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Livestock, Nutrient Cycling And Sustainable Agriculture In The West African Sahel

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LIVESTOCK, NUTRIENT CYCLING AND SUSTAINABLE AGRICULTURE IN THE WEST AFRICAN SAHEL

J.M. Powell and T.O. Williams

Introduction

Annual rainfall has been declining over the past 20 years in the West African Sahel. Rainfall distribution has also been erratic. At the same time the region has experienced rapid population growth. The combination of increasing aridity, drought and population pressure has put stress on the resource base. The practice of fallowing to maintain soil productivity has decreased dramatically, or disappeared in many areas. Nutrient balances are negative for many cropping systems, with offtake greater than input, indicating that farmers are mining their soils (Stoorvogel and Smaling, 1990). The depletion of soil nutrients without adequate replacement have caused cereal yields to decline over time. As more land is brought under cultivation in order to maintain production levels, farmers have had to cultivate more marginal areas. As a result, communal grazing lands have diminished and livestock have become more dependent on crop land forages, especially during the six to eight month dry season.

While the cycling of nutrients between rangeland, crop land, ruminant livestock and soils has long been important to sustained agricultural productivity in the Sahel, the nutrient transfer mechanisms are poorly understood. The climatic and socio-economic changes currently taking place suggest that sustaining the productivity of an increasingly fragile ecosystem requires a better understanding of these nutrient cycles and the development of new and innovative management strategies.

This paper addresses the issue of nutrient cycling by livestock in the West African Sahel. Its basic premise is that an efficient cycling of nutrients between soils, crops and livestock is vital to the sustained productivity of farming systems in the Sahel. It reviews traditional linkages between ruminant livestock (cattle, sheep and goats) and soil productivity, and assesses the adequacy of such practices in light of changes taking place in the region. It concludes by suggesting ways in which nutrient cycling could be improved and made part of a broader strategy to enhance sustainable crop-livestock production in the West African Sahel.

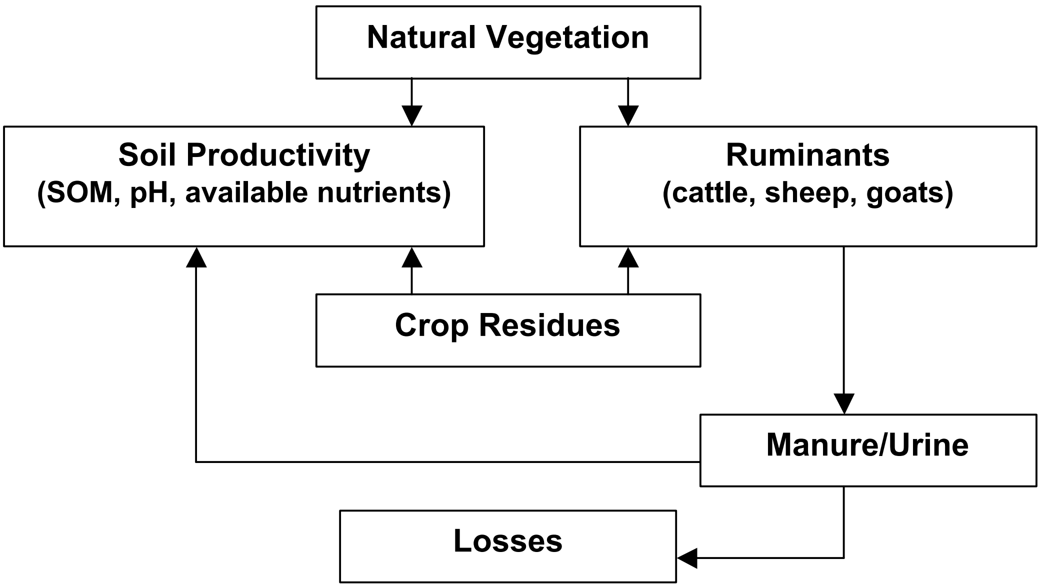
Linkages between Livestock and Soil Productivity

The poor fertility of the sandy soils found in the Sahel has always ensured a role for ruminant livestock in traditional soil management practices. These soils have very low soil organic matter (SOM) contents and low buffering and nutrient exchange capacities. They are deficient in nitrogen (N), and especially phosphorus (P) (Breman and DeWitt, 1983).

