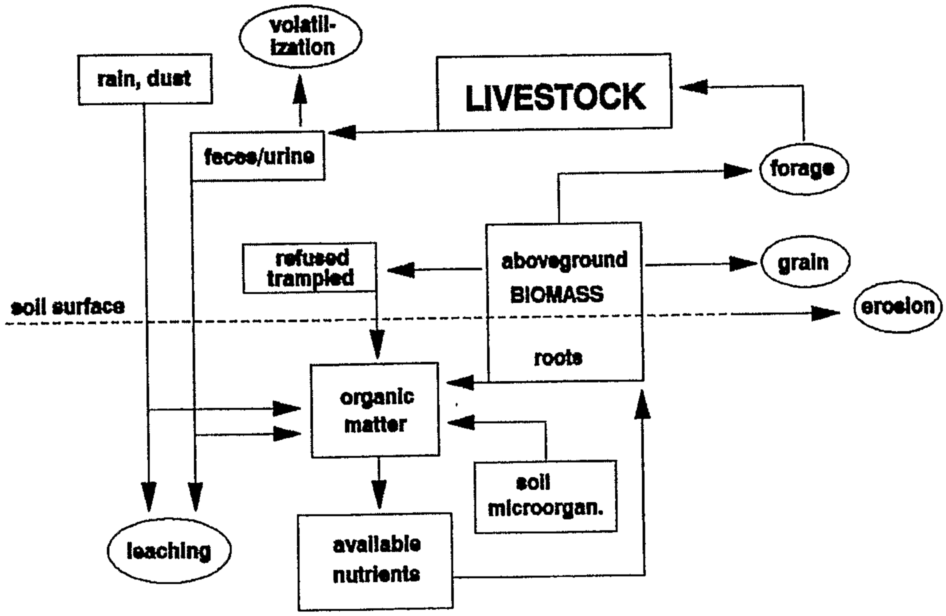

Figure 1. Internal nitrogen cycle of mixed farming systems in West Africa (*Source:* Powell *et al.* 1996).

In West Africa, seasonal fluctuations in feed supply and quality result in great variations in manure output and nutrient content (Landais and Lhoste 1993; Powell and Saleem 1987). Lower concentrations of organic matter, N and P are found during the dry season, when the quality of feed is lowest. As the concentration of polyphenolic compounds in the feed increases, the excretion of faecal-N increases and urinary-N decreases. Since approximately two-thirds of urine-N is in the form of urea, which can be rapidly converted to ammonia and lost via volatilisation, feeding tanniferous feeds may improve nutrient cycling. The insoluble-N fraction in the faeces also increases in response to the consumption of polyphenolic compounds, which may lower the mineralisation rate and increase the availability of N to crops when manure is used as a source of soil nutrients (Powell *et al.* 1994).

Feeding biomass results in nutrient losses. Grazing leads to a spatial redistribution of nutrients, since faecal and urinary spots are localised in small heterogeneous patches (Russelle 1992). Nutrient losses, especially from urine-N through volatilisation can be great (Floate 1981; Russelle 1992; Senft *et al.* 1987). Confinement feeding systems relying principally on the importation of feeds can become nutrient sinks and resulting in high nutrient losses if manure accumulates excessively.

The feeding of biomass to livestock accelerates nutrient cycling. For example, manure applied to soil decomposes and releases nutrients faster than biomass (Fig. 2). The pattern of nutrient release from manure appears to coincide closely with plant nutrient demands (Powell *et al.* 1994). Since most soils of West Africa have high iron and aluminium oxide contents, which render P and other nutrients unavailable to plants, the accelerated flow of P through manure (Fig. 2) can be particularly advantageous in soils having low P levels (Floate 1981). Soil organic matter, perhaps the most key factor in controlling the productivity of West African soils (Moorman and Kang 1978) is increased with manure applications (Abdullahi and Lombin 1978; Bationo and Mokwunye 1991; Powell 1986).

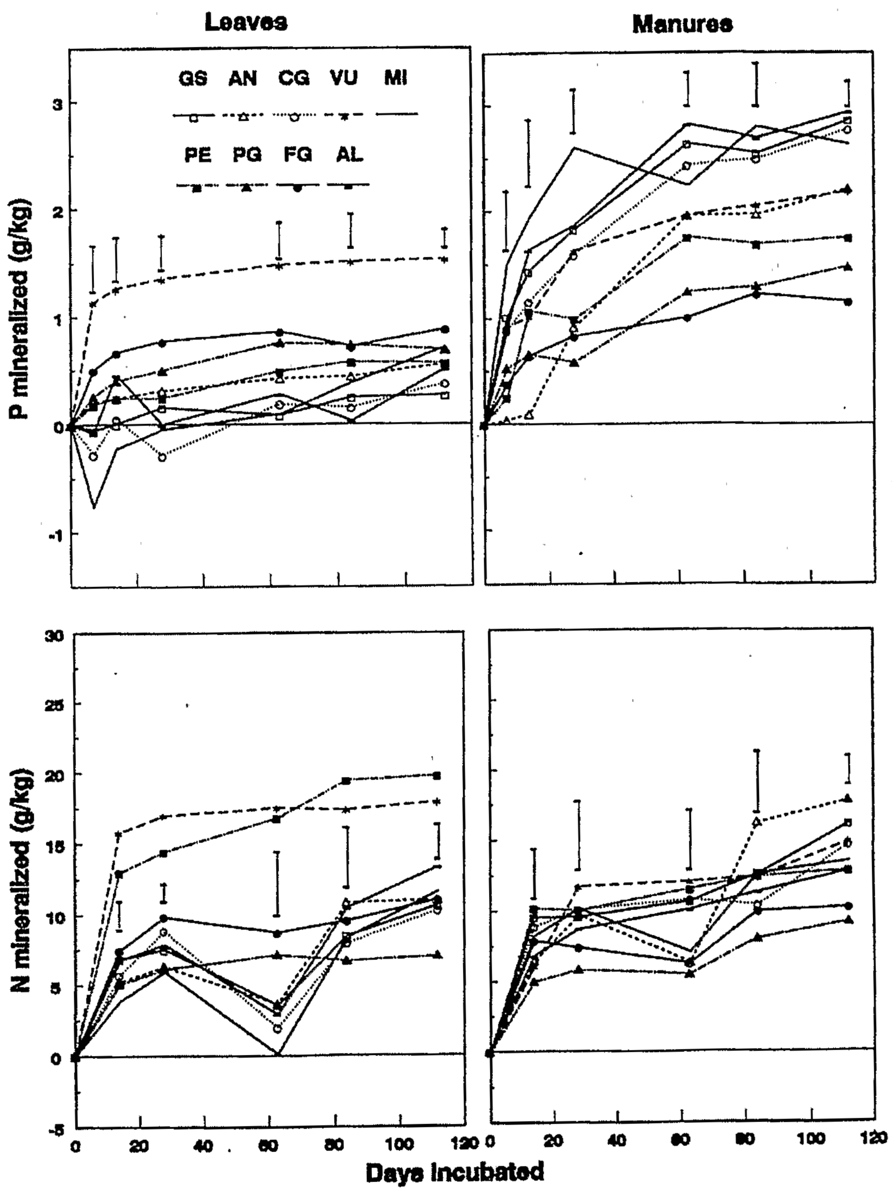

Figure 2. Nitrogen and phosphorus release from forage leaves and sheep manure applied to soil during a cropping season in Niger (*Source:* Somda *et al.* 1995).

