Managing Africa's Soils No. 9

In the balance?

Evaluating soil nutrient budgets for an agro-pastoral village of Southern Mali

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About the Author

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About NUTNET

NUTNET stands for *Networking on soil fertility management: improving soil fertility in Africa-Nutrient networks & stakeholder perceptions*. NUTNET is a partnership of 15 organisations coming from 6 African and 2 European countries. They are INERA, Burkina Faso; SOS Sahel, Ethiopia; KARI, KIOF & ETC East Africa, Kenya; IER, Mali; Environment Alert & Makerere University, Uganda; IES, Zimbabwe; IIED & IDS, United Kingdom; AB/DLO, LEI/DLO, SC/DLO, ETC & KIT, The Netherlands. NUTNET has been made possible through generous funding from the Netherlands Development Agency (NEDA), Ministry of Foreign Affairs, the Netherlands. It was drawn up with the primary aim of bringing together the following three research programmes:

- *The dynamics of soil fertility management in savannah Africa* co-ordinated by IIED and IDS/UK;
- *Spatial and temporal variation of soil nutrient stocks and management in sub-Saharan Africa systems* (VARINUTS) co-ordinated by SC/DLO the Netherlands;
- *Potentials of low-external input and sustainable agriculture to attain productive and sustainable land use in Kenya and Uganda* (LEINUTS) co-ordinated by LEI/DLO, the Netherlands.

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Summary

A year-long study of an agro-pastoral community of southern Mali revealed three distinct farming systems associated with different ethnic sub-regions. Their varying reliance on livestock, inorganic fertilisers, and bush fallowing accounted for significantly different nutrient balances in each. The overall nitrogen balance of the region after the 1996 cropping year was -8.2 kg N/ha, while balances for the village core and hamlet cores were -3.2 and -4.7 kg N/ha, the village periphery -21.4 kg N/ha, and the Fulani system +23.3 kg N/ha. Phosphorus and potassium were in positive balance throughout the study area.

While nutrient balances proved indispensable for elaborating these different farming practices, they are methodologically complex tools. Their results often pass unquestioned into the discussion of soil fertility management. This paper outlines some of their potential difficulties, arising from assumptions made about soil processes and both spatial and temporal system boundaries. These difficulties suggest that nutrient balances be treated with caution and informed scepticism.

The different degrees of crop-livestock integration associated with each sub-region suggest that the discussion of soil fertility change must be informed by reference to local agro-pastoral practice. The growing livestock population and the presence of pastoral Fulani in the sub-humid zone are important components of these practices that are too often neglected. The access of different actors to key resources such as manure, animal traction, pasture, and crop-land determine the ability to increase agricultural production and the degree to which agricultural intensification will mine the soil of nutrients. Regional or national studies that make only aggregate generalisations about the extent of nutrient loss misrepresent soil fertility dynamics and risk feeding into an unrealistic "crisis narrative".

French summary

Résumé

Une étude d'un an sur une communauté agro-pastorale du sud du Mali a révélé trois systèmes agricoles distincts associés aux différentes répartitions ethniques. Leurs diverses dépendances à l' égard du bétail, des engrais inorganiques et des friches en brousse expliquaient les bilans d'éléments nutritifs sensiblement différents constatés dans chaque système. La teneur moyenne en azote dans la région après la récolte de 1996 était de -8,2 kg/ha, tandis que la teneur dans le centre du village et du hameau était de -3,2 kg/ha et de -4,7 kg/ha. A la périphérie du village elle était de -21,4 kg/ha et, dans le système Fulani, +23,3 kg/ha. La teneur en phosphore et en potassium était positive dans l'ensemble de la zone étudiée.

Bien que les bilans des éléments nutritifs se soient révélés des instruments indispensables pour évaluer les différentes pratiques agricoles, ils sont néanmoins d'une méthodologie complexe qui reste trop souvent incontestée lors des discussions à ce sujet. Cet exposé présente certaines des difficultés potentielles, soient chimiques, temporales, et spatiales. Il suggère que les bilans d'éléments nutritifs devraient être traités avec prudence et d'un oeil critique.