These soils also have poor structure, are susceptible to crusting, and have low water holding capacities. Sustaining their productivity is fundamental to the well being of the region.

A well-known linkage between livestock and soil productivity is the cycling of biomass (natural vegetation, crop residues) through animals (cattle, sheep, goats) into excreta (manure, urine) that fertilizes the soil (Figure 1). Manuring increases SOM and nutrient availability. It also improves nutrient exchange and water holding capacities, and increases crop and forage yields. The link between crop residues (cereal stovers, legume hays and weeds) and animal feeding during the long dry season is vital to the sustained productivity of livestock in mixed farming systems. However, the continuous removal of crop residue by grazing, trampling by animals, degradation by termites, and removals for fuel and construction leaves soil surfaces underprotected during the early part of the rainy season. The resulting high soil temperatures, erosion by wind, and sand blasting of young plants can pose severe limitations to crop production.

Figure 1: Ruminant-soil productivity linkages in mixed farming systems of the Sahel



Manuring cropland in the Sahel involves the night time corralling of animals directly on fields and/or hauling manure from homesteads. The advantage of corralling animals on cropland is that it returns both manure and urine to soils and requires little additional labour in animal management and no labour in manure handling, storage and spreading.

In addition to livestock owned by farmers, herds of transhumant pastoralists have long been an important source of manure for cropping. Various exchange relationships between pastoralists and farmers exist that allow animals to graze crop residues and animals to manure farmers' fields (McCown et al, 1979; Toulmin, 1983). These practices appear to be declining in many areas, however, due to sedentarization of pastoralists, increasing conflicts between pastoralists and farmers over land rights, transfer of cattle to non-pastoralist owners, and, in some areas, the increasing availability of chemical fertilizers.

During drought years, the loss of animals through death or forced sales can greatly decrease the ability of farmers to manure crop land. Reconstruction of herds, especially cattle, may take years and consequently cause reductions in manure availability and cropland productivity.

On-going studies of manuring practices show that cultivated and manured areas are three times larger in drier than in more "humid" areas of western Niger (Table 1). The amounts of manure dry matter and N and P applied to crop land are greatest, however, in the higher rainfall areas where cattle manure is more important than sheep and goat manure. The risk of excessive manure application and a consequent reduction in yields increases in drier areas.

Table 1. Cultivated and manured areas, manure dry matter (DM), nitrogen (N), and phosphorus (P) on farmers' fields in Niger, 1990.

	Zones		
	Wet	**Mild**	**Dry**
Rainfall (mm)	600	425	350
Households	15	10	15
Cultivated area (ha/household)	3.2	6.3	9.2
% manured	29	52	30
Manure DM (kg/ha)	3800	1700	1300
% cattle	52	55	19
% small ruminant	48	45	81
Manure N (kg/ha)	45	23	22
Manure P (kg/ha)	5.7	3.0	2.7

In-depth experimentation is underway to obtain more information on the effects of animal type and management on nutrient cycling, and to identify the constraints and opportunities in indigenous manuring practices. First year results of a six year trial showed that yields where animals were corralled (manure plus urine) were, on average, 52% greater than yields where just manure was applied. Also, manuring with sheep gave a greater positive crop response than manuring with cattle. This was likely due to greater nutrient losses due to leaching in plots where cattle were corralled (Powell et al, 1991). Low rainfall (400mm) and its uneven distribution during the first year of the trial produced little additional crop response to corralling animals more than one night. The remaining undecomposed manure from the first year would be available, however, for recycling in following cropping seasons.

The major preliminary finding of this long-term trial is the large benefit associated with urine application. The potential for nutrient cycling appears to be much greater when animals are corralled rather than when manure is transported from pens and spread on cropland. Animal and manure management, therefore, can play a key role in how efficient nutrients are cycled between livestock, soils, and crops.

Cycling of Nutrients in Manure

Influence of Animal Management on Nutrient Cycling

The types and amounts of manure nutrients available for recycling are highly influenced by differences in land use and the spatial and temporal distribution of livestock as dictated by animal management, and seasonal differences in animal diet. In areas where land is intensively cultivated and animals are stall-fed, manure must be handled, stored, transported, and spread on fields. By the time manure is taken from pens and applied to soil, it usually contains only about 50% of the total N originally excreted by animals (Bouldin et al, 1984). Most nutrients excreted as urine from stall-fed animals may be lost, either through volatilisation or leaching. Thus a move to more stall- feeding of animals could greatly reduce the amount of nutrients recycled through cropland.