Farmers purposefully manage their livestock to harvest nutrients on natural pastures and transfer them to cropland (Powell *et al.* 1996; Sandford 1989; Swift *et al.* 1989). Farmers manure their cropland in two ways: (1) herds are corralled overnight directly on fields between cropping seasons and (2) manure is gathered from stalls and hand-spread onto fields. Corralling returns both manure and urine to the soil, and involves no labour for manure collection, storage, transportation and spreading. Corralling has large positive effects on crop yields, which may last two to three cropping seasons (ILCA 1992). Higher yields can be attributed partially to urine effect on increasing soil pH and soil-P availability (Fig. 3). The capturing and recycling of urine, and urine's subsequent positive effects on soil-P availability perhaps make corralling a major pathway to more efficient nutrient cycling. Since corralling is practised between cropping seasons when soils are dry, the risk of soil compaction due to animal trampling is minimal on many soil types.

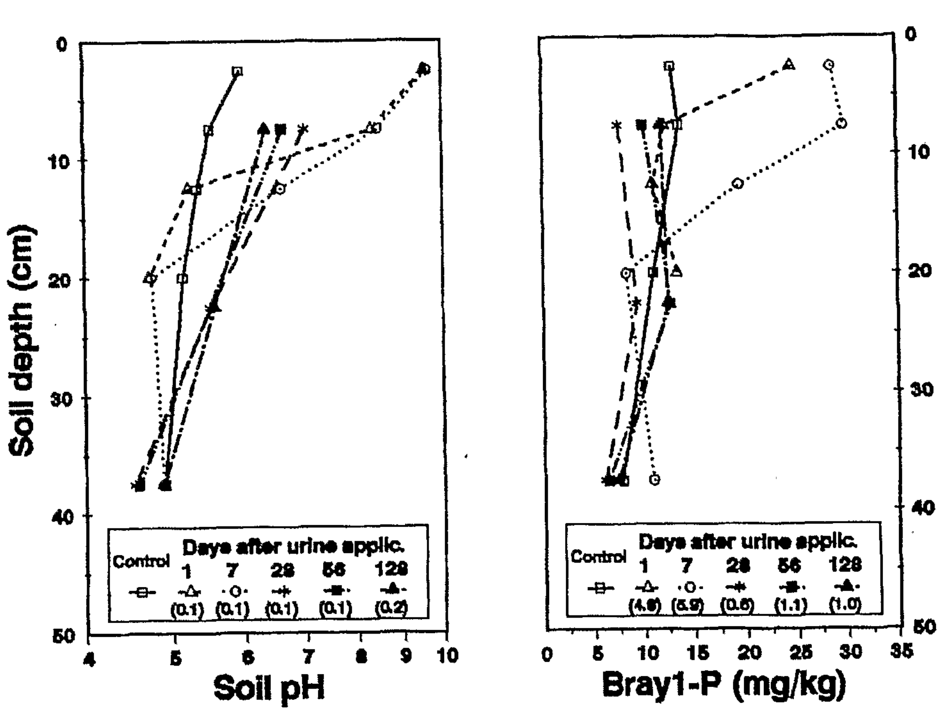

Figure 3. Sheep urine effects on soil pH and available-P of a sandy soil in Niger (*Source:* Powell, unpublished).

In the absence of external nutrient inputs, soil nutrient balances depend on the amount of nutrient removals in grain and forage and nutrient losses (leaching, erosion, etc.) *vs.* nutrient returns via trampled biomass, roots and various natural inputs (Fig. 1). In West Africa, even in situations of intense grazing pressure, livestock exports of N from rangelands remain lower or equivalent to N inputs (de Leeuw *et al.* 1995; Diarra *et al.* 1995; Powell and Coulibaly 1995). Even long histories of high animal densities appear to have no measurable impact on soil and plant uptake of N, and only marginally decrease soil and plant uptake of P (Tolsma *et al.* 1987; Turner 1992). The strong seasonality of Sahelian rangeland systems due to extremely high rainfall variability reduces the risk of overgrazing and has long ensured their sustained productivity (Cissé 1986; Hiernaux 1993; Hiernaux *et al.* 1995).

Croplands, unlike rangelands, do not have the internal capacity to replenish nutrient harvests. They must rely on external nutrient sources to maintain their productive capacities. Grain harvests constitute the largest nutrient exports from croplands. Whereas manure alone does not compensate for the amount of nutrients removed by livestock during crop residue grazing (Powell and Williams 1993), the amount of N in trampled and/or refused crop residue fractions, in manure, and via rain and soil micro-organisms approximately equals N removals during grazing (Powell and Coulibaly 1995). Feeding crop residues to obtain animal products is perhaps a rational strategy by farmers. Any residues remaining at the onset of planting are usually burned to facilitate manual cultivation.

High negative nutrient balances (nutrient imports minus exports) have been calculated for mixed farming systems of West Africa on country and regional scales indicating high risks of environmental degradation (Stoorvogel and Smaling 1990). However, the relationship between such large scale estimates and actual farm or field situations is likely low. This variation is less from a lack of basic knowledge of nutrient inputs and outputs, but more from a limited understanding of the effects of different management practices on landscape-level nutrient cycles; the variation structure of these management practices (individual, household, community, watershed); and the social and biophysical factors that affect these practices (Turner 1995). For example, modelling nutrient inputs and outputs for various mixed farming systems in Mali indicated that cropland nutrient balances were highly negative (Powell and Coulibaly 1995). However, on-farm surveys revealed that farmers who cultivate subsistence crops with commercial rice (*Oryza glaberrima*) and cotton (*Gossypium spp.*) have assess to, and apply sufficient fertilisers, and/or manure to their fields to offset nutrient harvests.

Despite manure's important role in sustaining soil fertility, two key questions arise: 1) Are sufficient amounts of manure available to permit adequate food production and improve soil quality on a long-term basis (de Ridder and van Keulen 1990; McIntire *et. al.* 1992; Sandford 1989; Schleich 1986) and 2) is the nutrient supply of natural pastures being depleted by livestock for the purpose of manuring cropland? Whereas farmers with many livestock have the potential capacity to maintain soil fertility through manuring, either with their own livestock or through their financial resources to engage transhumant herds in manuring their fields, the majority of farmers are poor in livestock assets (and cash income) and therefore less capable of countering soil nutrient depletion. As long as natural pastures are the major source of livestock feed, livestock-rich farmers will benefit the most from nutrient harvesting from rangelands and transfer to cropland via manure (Scoones and Toulimin 1995).

In Niger it has been estimated that an additional 9 to 21 cattle per hectare of millet would be required to replenish the 22 to 38 kg N and 2 to 6 kg P ha^{-1} harvested in grain and crop residues (Williams *et al.* 1995). Powell and Coulibaly (1995) estimated that three to seven cattle and seven to twelve small ruminants additional to farmers' current livestock holdings would be required to replenish the N harvests from various cropping systems. The amount of natural pasture required to support livestock for the purpose of manuring cropland has been highly debated. Rangeland:cropland ratios range between 10 to 40:1 (Breman and deWitt 1983; Fernández *et al.* 1995; McIntire and Powell 1995; Turner 1995) have been proposed for West Africa depending on range and cropland productivities, production goals of farmers, livestock and manure management, etc.