Les différents degrés d'intégration culture-élevage associés à chaque sous-région suggèrent que l'importance des problèmes de fertilité doit être comprise en se référant à la pratique agro-pastorale locale. La croissance du cheptel et de la population Fulani dans la zone sous-humide est un élément important trop souvent négligé. L'accès des différents intervenants aux principales ressources telles que le fumier, la traction animale, les pâturages et les terres agricoles détermine la capacité d'accroître la production agricole et dans quelle mesure l'intensification agricole va épuiser les éléments nutritifs du sol. Les études régionales et nationales qui ne font que des généralisations abusives sur l'ampleur des pertes d'éléments nutritifs ne représentent pas correctement la fertilité des sols d'une région et risquent de contribuer à alimenter une "rumeur de crise" irréaliste.

1 Introduction

This paper addresses the methodological complexity of using nutrient balances in the study of sub-Saharan African farming systems. It grew from reflections on a year's Ph.D. research conducted in an agro-pastoral village of southern Mali (Ramisch, 1998). That research's goal was identifying the means through which different actors gained access to animal draught power and manure. As it turned out, nutrient balances became indispensable tools for evaluating whether such access could facilitate agricultural intensification through better crop-livestock integration.

Agricultural intensification and soil mining

The overall balance of soil nutrients for the study area – which was only a moderate deficit – could not adequately depict the "sustainability" of the intensification strategies pursued by any of the region's actor groups. Systematic differences in their cropping systems, and different degrees of reliance on livestock for labour and manure, led to important differences in the nutrient balances of these groups. This more nuanced story of areas and actors showed some faring consistently above (and others well below) the region-wide "average balance". These differences helped to explain why soil mining persists and whom it is benefiting (cf. Ramisch, 1999).

This guardedly optimistic conclusion appears to contradict the prevailing orthodoxy that sub-Saharan Africa is in the throes of a long, dry season of despair. Unlike other regions of the world, Africa's agricultural output per capita has stagnated or declined over recent decades (Turner *et al*., 1993; Pieri, 1992). With populations expected to double in the next thirty years, farming systems are widely seen to be expanding cultivation onto marginal lands and reducing the length of soil-regenerative fallows (Matlon, 1987). The observation of this process has contributed to the interest in soil fertility issues and in evaluating soil nutrient balances (Smaling, 1993; Pieri, 1992; Ramaswamy and Sanders, 1992).

Such balances are typically derived from data collected in farm or village-level case study areas (cf. Harris, 1995; Krogh, 1995; Powell and Coulibaly, 1995; van der Pol, 1992;

Smaling *et al*., 1993; Pieri, 1992). Such studies report nutrient losses that range from just a few kilograms (of nitrogen, for example) per hectare (Harris, 1995; Powell and Coulibaly, 1995) to over a hundred kilograms per hectare (Smaling *et al*., 1993). The median deficit falls between 20-40 kilograms of nitrogen per hectare. The local negative nutrient balances of small scale studies are frequently then extrapolated to entire regions (or countries) that have comparable farming systems (Smaling *et al*., 1993; van der Pol, 1992). The most ambitious studies quantify nutrient losses at the national or continental scale (World Bank, 1996; Stoorvogel *et al*., 1993).

The ever-growing literature of soil nutrient studies bolsters the image that agriculture in most developing regions is heavily reliant on unsustainable "soil mining" practices. This literature forms, in the sense that the term was used by Roe (1991), a powerful development "narrative" that persuasively unites and explains environmental degradation phenomena using seemingly exhaustive budgets of nutrient inputs and outputs for farming systems.

The soil mining narrative's power comes from its quantification of the soil degradation problem: "millions of tonnes" of nutrients are being lost across sub-Saharan Africa (World Bank, 1996), representing sizeable percentages of national budgets (Stocking, 1986) or of farmers' incomes (van der Pol, 1992). Farming systems are observed to be functioning at low levels of productivity, or are suffering declining yields, and the nutrient budgets further demonstrate that these systems are functioning in states of constant nutrient deficits. Knowing the scale of the soil fertility reserves that the systems operate on, these models may estimate a time-frame beyond which present production will cease to be viable, having exhausted the soil resource (Bishop, 1995; van der Pol, 1992; Elwell and Stocking, 1982). The conclusion is often that these alarming nutrient deficits **must** be redressed, through massive investments in inorganic fertilisers (World Bank, 1996; World Bank/FAO, 1996) and through more efficient use of local resources, especially livestock (McIntire and Powell, 1995).