In the extensive land use and animal management systems commonly found in the Sahel, animals graze to satisfy feed requirements and are herded in close proximity to watering points. In these situations, animal manure and urine is highest in non-productive areas such as near watering holes, resting areas and along paths of animal movement. This results in high accumulation of nutrients in these areas and increases the risk of nutrient losses (West et al, 1989).

A total capture of nutrients and application to crop land is, however, rarely possible given the predominant and extensive nature of livestock management in the Sahel, uneven distribution of manure/urine deposition in the landscape and the costliness of manure handling, storage, and transportation. Corralling livestock at night on cropland is perhaps the most efficient, traditional animal and manure management practice for maximizing nutrient cycling.

Effect of Animal Feed on Nutrient Cycling

Seasonal differences in the diet of grazing animals can also greatly influence manure output and its nutrient content. Manure output by grazing cattle during the rainy season (2.2 kg/animal/day) is twice as great as manure output during the dry season (Siebert et al, 1978). Likewise, the N and P concentration in cattle manure varies considerably by season (Powell, 1986). Wet season manure is more abundant and of higher quality. But it is largely unavailable to cropping, as animals are largely outside the cultivation zone in the wet season.

The total amount and proportion of N excreted in urine and manure depends on animal diet. Feeds that have high levels of intake, high rates of passage through the rumen, low protein solubility and small particle sizes generally have low N use efficiencies by ruminants (Van Soest, 1982). Feeds with high levels of soluble phenols (e.g., browse) decrease the digestibility of N, and a relatively high proportion of excreted N from animals is passed through manure (Coppock and Reed, 1992).

The urine and manure excreted by animals fed highly digestible diets is more susceptible to N losses than excreta from diets containing greater amounts of roughage. More than twice the amount of N is excreted as urine by animals fed cowpea hay, than from animals fed Acacia tortilis pods, or no supplement (Coppock and Reed, 1992). Much of this urine N would be lost via ammonia volatilisation. Manure from animals fed A. *tortilis* pods contains greater amounts of structural carbohydrates and, therefore, decomposes slower in the soil than manure from other diets. This results in a greater build- up of soil organic matter which increases the efficiency of nutrient cycling and the productivity of sandy soils.

In the above feeding trial, growth rates were similar for animals supplemented with cowpea hay and A. *tortilis* pods. Gains in nutrient cycling may be possible, therefore, by developing feeding strategies that not only satisfy the nutritional demands of animals, but also produce animal excreta less susceptible to nutrient losses when applied to crop land.

Cycling of Nutrients in Crop Residues

Farmers in the West African Sahel depend almost exclusively on rainfall for agricultural production. The main crops are drought resistant millet, (*Pennisetum glaucum*), sorghum, (*Sorghum bicolor*), cowpea, (*Vigna unguiculata*) and groundnut (*Arachis hypogea*). The residues of these crops perform various functions within the farming systems. When left in fields after harvest, cereal stovers can play an important role in erosion control, nutrient cycling, and the maintenance of favourable soil chemical and physical properties (Bationo and Mokwunye, 1991).

Most crop residues in the Sahel are, however, unavailable for direct application to soils. Cereal stovers are either grazed or harvested for feed, fuel, or construction material. As demographic pressures increase, more intensive modes of production are adopted. All cereal stovers may be harvested from fields for stall-feeding and/or for sale. Cowpea and groundnut residues are harvested and stored for feeding to select animals, or they are sold. The income derived from the sale of crop residues can be particularly important during years of poor grain production (Hopkins and Reardon, 1989).

Crop residues provide an important source of feed for ruminant livestock during the dry season in the Sahel. Cereal stovers are generally grazed communally by cattle, sheep and goats. Grazing times on crop residues are much greater in semi-arid areas, than in more humid areas of West Africa (Sandford, 1990).