The efficiency in which manure is recycled in mixed farming systems depends on land type (slope, texture, nutrient attenuation potential, etc.), amounts and method of manure application (corralling, surface applied with or without incorporation), timing of application (months before or just prior to planting) and the nutrient demands of the subsequent crop to be grown. Managing manure to maximise nutrient recycling through plants needs to consider the hazards of nutrient runoff and leaching. Runoff is greatest from slopping land and on heavier textured soils having slow infiltration. Leaching losses can be great on sandy soils (Brouwer and Powell 1995) having high infiltration rates.

Effective recycling of nutrients excreted by livestock through crops presents many challenges. Pathways of faecal- and urinary-N recycling are very different. Whereas urine-N is subject to high losses mostly via volatilisation, manure-N goes through soil immobilisation and mineralisation process and becomes slowly available to plants. Also, the N:P ratios in manure and crops can differ greatly. If manure is applied to meet crop-N requirements, insufficient P would be applied. Applying manure to meet crop-P demands would result in excessive application of manure-N, which would be wasteful. Efficient nutrient cycling for farmers having (limited) access to both manure and fertiliser could be obtained by applying sufficient manure to meet crop-N demands and applying a small amount of supplementary fertiliser to meet crop-P demands.

It is widely believed that a much wider use of chemical fertilisers in West Africa will be crucial to achieving the necessary sustainable increases in food and feed supply and its quality (Breman 1990; McIntire and Powell 1995; Powell and Fussell 1993). The efficiency of fertiliser use increases dramatically when combined judiciously with organic nutrient sources such as manures (Bationo *et al.* 1995). Improved nutrient management will be particularly important in locations having high yield potential due to favourable soil water conditions.

Estimates of additional nutrient requirements to offset nutrient harvests do not advocate an indiscriminate use of fertilisers nor an increase in herd size for manure production. Fertilisers need to be used judiciously and match crop-soil associations to avoid soil acidification, loss of soil structure, etc. There is a need for more information on current rangeland and cropland carrying capacities and stocking rates, especially the ability of rangelands to support more animals for manuring cropland. Also, the manuring practices of farmers would need to be evaluated to estimate more precisely how much additional manure would be required to offset nutrient harvests. In Niger, for example, farmers manure their fields only every two to three years depending on rainfall and manure availability (Powell and Williams 1993). The positive residual effects of manure on crop yields (ILCA 1993; Powell and Ikpe 1992) indicates that only a fraction of farmers' total cultivated fields would have to be manured annually.

LIVESTOCK IMPACTS ON SOIL TRAMPLING, CRUSTING AND EROSION

Livestock are often considered main culprits of soil nutrient depletion and erosion. Overgrazing, trampling of the soil surface, lopping trees by herders for fodder and the setting of bush fires by herders to enhance the feeding value of pastures are considered major livestock management practices associated with environmental degradation (Delwaulle 1973; Okaeme 1988). However, livestock can also have positive effects on soil physical properties. For example, trampling sandy soil surfaces disperses soil from micro-mounds over adjacent barren and crusted spots, incorporates mulch, enhances water infiltration, reduces evaporation and creates favourable seed bed for grasses. Trampling and grazing near watering points increases forage productivity and its palatability, (Bille 1977; Boudet 1972; Valenza 1970). Soil organic matter levels (8%) in these areas can be eight times greater than in undisturbed areas, and 40 times greater than levels found in heavily grazed areas.

The greatest negative effects of livestock on soil physical properties occurs within a ring located between 0.5 and 2 km from the watering points (Valentin 1985) where livestock congregate and wait their turn at watering. Soil silt and clay fractions are wind-blown from the soil surface leaving sand ripples. The ratio between the silt:clay content in the top layer and silt:clay content in the 5 cm directly underneath is approximately 1.0 at a distance between 3 to 4 km declining to 0.5 between 1 and 2 km from the water point. Extremely low values of organic matter content are also recorded within the 1 to 2 km ring. Bulk density of the layer that underlies the trampled and sandy surface layer increased significantly as the distance to the wells decreased.

Soil crusting has been attributed to the combined effects of overgrazing and trampling of soil surfaces (Boudet 1977; Breman *et al.* 1980; Mott *et al.* 1979). However crusting of sandy soil surfaces cannot be attributed to overgrazing and trampling alone. Large-scale crusting also occurs in areas far from livestock watering points, and even in long-term exclosures. In unprotected sandy soils, soil crusting results from a textural sorting caused by rainfall (Valentin and Bresson 1992). Crusted soil have poor infiltration, greater overland flow of water, serious erosion problem and support low biomass productivity.

On light-textured soils cattle manure applications tend to improve soil structure (Chandras and De 1982). Dung attracts faunal activity (e.g. Roth *et al.* 1991) which perforate soil crusts and thus improve infiltration (Casenave and Valentin 1992). A recent on-farm trial in Niger (de Rouw *et al.* in press) showed that soil surface roughness increased with dung application (5 t ha^{-1}) which reduced therefore wind erosion. Conversely, dung favoured sand trapping and thus infiltration. On plots without dung, erosion crusts developed and infiltration was hampered.

In semi-arid and arid regions of West Africa, causes of vegetation losses are difficult to distinguish between the effects of overgrazing and trampling and the effects of drought. All three processes lead to denuded soil surfaces and increases soil loss by water and wind erosion. Under most circumstances, trampling causes only little reduction in the available biomass (Hiernaux and Gérard in press; Plumptree 1994). When drought and overgrazing occur simultaneously, denuding of soil surfaces in the vicinity of herdsmen settlements and watering points, is almost complete, especially were pasture productivity was already low (de Wispelaere 1980; Valentin 1985). Loss of soil structure and erosion can be avoided if at least 40% ground cover is maintained. A detailed study in Queensland (Australia) by Miles and McTainsh (1994) showed that soil loss on a heavily grazed site (with 12% cover) and on the ungrazed site (with 34% cover) were 5.2 and 2.8 t ha^{-1} $year^{-1}$, while losses of 89.5 t ha^{-1} yr^{-1} were measured at the bare site.

Soil crusting

Soil crusts are smooth, hard layers composed of fine particles remaining after a sandy surface layer has been removed by water and wind (Chase and Boudouresque 1989; Hoogmoed 1986; Valentin and Bresson 1992). Porosity of soil crusts is restricted to a few cracks and vesicles so that infiltration (0 to 2 mm h^{-1}) and evaporation (1 to 2 mm day^{-1}) are very low (Casenave and Valentin 1992; Le Fevre 1993). Crust development may result from drought independently of livestock influence (Valentin 1985). They continue to remain bare despite long (8 years) exclusion of cattle (Silburn *et al.* 1992). In northern Burkina Faso the percentage of bare and crusted soils increased from 5.6% in 1952 to 30.4% in 1984 (Serpantié *et al.* 1992). Although many crusted areas were likely due to many interacting causes, including the severe droughts of the early 1970's, it was clear that crusted areas were pronounced along tracks of livestock movement.