The weaknesses of nutrient balances

Although calculating nutrient balances is a summing of all the relevant inputs and outputs from a plot of land, it is a process fraught with obvious (and not so obvious) obstacles. Issues of quantification and uncertainty surround many of the transfers.

Many of the soil processes involved are poorly understood and are difficult to evaluate in the field (cf. Smaling and Braun, 1996). Nevertheless, processes like erosion and volatilisation account for some of the most important exports of soil nutrients. Likewise, little data is available for processes that could incorporate nutrients back into the soil (i.e.: weathering of parent material, inputs from dust and rain). Most balances estimate values for these processes from transfer functions and regression equations of untestable relevance for the study area (Smaling *et al*., 1993; Stoorvogel and Smaling, 1990). Calculating nutrient balances quickly becomes an exercise involving "black boxes" nested within other "black boxes" – something too easily forgotten when a single number is generated and published at the end.

Regardless of one's vigilance in data collection and calculation, other problems remain. A balance is just an instantaneous snap shot of what was applied and extracted from a plot in a given cropping year, not a dynamic measure of "sustainability". The highest positive balances may arise on the poorest soils, since the farmers' decisions about balancing perceived imports and exports from a given plot of land are based on their understanding of that soil's fertility. In the study area, heavy doses of manure and inorganic fertiliser are applied to cotton because it is perceived to be a demanding crop. When maize is typically planted on this land the following year, farmers assume the manure's influence is still lingering in the soil, so none is applied. But since inorganic nutrients are thought to be more ephemeral, and it is assumed that they have all been consumed by the "greedy" cotton, a new and heavy dose of fertiliser is applied to the maize.

Estimating the viable "life" of a particular farming system based on nutrient balance calculations is therefore of dubious value. The mining of soil nutrients will always be profitable so long as alternative sources of soil fertility (whether clearing new land or importing nutrients to the field from elsewhere) remain more expensive locally (Bishop, 1995). However, there is little evidence that farming systems anywhere have persisted unaltered in the face of soil fertility change (Scoones, 1997; Loomis and Connor, 1992; Connelly, 1994; Frissel, 1978). Many farming systems undergo (often long) periods of soil mining as they intensify (Ruthenberg, 1980), but many of the regions that were written off as disasters in the 1930s and 40s (i.e.: Machakos District in Kenya or Sukumaland in Tanzania) today support dense populations and thriving agricultural systems (Tiffen *et al*., 1995; Meertens *et al*., 1995). Nutrient budgets may be useful for identifying the faults of present systems, but the extrapolation of present deficits forwards, as if they would be valid over many decades, can offer little predictive power for identifying future states.

2 Description of the study area

The setting

The village of Lanfiéla was selected as "typical" of agro-pastoral southern Mali (see Figure 1). Both an intensifying agricultural production, based on cotton and draught power, and large cattle herds coexist within its boundaries. Throughout the text, the term "Lanfiéla" refers to the entire study area. "Village" refers only to the cluster of inter-connected compounds found at the centre of the cultivated plain in the east of the study area (Figure 2). "Fulani" refers to the semi-sedentary Fulani residents of both the principal "Fulawere" camp and the smaller camp near the hamlet known as "Miniankabougou" ("village of the Miniankas"). The term "hamlets" covers all non-Fulani households whose compounds are surrounded, not by other compounds as in the village, but by their own cultivated fields as is the case for Miniankabougou itself and several households scattered across the area.