Grazing animals remove much greater amounts of biomass and nutrients from cropland than they return in the form of manure; an exception being data from Burkina Faso (Table

2). In all studies, however, some of the biomass and nutrient disappearance can be attributed to termites and trampling by animals. Some of these components remain in the soil surface, decompose, and become available during the subsequent cropping season. The small manure return relative to the large amount of crop residue removed is due to the characteristics of uneven distribution of animal manure in pastures.

Table 2. Cereal stover removals and manure returns during crop residue grazing in West Africa.

STOVER REMOVALS				
Location	**Total Dry matter (kg/ha)**	**Nitrogen (kg/ha)**	**Phosphorus (kg/ha)**	**Source**
Nigeria	2470	24.5	3.9	1
Burkina Faso	1570	14.8	4.0	2
Burkina Faso	1450	13.8	1.5	2
Niger	2135	16.8	1.8	3
Niger	3495	33.1	3.6	3
Niger	1298	13.5	1.5	3
MANURE RETURNS				
	Total Dry matter)	**Nitrogen**	**Phosphorus**	**Source**
Nigeria	70-400	0.8 – 4.3	0.2 – 0.8	4
Nigeria	27-262	0.3 – 1.7	0.1 – 0.3	1
Burkina Faso	600-1600	7.5 – 20.0	1.5 – 4.0	2

Adapted from the following sources: (1) Powell and Saleem, 1987; (2) Quiflin and Milleville, 1981; (3) unpubl. data from ILCA Niger; (4) van Raay, 1975. N and P concentrations to calculate REMOVALS for sources (2) and (3), collected from various trials in Niger were 12.6 and 1.3 g/kg for millet leaves and 7.0 and 0.8 for millet stalks, respectively. N and P concentrations to calculate RETURNS for sources (2) and (4) were 10.8 and 2.1g/kg, respectively, taken from source (1).

Rangeland and Sustainable Nutrient Cycles

The ability of rangeland to sustain livestock and supply cropland with nutrients depends on rangeland grass and browse production, the crops grown and their expected yields. When livestock numbers are high, excessive vegetation may be removed from the soil which can lead to the depletion of soil organic matter and nutrient levels, and an eventual decline in productivity. Soil nutrient levels can be in balance (with inputs equal to losses) in moderately grazed areas. A build-up of nutrients is possible in areas where grazing pressure is light or animals have been removed from the system.

Sustainable nutrient cycling in the southern Sahel requires from 4 to 40 hectares of rangeland per hectare of cropland (Breman and Traoré, 1986). The highest rangeland requirements are associated with mixed farming systems which have production goals of breeding and feeding draught oxen as well as maintaining soil fertility. These range:cropland ratios calculated for the Sahel are similar to the range of values estimated for low-input mixed farming systems of semi-arid Zimbabwe (Swift et al, 1989).

Decomposition of Manure and Crop Residues in Soil

The efficiency with which nutrients are cycled from animal manures and crop residues through soils depends on the type and form of nutrients contained in the organic material, application methods and an array of environmental and soil factors. Manures contain lower C:N ratios and higher N levels than cereal stovers, and, therefore, mineralise faster in soil. Such an accelerated flow of P from manure can be of particular importance to plant growth in nutrient poor soils (Ruess, 1987).

Soil micro organisms readily decompose the soluble carbohydrates in organic materials. But structural carbohydrates and lignin decompose more slowly. Since lignin is the most resistant compound to decomposition, it is a major component of stable soil organic matter. As crop residues, animal feeds and manures have different chemical compositions, field level management of organic materials will have an impact on nutrient dynamics. Synchronizing organic matter decomposition with crop nutrient demands can enhance the efficiency of nutrient cycles in low-input agricultural systems (Ingram and Swift, 1989).

Technologies for Sustainable Nutrient Cycles

Need to Increase Biomass Productivity: The Role of Fertilizers.

Sustainable increases in biomass production are fundamental to livestock and soil productivity in the Sahel. The proper use of chemical fertilizers will be crucial in obtaining greater yields. This, however, will depend on fertilizer availability, pricing policies, and extension services largely external to farmer control. For the foreseeable future, fertilizers will continue to be costly and unavailable to many. In the meantime, options exist to combine high and low input technologies to enhance the output of indigenous practices.