Loamy soils are more susceptible to trampling and crust formation than sandy soils (Valentin 1985). Trampling loamy soils results in a crumbled soil surface which agglomerates under moist conditions resulting in a hard layer when dry (Bresson and Moran 1995). Microphytes consisting of blue-green algae such as *Cyanobacteria* strengthen soil crusts. Crusts are generally disturbed by grazing and trampling under dry conditions (Marble and Harper 1989). For these reasons crusts are generally not found in heavily grazed areas.

Soil compaction

Because grazing ruminants generally have small hooves compared to their mass, trampling tends to compact soil surfaces, especially under moist conditions (Lagocki 1978). Whereas compression beneath the hoof is the major process in soils having low to medium soil water, plastic flow around hooves damages the structure of wetter soils. In swelling soils, damaged pores can be regenerated by shrink-swell (Taboada and Lavado 1993). Trampling decreases soil surface macro-porosity from 8 to 5% under dry soil conditions (Taboada and Lavado 1993). On loamy and clayey soils, trampling remoulds soil surfaces increasing their susceptibility to crusting processes. The degree of soil structure deterioration caused by livestock can be reduced by removing stock for brief periods when the soil is close to its plastic limit (Proffitt *et al.* 1995).

Soil compaction is often influenced not only by the soil water conditions but also by the composition of the vegetative cover. For example, Carter and Sivalingam (1977) observed that with increasing intensity of trampling, soil bulk density increased under clover (*Lolium rigidum*) but not under grass and mixed grass/legume swards. Grasses apparently provide a cushioning effect between the hoof and soil. Heavily grazed pastures containing the legumes *Stylosanthes hamata* cv. Verano and *Alysicarpus vaginalis* had more macropore space in the surface soil than a lightly grazed native grassland. Pastures containing *Stylosanthes humilis* (Townsville stylo) had the same reduced macropore space as degraded areas (Bridge *et al.* 1983).

Hydraulic conductivity

Livestock affect water infiltration thorough not only the combined effects of grazing and trampling on soil compaction and crusting, but also on their indirect effects on soil fauna. Trampling greatly reduces the number and distribution of earthworms (McCredie and Parker 1992; Castilla *et al.* 1995). Faunal activity increases after livestock are removed leading to a rapid production of continuous macropore network, improved soil structure and increased infiltration (Kemp *et al.* 1994). The deterioration in soil hydraulic properties under heavily grazed conditions can be associated with both trampling and decreased termite activity in the top 25 mm of soil (Holt *et al.* 1996).

Many authors have reported strong decreases of hydraulic conductivity due to grazing (Braunack and Walker 1985; Bridge *et al.* 1983; Mbakaya *et al.* 1988; Radke and Berry 1993). In north-eastern Nigeria hydraulic conductivity and infiltration rates were 11-fold less in heavily than in lightly grazed areas (Usman 1994). Trampling during the wet season under high stocking rates decreases hydraulic conductivity (Bridge *et al.* 1983). Trampling can explain 35 to 48% of the variation in infiltration rates (Dadkhah and Gifford 1980). At the watershed scale, cessation of grazing sharply reduces runoff (Sartz and Tolsted 1974).

Soil erosion

In the more arid regions of West Africa the sandy materials derived from ancient dunes are highly susceptible to wind erosion when vegetation is removed by overgrazing (or drought) and intensively trampled (Eldridge *et al.* 1995). One of the consequence of wind erosion is a great decrease in fine soil particles, soil organic matter and fertility (Valentin 1985). On the other hand, the fact that such materials are extremely sandy can protect them from crusting hazards and thus from heavy runoff and water erosion (Valentin 1994).

Overgrazing and trampling depletes the soils vegetative cover leading to decreases in soil structure, porosity and infiltration. These processes promote soil crusting and increase runoff and soil erosion. In semi-arid areas, the sediment concentration from a high stocking rate paddock was significantly greater than that from a low stocking rate paddock (Greene *et al.* 1994). The authors ascribed this difference to greater hoof activity and lower organic matter (and hence lower structural stability) of the 0 to 20 mm layer in the high stocking rate paddock.

Rill and channel erosion can be problematic along paths of livestock movement, especially on loamy soils (Valentin 1985). Despite some conspicuous rills and gullies favoured by livestock concentration around watering points (Bougere 1979) livestock are often unjustly widely associated with this natural phenomenon that occurs on ancient dunes which have an inherently high susceptibility to surface crusting, even in the absence of livestock (Barbey and Carbonnel 1972; Talbot and Williams 1978).

Vegetation cover

Low intensities of livestock may increase vegetation diversity (Blanch and Brock 1994). Trampling and grazing favour certain species and change, therefore, the botanical composition of pastures (Belyuchenko 1995; Valenza 1981). Tillering can be encouraged by intense defoliation at high stocking rates (Witschi and Michalk 1979). High-intensity short-duration grazing promotes seedling emergence, presumably by breaking up the surface crust and increasing infiltration (Eldridge *et al.* 1995). Furthermore, larger seed banks have been associated with higher levels of soil disturbance due to trampling (Pandetta 1985).

CONCLUDING REMARKS

Minimising the negative impacts of livestock on the soil environment is but one of many challenges facing West African agriculture. However, national and international concerns about mismanagement of natural resources are heightening. There will be no simple solutions to mitigating the negative effects of livestock on soil fertility. Improved livestock and soil management involve complex interactions among various farming system components. This demands an examination of the whole system including off-farm activities and a focus on interrelationships among feed, livestock performance and the soil environment. Evaluation of alternative livestock feeding and management strategies needs to consider multiple impacts, such as effects on livestock production, nutrient cycling, the soil environment and farm profitability. Management options need be flexible so they fit within the resource constraints of the farmer.

Research focuses often on the biological, technical and economic components of either livestock or soil management. Whereas these factors and their interactions directly affect agricultural production and profits, farmer management often has the greatest impact of agriculture on the environment. Any evaluation of livestock impacts on soil fertility need to consider not only complex interactions among biophysical factors, such as the source and fate of nutrients fed, excreted, applied to soil and recycled through plants, but also how management affects these processes.

The stability of agricultural production in many parts of West Africa depends heavily on livestock. Animals provide manure and transport to the cropping sector, and meat and milk for household consumption and sale. In semi-arid and arid regions, livestock provide vital food and are sold to purchase grain during years of low rainfall when crop production is poor or fails completely. These important roles of livestock, and the lack of alternative feeds, dictates that most biomass in West African mixed farming systems must be fed to livestock and manure/urine used to fertilise the soil. As long as fertilisers remain costly and widely unavailable to farmers, livestock will remain major vectors of transferring nutrients from pastures to croplands for soil fertility maintenance. However, the sustainability of such nutrient transfers will continue to depend on the balance between livestock numbers and feed supplies.