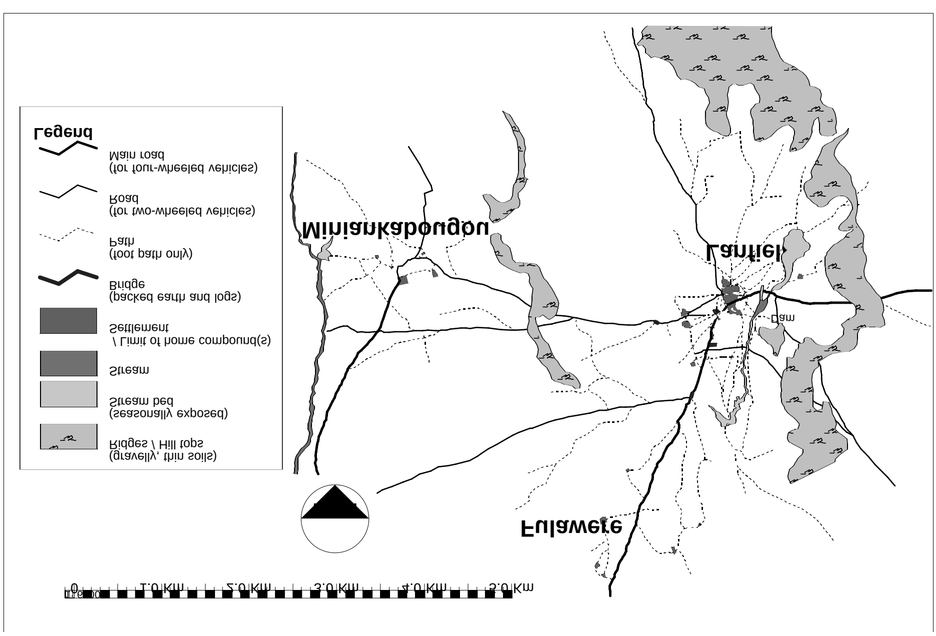
Agro-climate and soils

Lanfiéla lies in the furthest south, wettest, and one of the most agriculturally productive parts of Mali. However, according to both farmers and regional rainfall data series, this region has become drier and rainfall more erratic over the last generation. The average annual rainfall in the ten years 1962-1971 was 1219 ±101 mm, significantly higher than the average for 1987-1996 of 1078 ±168 mm (Loulouni *arrondissement*, unpub.).

In the FAO soil classification, the principal soils cultivated in Lanfiéla are ultisol sandy loams with a tendency to form laterite hardpans (PIRL, 1988). The regional soil maps identify these as Mollic and Typic Cuirusthults. Farmers have their own classifications that identify at least six or seven soils types of local importance, usually based on the soil types closest to the land that they cultivate. Textural and chemical analysis identified six main soil types, all quite sandy (30% clay + silt fraction).

Figure 1. Location of the study region (Lanfiéla) in Mali.

Figure 2. Settlements and major landscape features of the study area.



Population and social organisation

The study area included 89 households (Bam: *ga*; Fr: "*exploitations*") and close to 1500 individuals in 1996-97. The data is collected from a stratified sample of 50% of these households, based on the different ethnic and cultivation regions. The soil nutrient balance data presented in this paper originates from the 38 of the 44 sample households that practise cultivation (six sample Fulani households did not).

Using the term *ga* for "household" implies a shared hearth, but many of the larger sample households defined themselves on the basis of co-residence within a compound of several hearths (the *du*, or "compound"; Fr: "*concession*"). The household's land (inherited from ancestors or cleared by the present generation) is allocated by the household's head (male in all cases) to either collective or private uses. He is also the owner of the family livestock, ploughs and other draught equipment. In terms of nutrient balances influenced by access to livestock, this study's detail stopped at the level of the household and did not enter any discussion of the (presumably complex) intra-household dynamics.

Table 1. Average demographic and livestock holdings of the sample households, taken by region and as a whole, 1996.

	Village (n=24)		Hamlets (n=8)		Fulawere (n=12)		Full sample (n=44)	
Household size	16.6	±10.8	13.2	±9.3	12.7	±3.7	**14.9**	**±8.6**
No. of labourers *	5.3	±4.4	3.4	±2.1	4.0	±2.5	**4.7**	**±3.8**
No. of cattle	4.4	±9.4 **a**	8.8	±11.6 **a**	73.9	±89.7 **b**	**1063**	Total
No. of draft oxen	2.2	±2.2	2.3	±1.2	2.4	±1.7	**90**	Total
No. of small ruminants	2.8	±6.4 **a**	7.3	±8.9 **ab**	10.1	±12.1 **b**	**245**	Total
No. of donkeys	0.3	±0.5	0.4	±0.5	0		**10**	Total