Combining High and Low Input Technologies

Sustainable increases in the productivity of mixed farming systems of the Sahel can be achieved through a combination of external inputs, such as fertilizers, with inputs common to low-input agricultural systems, such as N fixing legumes and organic sources of nutrients (Breman, 1990). The efficiency of fertilizer use increases dramatically when combined with crop residues and manures (Bationo and Mokwunye, 1991). Forage legumes in fallow systems and dual purpose grain legumes can increase soil productivity while providing high quality forage for animals. The introduction of leguminous browse as wind breaks can increase the sustainability of mixed farming systems by providing food, fodder, wood, soil amendments, and controls to soil erosion. The appropriateness and adoption of such techniques depends on farmers involvement in technology development and assessment, on national extension services, and the efficient use and provision of the necessary inputs.

More Efficient Animal and Manure Management

Management systems are required that recycle greater amounts of animal excreted nutrients. Few gains can be made in extensive grazing systems where nutrients are concentrated at watering points and in shaded areas. More widespread corralling of animals on cropland that returns urine could greatly reduce nutrient losses from mixed farming systems. This may require the provision of feed and water closer to cultivated areas. Setting up mobile corrals and stall-feeding animals on cropland involves, however, considerable labour in harvesting and transporting feeds and water.

If the trend in animal management is towards increased stall-feeding, then composting will have to play a greater role in minimizing nutrient losses. Compost pits that capture feed refusals, and manure and urine need to be designed to minimize nutrient losses. Low-cost appropriate implements to spread compost over the typically large cultivated areas of the Sahel are also needed.

Evaluation of Feeds for Improving Nutrient Cycling

Criteria for selecting legumes for use as windbreaks, in fallow systems, and as intercrops with cereals in mixed farming systems need to consider their value as animal feed. Feed evaluation should also consider the effect of animal diet on nutrient cycling. There is a need to evaluate plants and feeds not only in view of satisfying animal nutritional demands but in the production of animal excreta less susceptible to nutrient losses.

Crop Residue Management

The critical linkage between crop land forages and livestock production necessitates that most biomass produced in mixed farming systems pass first through the rumen before becoming available as an addition to the soil. Although fertilizers play a major role in increasing grain and crop residue yields and allow for greater organic matter to be returned to fields, improved crop residue and feeding strategies will still be required that minimize the competition between animals and soil management for crop residues.

Selective harvesting of crop residue plant parts (e.g. upper leaf and stalk portions of cereal stover) could provide a relatively high quality feed while allowing parts of poorer feeding value (e.g. lower stover portions) to be returned for soil management. The economics of such practices in terms of labour, and animal and soil responses to selective crop residue harvesting needs to be assessed before they become viable management strategies.

Conclusion

The relative importance of animal manures in increasing crop production largely depends on its availability in sufficient quantities. At present, between 30-50% of the cultivated area is manured annually (Table 1; Prudencio, 1987). This proportion can, however, vary considerably. In the Sahel, low and erratic rainfall can cause large fluctuations in animal populations. The 50 to 80% reduction in animal numbers during the droughts of the early 1970's and mid 1980's greatly reduced manure availability during subsequent years. This is perhaps a major reason why yields per unit area have declined over the same period. Even during periods of good rainfall and high animal populations (and manure availability), mixed farming systems can never rely solely on manure to improve soil productivity. Sustainable increases in agricultural productivity must come from an optimal use of manures and fertilizers in combination with crop and animal management strategies that minimize nutrient losses.

Implications for Research and Policy

- The indigenous practice of corralling animals on cropland represents an appropriate manure management practice for the extensive mixed-farming systems of the west African Sahel. A move to stall feeding animals could increase nutrient losses if the nutrients excreted by animals are not captured, stored, and spread on cropland.

- Research is needed on the field level management of organic materials to ensure that organic matter decomposition and nutrient release is synchronized with crop nutrient demands.

- The achievement of sustainable increases in the productivity of mixed farming systems in this region will depend a judicious use of organic and external inputs. Appropriate policies to facilitate the provision and efficient use of external inputs such as fertilizers, and farmers involvement in the design and assessment of techniques to use these inputs are essential.

- The range of cultural, technical, and socio-economic issues involved in efficient nutrient cycling necessitates a multidisciplinary research approach to ensure the development of scientifically and socially acceptable techniques that will enhance sustainable crop-livestock production and the well being of people in the region.

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