Compared to commercial confinement-based feeding systems which import feed and stockpile manure, grazing systems are generally considered environmentally benign. However, negative impacts of livestock on soils can be great in improperly managed intensive grazing systems. Overgrazing, trampling and loss of soil fertility can be great in locations where livestock congregate, such as along paths of their movement, in sheltered areas, around watering points, etc. Concerns about the negative impacts of agriculture on the environment calls for a re-evaluation of livestock production and its relationship to soil fertility. Alternative grazing practices are required that modify livestock temporal and spatial distributions and avoid negative environmental impacts.

Although animal manure is perhaps the most important soil fertility amendment farmers apply to cropland, the nutrient transfers mechanisms are poorly understood. An identification of nutrient pools and quantitative estimates of nutrient flows across landscapes are essential for identifying management strategies that can improve and sustain their productive capacity. The move from extensive, grazing-based livestock production where animals can be corralled to capture both manure and urine on cropland, to confinement feeding systems will require new methods of nutrient capture and transfer and improved land management to avoid excessive nutrient accumulations, pollution and environmental degradation. Composting in confinement-based feeding systems could reduce nutrient losses by capturing and stockpiling feed refusals, manure and urine, allow farmers to calculate more precisely the nutrients they have to apply, allow for a more even distribution of nutrients over fields and at a time when its nutrient release coincides closely with crop nutrient demands.

Manure of the large transhumant herds remains vital to sustaining the productivity of many cultivated areas. Access to manure and, therefore, transhumance needs to be encouraged in many West African farming systems. Factors that inhibit livestock movement and, therefore, farmers access to the manure of transhumant herds, will greatly increase the need for other external nutrient inputs such as fertilisers to prevent declines in soil fertility and crop yields (Breman 1990; de Ridder and van Keulen 1990; Powell and Coulibaly 1995).

Perhaps the biggest challenge facing efforts to mitigate the negative impacts of livestock on the soil environment is how to modify the behaviour of farmers. For many generations farmers have relied on communal pastures to feed livestock. This option is diminishing rapidly. Greater emphasis on nutrient management education could increase awareness among researchers, extension agents, the private sector and governments of the important linkages between livestock management and the soil environment. Targeted, incremental and flexible approaches, with farmer involvement, are likely to be more effective than top-down, inflexible prescriptions. Research and policy recommendations related to farming practices are often based on poor understanding of the farmers' needs and their abilities to incorporate new practices and cope with new regulations.

A clearer delineation of production systems and related constraints will be essential for focusing research on relevant issues having the highest probability of positive impact. Farmer knowledge of, and access to many technologies associated improving soil fertility is often not a barrier to their adoption and use. Most farmers have few resources to take on additional technologies. Also, many technologies are not profitable and farmers are not convinced of the need to have them. Technical information and approaches to improving livestock impacts on soil fertility is not synthesised into unified, yet flexible approaches that can be adapted to an array of production systems.

Basic research should remain the linchpin in generating new information, for example how livestock metabolise nutrients; applied research will continue to be needed for using this knowledge, for example in developing improved feeding strategies to make the most efficient use of feed nutrients in animal rations and adaptive research should continue to not only move, but seek to keep, technologies on-farm. Farmer feedback through adaptive, on-farm research should be a key resource of institutional learning and used to prioritise and plan future research. An appropriate mix of disciplinary/basic and, interdisciplinary/applied and adaptive research targeted at specific goals and outcomes, backed by adequate and sustainable funding, offers the most viable approach for resolving many of the complexities of improved livestock and soil management.

REFERENCES

Abdullahi, A. and G. Lombin 1978. Long-term fertility studies at Samaru-Nigeria: Comparative effectiveness of separate and combined applications of mineral fertilizers and farmyard manure in maintaining soil productivity under continuous cultivation in the Savanna. Samaru Misc. Pub. No 75, Ahmadu Bello University, Zaria, Nigeria. 54 pp.

Arnal, J.P. and M. Garcia 1974. Evaluation des pertes de bétail dues à la sécheresse (Niger, Haute Volta) *in* Bulletin Trimestriel Information technique économique de la Communauté Economique de l'Afrique de l'Ouest, No 8-9, Ouagadougou, Burkina Faso.

Barbey, C. and J.P. Carbonnel 1972. Le ravinement dunaire en milieu sahélien. Observations lors des pluies récentes dans la région de Nouakchott (Mauritanie). Comptes rendus de l'Académie des Sciences, Paris, 274, série D: 2933–2935.

Bationo, A. and A.U. Mokwunye 1991. Role of manures and crop residues in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. pp. 217–226. *in* A.U. Mokwunye (ed.) Alleviating soil fertility constraints to increased crop production in West Africa. Kluwer Academic Publishers, Dordrecht, The Netherlands.

awareness among researchers, extension agents, the private sector and governments of the important linkages between livestock management and the soil environment. Targeted, incremental and flexible approaches, with farmer involvement, are likely to be more effective than top-down, inflexible prescriptions. Research and policy recommendations related to farming practices are often based on poor understanding of the farmers' needs and their abilities to incorporate new practices and cope with new regulations.

A clearer delineation of production systems and related constraints will be essential for focusing research on relevant issues having the highest probability of positive impact. Farmer knowledge of, and access to many technologies associated improving soil fertility is often not a barrier to their adoption and use. Most farmers have few resources to take on additional technologies. Also, many technologies are not profitable and farmers are not convinced of the need to have them. Technical information and approaches to improving livestock impacts on soil fertility is not synthesised into unified, yet flexible approaches that can be adapted to an array of production systems.

Basic research should remain the linchpin in generating new information, for example how livestock metabolise nutrients; applied research will continue to be needed for using this knowledge, for example in developing improved feeding strategies to make the most efficient use of feed nutrients in animal rations and adaptive research should continue to not only move, but seek to keep, technologies on-farm. Farmer feedback through adaptive, on-farm research should be a key resource of institutional learning and used to prioritise and plan future research. An appropriate mix of disciplinary/basic and, interdisciplinary/applied and adaptive research targeted at specific goals and outcomes, backed by adequate and sustainable funding, offers the most viable approach for resolving many of the complexities of improved livestock and soil management.

REFERENCES

Abdullahi, A. and G. Lombin 1978. Long-term fertility studies at Samaru-Nigeria: Comparative effectiveness of separate and combined applications of mineral fertilizers and farmyard manure in maintaining soil productivity under continuous cultivation in the Savanna. Samaru Misc. Pub. No 75, Ahmadu Bello University, Zaria, Nigeria. 54 pp.

Arnal, J.P. and M. Garcia 1974. Evaluation des pertes de bétail dues à la sécheresse (Niger, Haute Volta) *in* Bulletin Trimestriel Information technique économique de la Communauté Economique de l'Afrique de l'Ouest, No 8-9, Ouagadougou, Burkina Faso.

Barbey, C. and J.P. Carbonnel 1972. Le ravinement dunaire en milieu sahélien. Observations lors des pluies récentes dans la région de Nouakchott (Mauritanie). Comptes rendus de l'Académie des Sciences, Paris, 274, série D: 2933–2935.

Bationo, A. and A.U. Mokwunye 1991. Role of manures and crop residues in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. pp. 217–226. *in* A.U. Mokwunye (ed.) Alleviating soil fertility constraints to increased crop production in West Africa. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bationo, A., A. Buerkert, M.P. Sedogo, B.C. Christianson and A.U. Mokwunye 1995. A critical review of crop residue use as soil amendment in the West African semi-arid tropics. pp. 305–322 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Belyuchenko, I.S. 1995. Vegetation of the Kalahari zone of Zambia and its economic use. Problems of Desert Development 6: 72–74.