Letters indicate significantly different means (a = 0.05, one-way ANOVA)

The average Lanfiélan household included 14.9 residents, of whom 4.7 worked household fields all year round (Table 1). The three sub-regions did not differ much demographically, but showed pronounced differences in terms of livestock. The average Fulani household owned nearly twenty times as many cattle, and nearly twice as many sheep, as village households. Fulani cattle are kept in herds of 50-300 and tended by family or hired herdsmen who graze them in seasonally defined bush pastures. Village and hamlet cattle from several households are usually combined into small "herds" of up to 30 draught oxen, and grazed either in the hills around the village or on the harvested village or hamlet plains. Sheep are less common in the village than in the hamlets and Fulani camps, where there are more fields and bush pastures to graze flocks.

Only a third of hamlet and village households owned at least one donkey (used for cart pulling). Fulani stated that they would rather hire a donkey for transporting manure or crops than worry about looking after one all year. Given the scarcity of carts, the lending of carts and donkeys for harvest-, residue- or manure-hauling is an important activity for cart owners. One common arrangement was that the owner would be "paid" with half of the manure pile being transported by a borrower. The dry season was therefore characterised by cart-owners soliciting the business of other households in the hopes of enlarging their supply of organic matter.

Crops and land use

The area of land cultivated by households in the village and hamlets was significantly larger than that cultivated by Fulani (Table 2). Fulani households devoted more labour and attention to keeping large herds of cattle, while sedentary farmers directed household energy towards cotton growing.

Table 2. Land holdings of the sample households, 1996.

	Village (n=24)	**Hamlets (n=8)**	**Fulawere (n=12)**	**Full sample (n=44)**
Cultivated field size (ha)	7.2 ± 4.3 **a**	7.0 ± 3.2 **a**	3.2 ± 1.6 **b**	**6.6 ± 4.0 a**
- cotton area (ha)	2.0 ± 1.5 **a**	2.6 ± 2.3 **a**	0.1 ± 0.2 **b**	**1.8 ± 1.8 a**
- cereal area (ha)	4.5 ± 3.0	4.1 ± 1.9	3.1 ± 1.8	**4.2 ± 2.6**

Letters indicate significantly different (a = 0.05, one-way ANOVA) mean areas

Most local farmers felt that cotton, which is promoted by the para-statal Compagnie Malienne pour le Développement de Textiles (CMDT), offered a greater and more reliable income than that generated by the other, "traditional" agricultural mainstays of the southern Malian economy: rice, fruit, and tubers. Some of the wealthiest households of villageelders have grown cotton since the 1960's. Most households became interested only once the CMDT placed an extension agent in Lanfiéla in 1984. Amongst the village and hamlet households, only one did not plant cotton in 1996. At the same time, only three Fulani households grew any cotton, although in 1997 this number increased as one more local Fulani, and four newly settled households joined them.

Local varieties of cereals (maize, millets, and sorghum) constituted the main food crops for all three communities. Smaller plots of groundnuts, yams, sweet potatoes, and upland rice made up the remaining cultivated area. Cowpeas were frequently inter-planted in cereal plots. Most households did not remove crop residues from their fields, except those of cowpea (which were stocked for animals) and cotton (which were burned or composted). Cereal stover was typically grazed by household or Fulani livestock in the fields immediately after harvest. Everything else was allowed to decompose in the fields.

Land rights are based on use and customary law vested in the founding lineage of the village. The founding households of the hamlets and Fulawere were "allowed" to settle in the area only when they agreed to clear and farm land of their own. The Fulani households that did not farm were therefore often considered transient, even though some of them had been in Lanfiéla for nearly ten years.