Bille, J.C. 1977. Etude de la production primaire nette d'un écosystème sahélien. Travaux et Documents de l'ORSTOM, No 65. 82 pp.

Blanch, S.J. and M.A. Brock 1994. Effects of grazing and depth of two wetland plant species. Australian Journal of Marine and Freshwater Research 45(8): 1387–1394.

Boudet, G. 1972. Désertification de l'Afrique tropicale sèche. Adansonia, série 2 12(4): 505–524.

Boudet, G. 1977. Désertification ou remontée biologique du Sahel. Cahiers ORSTOM, série Biologie 12(4): 505–524.

Bougere, J. 1979. L'état de dégradation des formations sableuses du Sahel voltaïque ou l'urgence d'une intervention. Travaux de l'Institut de Géographie de Reims 39/40: 91–101.

Braunack, M.V. and J. Walker 1985. Recovery of some surface soil properties of ecological interest after sheep grazing in a semi-arid woodland. Australian Journal of Ecology 10: 451–460.

Breman, H., M.A. Cisse, A.M. Djiteye and W.T.H. Elberse 1980. Pasture dynamics and forage availability in the Sahel. Israel Journal Bot. 28: 227–251.

Breman, H. and C.T. de Wit 1983. Rangeland productivity and exploitation in the Sahel. Science 221: 1341–1347.

Breman, H. 1990. No sustainability without external inputs. pp. 124–134 *in* Beyond adjustment: sub-Saharan Africa. Africa Seminar. Maastricht, The Netherlands.

Bresson, L.M. and C.J. Moran 1995. Structural change induced by wetting and drying in seedbeds of a hardsetting soil with contrasting aggregate size distribution. European Journal of Soil Science 46: 205–214.

Bridge, B.J., J.J. Mott, W.H. Winter and R.J. Hartigan 1983. Improvement in soil structure resulting from sown pastures on degraded areas in the dry savanna woodlands of northern Australia. Australian Journal of Soil Research 21(1): 83–90.

Brouwer, J. and J.M. Powell 1995. Soil aspects of nutrient cycling in a manure application experiment in Niger. pp. 211–226 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Carter, E.D. and T. Sivalingam 1977. Some effects of treading by sheep on pastures of the Mediterranean climatic zone of South Australia. pp. 307–312 *in* Proceedings of the 13th International Grassland Congress.

Casenave, A. and C. Valentin. 1989. Les états de surface de la zone sahélienne. Influence sur l'infiltration. Editions de l'ORSTOM, Collection Didactiques, Paris. 229 pp.

Casenave, A. and C. Valentin 1992. A runoff capability classification system based on surface features criteria in the arid and semi-arid areas of West Africa. Journal of Hydrology 130: 213–249.

Castilla, C.E., M.A. Ayarza and P.A. Sanchez 1995. Carbon and potassium dynamics in grass-legume grazing systems in the Amazon. pp. 191–210. *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Chandras, S. and S.K. De 1982. Effect of cattle manure on soil erosion by water. Soil Science 133(4): 228–231.

Chase, R.G and E. Boudouresque 1989. A study of methods for the revegetation of barren crusted Sahelian forest soils. pp. 125–135 *in* Soil, crop, and water management systems for rainfed agriculture in the Sudano-Sahelian zone. ICRISAT Sahelian Center, Niamey, Niger.

Cissé, A.M. 1986. Dynamique de la strate herbacée des pâturages de la zone sud-sahélienne. CABO, Wageningen, 211 pp.

Commonwealth Agricultural Bureaux (CAB). Agricultural Research Council 1984. The nutrient requirements of ruminant livestock, Supplement N° 1. The Lavenham Press Ltd., Lavenham, Suffolk. 45 pp.

Dadkhah, M. and G.F. Gifford 1980. Influence of vegetation, rock cover, and trampling on infiltration rates and sediment production. Water Resources Bulletin 16(6): 979–986.

Dahl, G. and A. Hjort 1976. Having herds. Pastoral herd growth and household economy. Stockholm University, Stockholm.

de Leeuw, P.N., L. Diarra and P. Hiernaux 1993. An analysis of feed demand and supply for pastoral livestock: The Gourma region of Mali. pp. 136–152 *in* R.H. Behnke Jr., I. Scoones and C. Kerven (eds.) Range ecology at disequilibrium. ODI, London, U.K.

de Leeuw, P.N., L. Reynolds and B. Rey 1995. Nutrient transfers from livestock in West African agricultural systems. pp. 371–392 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

de Ridder, N. and H. van Keulen 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West African semi-arid tropics. Fertilizer Research 26: 299–310.

de Rouw, A., J.L. Rajot and G. Schmelzer 1997. Effets de l'apport de bouses de zébus sur les composantes du rendement du mil (*Pennisetum glaucum* (L.) R. Br.), les mauvaises herbes et l'encroûtement superficiel du sol (Niger). ORSTOM, Paris.

de Wispelaere, G. 1980. Les photographies aériennes témoins de la dégradation du couvert ligneux dans un géosystème sahélien sénégalais. Cahiers ORSTOM, Série Sciences Humaines 17(3-4): 155–166.

Diarra, L., P. Hiernaux and P.N. de Leeuw 1995. Preferential grazing of herded cattle in a semi-arid rangeland in central Mali at three spatial levels: Vegetation type, biomass on offer and species composition. pp. 99–114 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Eldridge, D.J., C.J. Chartres, R.S.B. Greene and J.J. Mott 1995. Distribution, characteristics and management of sealing, crusting and hardsetting soils under rangeland conditions in Australia. pp. 381–399 *in* H.B. So, G.D. Smith, S.R. Raine, B.M. Schafer and R.J. Loch (eds.) Sealing, crusting and hardsetting soils: Productivity and conservation. Australian Society of Soil Science, Brisbane, Queensland.

Floate, M.J.S. 1981. Effects of grazing by large herbivores on nitrogen cycling in agricultural ecosystems. pp. 585–601 *in* F.E. Clark and T. Rosswall (eds.) Terrestrial nitrogen cycles. Ecol. Bull. 33, Stockholm, Sweden.

Gallais, J. 1979. La situation de l'élevage bovin et le problème des éleveurs en Afrique occidentale et centrale. Les Cahiers d'Outre-Mer 32: 113–138.

Greene, R.S.B., P.I.A. Kinnell and J.T. Wood 1994. Role of plant cover and stock trampling on runoff and soil erosion from semi-arid wooded rangelands. Australian Journal of Soil Research, 32(5): 953–973.

Hiernaux, P. 1993. The crisis of Sahelian pastoralism: Ecological or economic ? ILCA, Addis Ababa, Ethiopia. 15pp.

Hiernaux, P., P.N. de Leeuw and L. Diarra 1995. The interactive effects of rainfall, nutrient supply and defoliation on herbage yields of Sahelian rangelands in north-east Mali. pp. 337–352 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Hiernaux, P. and B. Gérard 1997. Does patchiness increase vegetation productivity, diversity and stability? The case of 'brousse tigrée' in the Sahel. Acta Oecologica (in press).