Since land rights are based on active cultivation, the concept of "fallow" land was sometimes vague. Some households stated they "owned" vast hectares of fallow land while others said they had none at all (i.e.: owned only cultivated land). In the region as a whole, the ratio of cultivated to uncultivated land was roughly 1:4. However, the plain that lies around the village was almost entirely cultivated and has been so for over thirty years. Similar "core" regions of high cultivation intensity with minimal fallows were forming around the centres of hamlet and Fulani settlement. Many of the village households supplemented their fields in the village "core" area with a secondary "bush" field cleared in the bush regions between the village and its hamlets. "Bush" fields were considered to benefit from the inherent fertility of freshly cleared land and did not normally receive fertilisation.

Altogether, cropland received slightly more nutrients from inorganic sources than from organic. Inorganic fertilisers were available from local markets, but most farmers obtained them on credit from the CMDT. Since these loans are made against anticipated cotton harvest revenue, the use of such fertilisers is strongly correlated with cotton income. This also explains why cotton receives the lion's share of nutrients, in the form of a "cotton" formulation and urea. Most farmers also apply at least some "cereal" formulation and urea to the maize that follows cotton in rotation. Some of Fulani explained that their interest in planting cotton was partly to obtain fertilisers more cheaply and easily.

Organic fertilisers (livestock manure, compost, and household wastes) were also primarily spread on cotton plots, usually with the aid of donkey carts. The heaviest manure applications were on land where Fulani herds were corralled during the dry season. In Fulawere, these corrals are of course on the herd owner's cropland. However, many of the Fulani who reside near Miniankabougou in the wet season relocate their herds to the plain north of the village, where access to clean water in the dry season is easier. Here they are joined by transhumant herds from near the Ivoirian border. Village elders have encouraged this seasonal resettlement by installing wells in their cropland and give grain and salt to these Fulani households in exchange for milk and manure.

3 Methods and approach

The approach that was used combined the participatory modelling of nutrient transfers (cf. Defoer *et al*, 1995) with intensive field observations of crop activity and herd movements. The results were analysed in databases referenced to the farmers' plots, which were themselves mapped onto the Lanfiélan landscape as a geo-referenced information system.

The nutrient balance model

The term "nutrient" in this paper is confined to the three macro-nutrients: nitrogen (N), phosphorus (P), and potassium (K). Nitrogen is the most mobile and the most limiting nutrient in Lanfiéla. Phosphorus and potassium balances have been calculated using the plant-accessible forms of P_2O_5 and K_2O.

Most of the nutrient balance work on West African and sub-Saharan farming systems has made use of the model developed by Stoorvogel and Smaling (1990) (i.e.: Defoer *et al*., 1998; Harris, 1995; van der Pol, 1992). This model determines net surpluses or deficits of nutrients by measuring and summing all of the "imports" and "exports" of resources from a given plot (see list of flows in Table 3).

Exports that are management-influenced are all those concerning the fate of crop residues. These include whether to a) stock them for livestock feed or litter, b) to compost them directly with other organic waste, c) to burn them in the fields (either immediately after harvest or later in the season). Residues that have been d) left in the fields unburned are often (but not necessarily) grazed *in situ* by livestock, and are then allowed to decompose under the influence of termites and other processes. Grazing that was done by the household's own animals was distinguished from that done by the animals of other farms, where relevant. Grazing by one's own animals is, like stocking or composting, a transfer that at least potentially keeps nutrients within the same field-herd-household, while grazing by other animals more completely exports nutrients outside of that system.

Table 3. Variables considered in the nutrient balance calculations.

	Exports	Imports
Management	OUT1 Harvested crop	IN1 Inorganic fertiliser
		{"Complex" (NPK+SB)
		{Urea
	OUT2 Crop residues	IN2 Transported to field
	{Stocked	*{Compost*
	{Composted	*{Household Waste*
	{Grazed in situ	*{Pen Manure*
	{Burnt	Manure deposited by corralled animals
	{Left in fields	Manure deposited by grazing animals
Environmental	OUT3 Leaching	IN3 Atmospheric deposition
	OUT4 Denitrification	IN4 Biological fixation
	& Volatilisation	
	OUT5 Erosion	IN5 Parent material (Sedimentation)

Source: derived from Stoorvogel and Smaling, 1990.

On the import side of the balance sheet, management-related transfers involve all the "intentional" movements of organic matter to the fields from livestock pens or compost pits, as well as the application of inorganic fertilisers. The manure from livestock herds corralled on fields in the dry season is also a "management"-related input. "Management" also influences the movement of livestock within and across the fields, determining the nutrients introduced "in passing" by grazing animals allowed to use the field as corridors across the landscape even after the residues have been consumed.

The environmental transfers are largely determined by regional climate, especially the inputs via atmospheric deposition (in Harmattan dust and rainfall), asymbiotic fixation, and the weathering of parent material. The exports are also driven by factors external to management, but interact with the management transfers. Erosion, for example, while largely a function of slope, soil type, and rainfall, is also influenced by crop cover and human management. Mineral leaching, and the gaseous losses of nitrogen (through volatilisation and denitrification) are also a function of the quantities of nutrients applied. Quantifying these transfers in the field was limited by logistics and they have been estimated by criteria described below (see Table 6).

Farmer involvement in the model

After having visited each farmer's fields, we and the farmers would draw maps of those fields and discuss all the "management"-related transfers of material that had entered or exited each plot. This participatory "flux mapping" exercise (cf. Defoer *et al*, 1995) elaborated the use of crop residues by livestock and the origin and nature of manure applied to fields.

These flux maps provided the starting point for constant monitoring and evaluation of the fields over the season. The quantities of harvested crops and of crop residues left in the field were measured at the start of the dry season. The in-field grazing of residues and the deposition of manure by grazing animals were also followed over the season. Estimates of rates of loss to decomposition, termites, and burning were based on photographs taken over the season, conversations with farmers, and regular visits to the fields. Households also kept simple tally records of the transport of manure, compost, and household waste to fields, which we could confirm against our field visits.

Our good relations with the herdsmen allowed us to visit their cattle at their corrals or along their grazing routes and watering points. We were also able to conduct several trials that calculated the production of manure by grazing animals. In the most elaborate, *culotte* bags were strapped to the cattle in the morning and replaced overnight to compare day and night-time defecation rates. Manure deposition on crop land was also determined by direct field measurements towards the end of the dry season.

A global positioning system (GPS) unit allowed us to obtain fixed geographic locations for farmers' fields, and to calculate their areas. The farmers' geo-referenced data could then be overlaid on calibrated aerial photographs to generate local maps. The GPS also allowed us to monitor and map the seasonal grazing patterns of the region's livestock in detail.

4 The balance of soil nutrients

The nutrient balances for cultivated plots in the study area are summarised in Table 4. To the right of the table are balances calculated for the household plots in the three different farming sub-regions, complete with standard deviations about the means. On the left are the region-wide balances, calculated across the entire sample of 263 plots. No standard deviation can be given for this (a weighted average), so to depict the considerable variation present in the data, values for the 5th and 95th percentile are given instead.

Table 4. Sample-wide balances (kg / ha) for the three macro-nutrients in the three farming regions and overall, 1996.

Nutrient	**Entire sample (256 ha)**	**Village n = 191**	**Hamlets n = 59**	**Fulani n = 13**
N	- 8.2 +44.7 $^{95\%}$ -71.6 $_{5\%}$	- 11.9 ± 18.5 **a**	- 4.7 ± 24.6 **b**	+ 23.3 ± 36.4 **c**
P_2O_5	+ 19.5 +32.3 $^{95\%}$ +3.2 $_{5\%}$	+ 26.5 ± 11.8	+ 35.1 ± 8.8	+ 39.4 ± 13.8
K_2O	+ 8.9 +94.4 $^{95\%}$ -26.6 $_{5\%}$	+ 3.3 ± 19.5 **a**	+ 20.8 ± 23.5 **b**	+ 74.5 ± 39.8 **c**

$^{95\%}$: 95th percentile $_{5\%}$: 5th percentile ± : standard deviation

Letters indicate significantly different (a = 0.05, one-way ANOVA) mean nutrient balances

There were significantly higher balances of nitrogen and potassium in the hamlets than in the village, and the highest balances of all occurred amongst the Fulani. The Fulani system fared so well not only because the cultivated plots were smaller than in either village or hamlets, but large cattle herds were able to supply them with abundant manure. Households in the hamlets used larger doses of inorganic fertiliser than villagers did. Hamlet residents maintained that living directly adjacent to their fields allowed them to nurture their crops better than villagers (whose crops are far from the home compound), and obtain higher yields. This was not immediately evident from production data, but hamlet residents did devote a greater proportion of their cotton income to fertilisers. The village system persisted at deficits below the regional average in part because the large “bush field” component subsisted off the native fertility of the shifting bush fallow region, receiving no external inputs.