Holt, J.A., K.L. Bristow and J.G. McIvor 1996. The effects of grazing pressure on soil animals and hydraulic properties of two soils in semi-arid tropical Queensland. Australian Journal of Soil Research 34(1): 69–79.

Hoogmoed, W.B. 1986. Crusting and sealing problems on West African soils. pp. 48–55 *in* F. Callebaut, D. Gabriels, M. De Boodt (eds.) Assessment of soil surface sealing and crusting. Flanders Research Centre for Soil Erosion and Soil Conservation.

IEMVT 1989. Elevage et potentialités pastorales sahéliennes: Synthèses cartographiques. IEMVT/CTA, Maisons-Alfort, France.

ILCA 1992. Nutritional evaluation of feeds for ruminants in semi-arid West-Africa. pp. 87–89 *in* Annual Programme Report 1992, ILCA, Addis Ababa, Ethiopia.

ILCA 1993. Annual Report and Programme Highlights. ILCA's long-term strategy, 1993–2010. ILCA, Addis Ababa, Ethiopia.

Kemp, R.A., J.A. Lee, D.A. Thompson and A. Prince 1994. Soil micromorphology: Studies in management and genesis. pp. 697–706 *in* A.J. Ringrose-Voase and G.S. Humphreys (eds.) Soil micromorphology: Studies in management and genesis, Elsevier Science Publishers, Amsterdam, The Netherlands.

Kowal, J.H. and A.H. Kassam 1978. Agricultural Ecology of Savanna: A study of West Africa. Oxford Press, U.K.

Landais, E. and P.G.H. Lhoste 1993. Systèmes d'élevage et transfers de fertilité dans la zone des savanes africaines. II. Les systèmes de gestion de la fumure animale et leur insertion dans les relations entre l'élevage et l'agriculture. Cahiers Agriculture 2: 9–25.

Lagocki, H.F.R. 1978. Surface soil stability as defined and controlled by a drainage criterion. pp. 234–237 *in* W.W. Emerson, R.D. Bondi and A.R. Dexter (eds.) Modification of soil structure. John Wiley and Sons, New York, U.S.A.

Le Fevre, J. 1993. L'évaporation au sein de sols sableux du Niger au cours de la saison humide. Ms. Sci., ENSA, Rennes, 43 pp.

Mbakaya, D.S., W.H. Blackburn, J.M. Skovlin and R.R. Child 1988. Infiltration and sediment production of a bushed grassland as influenced by livestock grazing systems, Buchuma, Kenya. Tropical Agriculture 65(2): 99–105.

McCown R.L., G. Haaland and C. De Haan 1979. The interaction between cultivation and livestock production in semi-arid Africa. pp. 297–332 *in* A.E. Hall, G.W. Cannell and H.W. Lawton (eds.) Agriculture in semi-arid environments. Springer-Verlag, Berlin, Germany.

McIntire, J. and J.M. Powell 1995. African semi-arid agriculture cannot produce sustainable growth without external inputs. pp. 539–554 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and

C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

McIntire J., D. Bourzat and P. Pingali 1992. Crop-livestock interactions in sub-Saharan Africa. World Bank, Washington D.C., U. S.A.

Mott, J., B.J. Bridge and W. Arndt 1979. Soil seals in tropical tall grass pasture of northern Australia. Australian Journal of Soil Research 30: 483–494.

Marble, J.R. and K.T. Harper 1989. Effect of timing of grazing on soil-surface cryptogamic communities in a Great Basin low shrub desert: A preliminary report. Great Basin Naturalist, 49: 104–107.

McCredie, T. and L. Parker 1992. The role of earthworms in Western Australia agriculture. Journal of Agriculture 33(4): 160–165.

Miles, B. and G. McTainsh 1994. Wind erosion and land management in the mulga lands of Queensland. Australian Journal of Soil and Water Conservation 7(3): 41–45.

Moorman, F.R. and B.T. Kang 1978. Microvariability of soils in the tropics and its agronomic implications with special reference to West Africa. pp. 29–43 *in* Diversity of soils in the tropics, ASA Special Publication No 34. Madison, WI, U.S.A.

Okaeme, A.N. 1988. Cattle movement and its ecological implications in the middle Niger valley area of Nigeria. Environmental Conservation 15(4): 311–316.

Pandetta, F.D. 1985. Population studies on pennyroyal mint (*Mentha pulegium* L.) II. Seed banks. Weed Research 25(4): 311–315.

Plumptree, A.J. 1994. The effects of trampling damage by herbivores on the vegetation of the Parc National des Volcans, Rwanda. African Journal of Ecology 32(2): 115–129.

Pieri, C. 1989. Fertilité des terres de savanes. Bilan de trente années de recherche et de développement agricole au Sud du Sahara. CIRAD-IRAT, Montpellier, France. 444 pp.

Powell, J.M. 1986. Manure for cropping: A case study from Central Nigeria. Experimental Agriculture 22: 15–24.

Powell, J.M. and M.A. Mohamed-Saleem 1987. Nitrogen and phosphorus transfers in a crop-livestock system in West Africa. Agricultural Systems 25: 261–277.

Powell, J.M. and F. Ikpe 1992. Fertiliser factories. ILEIA Newsletter 8: 13–14.

Powell, J.M. and L.K. Fussell 1993. Nutrient and structural carbohydrate partitioning in pearl millet. Agronomy Journal 85: 862–866.

Powell, J.M. and T.O. Williams 1993. Livestock, nutrient cycling and sustainable agriculture in the West African Sahel. Gatekeeper Series No 37. International Institute for Environment and Development, Sustainable Agriculture Programme, London.

Powell, J.M., S. Fernández-Rivera and S. Höfs 1994. Effects of sheep diet on nutrient cycling in mixed farming systems of semi-arid West Africa. Agriculture, Ecosystems and the Environment 48: 263–271.

Powell, J.M. and T. Coulibaly 1995. The ecological sustainability of red meat production in Mali: Nitrogen balance of rangeland and cropland in four production systems. Report to Projet de Gestion des Ressources Naturalles (PGRN), Bamako, Mali. 41pp.

Powell, J.M., S. Fernández-Rivera, P. Hiernaux and M.D. Turner 1996. Nutrient cycling by livestock in the Sahel. Agricultural Systems 52: 143–170.

Proffitt, A.P.B., R.J. Jarvis and S. Bendotti 1995. The impact of sheep trampling and stocking rate on the physical properties of a red duplex soil with two initially different structures. Australian Journal of Agricultural Research 46(4): 733–747.

Radke, J.K. and E.C. Berry 1993. Infiltration as a tool for detecting soil changes due to cropping, tillage and grazing livestock. American Journal of Alternative Agriculture 8(4): 164–174.

Roth, J.P., A. MacQueen and D.E. Bay 1991. Effect of introduced scarab beetles (*Coleoptera Scarabaeinae*) on coprophilic insects in central Queensland. Environmental Entomology 20(3): 909–914.

Russelle, M.P. 1992. Nitrogen cycling in pasture and range. J. Prod. Agric. 5: 13–23.

Sandford, S. 1989. Crop residue/livestock interactions. pp. 169–182 *in* Soil, crop, and water management systems for rainfed agriculture in the Sudano-Sahelian zone. ICRISAT Sahelian Center, Niamey, Niger.

Sartz, R.S. and D.N. Tolsted 1974. Effect of grazing on runoff from two small watersheds in south-western Wisconsin. Water Ressources Research 10(2): 354–356.

Schleich, K. 1986. Le fumier peut-il remplacer la jachère? Possibilité d'utilisation du fumier: exemple de la savane d'Afrique occidentale. Revue Elevage Médecine Vétérinaire Pays Tropicaux. 39: 97–102.

Scoones, I. and C. Toulmin 1995. Socio-economic dimensions of nutrient cycling in agropastoral systems in dryland Africa. pp. 353–370 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Senft, R.L., M.A. Stillwell and R.L. Rittenhouse 1987. Nitrogen and energy budgets of free-roaming cattle. J. Range Management 40: 421–424.

Serpantié, G., L. Tezenas du Montcel and C. Valentin 1992. La dynamique des états de surface d'un territoire agropastoral soudano-sahélien sous aridification climatique: Conséquences et propositions. pp. 419–447 *in* L'aridité: une contrainte pour le développement. ORSTOM, Collection Didactiques, Paris, France.

Silburn, D.M., C. Carroll, C.A.A. Ciesiolka and P. Hairsine 1992. Management effects on runoff and soil loss from native pasture in central Queensland. pp 294–295 *in* 7th Biennal Rangeland Conference, Cobar, NSW, 5-8 Oct. 1992, Rangeland Society.

Somda, Z.C., J.M. Powell, S. Fernández-Rivera and J.D. Reed 1995. Feed factors affecting nutrient excretion by ruminants and fate of nutrients when applied to soil. pp. 227–246 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Stoorvogel, J.J. and E.M.A. Smaling 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. The Winand Staring Centre, Wageningen, The Netherlands.

Swift, M.J., P.G.H. Frost, B.M. Campbell, J.C. Hatton and K. Wilson 1989. Nutrient cycling in farming systems derived from savanna: pp. 63–76 *in* M. Clarholm and D. Berstrom (eds.) Ecology of arid lands: Perspectives and challenges. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Swinton, S.M. 1988. Drought survival tactics of subsistence farmers in Niger. Human Ecology 16: 123–144.

Taboada, M.A. and R.S. Lavado 1993. Influence of cattle trampling on soil porosity under alternate dry and ponded conditions. Soil Use and Management 9(4): 139–143.

Talbot, M.R. and M.A.J. Williams 1978. Erosion of fixed dunes in the Sahel, Central Niger. Earth Surface Processes 3: 107–113.

Ternouth, J.H. 1989. Endogenous losses of phosphorus by sheep. J. Agric. Sci. 113: 291–297.

Tolsma, D.J., W.H.O. Ernest and R.A. Verwey 1987. Nutrient in soil and vegetation around two artificial waterpoints in eastern Botswana. Journal of Applied Ecology 24: 991–1000.

Turner, M.D. 1992. Life on the margin: Fulbé herding practices and the relationship between economy and ecology in the inland delta of Mali. PhD Thesis, Univ. Calif. Berkeley. 469pp.

Turner, M.D. 1995. The sustainability of rangeland to cropland nutrient transfer in semi-arid West Africa: Ecological and social dimensions neglected in the debate. pp. 435–452 *in* J.M. Powell, S. Fernández-Rivera, T.O. Williams and C. Renard (eds.) Livestock and sustainable nutrient cycles in mixed-farming systems of sub-Saharan Africa. Volume II: Technical Papers. Proceeding International Conference, ILCA, 22-26 November 1993, Addis Ababa, Ethiopia.

Usman, H. 1994. Cattle trampling and soil compaction effects on soil properties of a north-eastern Nigerian sandy loam. Arid Soil Research and Rehabilitation 8(1): 69–75.

Valentin, C. 1985. Effects of grazing and trampling on soil deterioration around recently drilled water-holes in the Sahelian zone. pp.51–65 *in* S.A. El Swaïfy, W.L. Moldenhauer and A. Lo (eds.) Soil erosion and conservation. Soil Cons.Soc.of America, Ankeny.

Valentin, C. and L.M. Bresson 1992. Morphology, genesis and classification of soil crusts in loamy and sandy soils. Geoderma 55: 225–245.

Valentin, C. 1994. Sécheresse et érosion au Sahel. Sécheresse 5: 191–198.

Valenza, J. 1981. Surveillance continue de pâturages naturels sahéliens sénégalais. Résultats de 1974 à 1978. Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux 34(1): 83–100.

Wilson, R.T. 1986. Livestock production in central Mali: Long-term studies on cattle and small ruminants in the agro-pastoral system. ILEA Research Report No 14, ILCA, Addis Ababa, Ethiopia.

Winrock International 1992. Assessment of animal agriculture in sub-Saharan Africa. Winrock International Institute for Agricultural Development, Morrilton, Arkansas, U.S.A. 162 pp.

Witschi, P.A. and D.L. Michalk 1979. The effects of sheep treading and grazing on pasture and soil characteristics of irrigated annual pastures. Australian Journal of Agricultural Research 30(4): 741–750.

Proceedings of the Regional Workshop
University of Hohenheim, ICRISAT Sahelian Centre and INRAN
4-8 March 1997, Niamey, Niger

SOIL FERTILITY MANAGEMENT IN WEST AFRICAN LAND USE SYSTEMS

Gestion de la fertilité des sols dans les systèmes d'exploitation d'Afrique de l'Ouest

Geneviève Renard, Andreas Neef, Klaus Becker, Matthias von Oppen
(Editors)

Margraf Verlag

Die Deutsche Bibliothek - CIP-Einheitsaufnahme

Soil fertility management in West African land use systems:
proceedings of the regional workshop, University of Hohenheim ...
4 - 8 March 1997, Niamey, Niger = Gestion de la fertilité des sols
dans les systèmes d'exploitation d'Afrique de l'Ouest / Geneviève
Renard ... - Weikersheim : Margraf, 1998
ISBN 3-8236-1272-7

Scientific Editors

Nestor Ahoyo Adjovi	INRAB, Bénin
André Bationo	IFDC, Niger
Klaus Becker	University of Hohenheim, Germany
Andreas Buerkert	University of Hohenehim, Germany
Niek van Duivenbooden	ICRISAT, Niger
Salvador Fernández-Rivera	ILRI, Niger
Franz Heidhues	University of Hohenheim, Germany
Pierre Hiernaux	ILRI, Niger
Gunnar Kirchhof	IITA, Nigeria
Issaka Mahamane	INRAN, Niger
Andreas Neef	University of Hohenheim, Germany

Cover Photo:

Zarma farmer spreading household refuse and millet stalks on his field, Liboré, Niger
Photograph by A. Neef

Typesetting:

Geneviève Renard

Printing and binding:

f. u. t. müllerbader gmbh
Filderstadt, Germany

P.O. Box 1205
D-97985 Weikersheim
Germany

ISBN 3-8236-1272-7