Overall, only nitrogen was in a deficit for the entire region, although potassium was also frequently in a negative balance. Negative nutrient balances are (by definition) the result of imported nutrients being exceeded by exports. However, this may occur under vastly different circumstances.

Many plots benefit only from a minimal input of nutrients from environmental or management sources. A negative balance invariably results when the harvest is removed from such plots, even if residues remain largely untouched. However, positive balances could occur if the crop “failed”, producing little biomass overall or no harvestable product, and therefore minimal exports. Harris (1995) describes a situation in northern Nigeria where soil fertility may stay relatively constant thanks to alternations of years of good yields, which mine the soil, with several low-yield years, effectively “enforced fallows” that restore the nutrients through environmental inputs. In Lanfiéla, when low-yielding plots have been in negative balance for several years this land is considered “tired”. At this point, the land may be retired to fallow, or moderate doses of manure and fertiliser will be applied, at least to cover the perceived nutrient needs of the crop.

Even well-fertilised plots often retain negative nutrient balances. A large addition of nutrients (and indeed of labour and management energy) can often stimulate an improved biomass production from the plot, but this in turn extracts considerable quantities of nutrients from the soil. This is especially true of cotton, which responds strongly to fertilisation. Typically all the cotton biomass is exported (the grain and fibre harvested, the stems burnt to avoid disease carry-over), leading to enormous losses. Unless a great deal of “excess” fertiliser was applied (i.e.: more than was incorporated in the crop and residues), or the residues composted and returned to the same plot, negative balances will still result on high-yielding cotton plots. For cereal crops, residues weigh up to five times the harvested grain but their fate is obviously just as crucial to the nutrient balance.

5 Chemistry-related issues

Soil "mining" and "soil life"

Chemical tests on Lanfiélan soil revealed them generally low in fertility (Table 5). The cation exchange capacity of Fulani soils may be marginally lower than the soils of the village or hamlets, but significant regional differences were not apparent. Comparing soils that received manure in 1996 with those that did not, revealed a significantly higher base saturation associated with manuring. There was also a significant decline in organic matter content between soils that had lain fallow for thirty or more years and those that were cultivated in 1996. Both these findings suggest that while manuring may increase cation availability, cultivation does have a noticeable "mining" effect on soil organic matter.

Table 5. Overall nutrient status of local soils (Rainy season, 1997).

Soil	Total Area (ha)	Farmed Area (ha)*	pH	Organic Matter	N (%)	P (ppm)	K (me%)	CEC (me%)	Base Saturation
Overall	3354	302	5.9	1.21%	0.052	11.5	0.23	16.40	21.17 %
Village	1357	150	6.1	1.15%	0.046	11.6	0.22	16.53	21.31%
Hamlets	1173	114	5.7	1.24%	0.052	8.6	0.25	17.03	18.60%
Camp	330	38	5.7	1.32%	0.070	10.0	0.12	11.45	24.49%
- Manure	n/a	234	5.9	1.16%	0.043	11	0.27	15.75	17.45 % **a**
+ Manure	n/a	78	6.0	1.13%	0.036	14	0.20	19.57	23.66 % **b**
Cultivated	~704	256	6.0	1.14% **a**	0.039	12	0.24	17.68	23.64 %
Fallow	~2650	~56	5.9	1.34% **b**	0.034	10	0.21	13.88	21.81 %

* "Farmed area" represents land planted with crops in 1996 by sample households only.
Letters indicate significantly different (a = 0.05, one-tailed t-test) means, compared within the column.

Van der Pol (1992) predicted that the present "soil mining" practices of southern Mali could be sustained by soil nutrient reserves only for another thirty years, all else being equal. This prediction was taken from the average deficit of 25 kg N/ha, which he calculated for the entire CMDT zone of southern Mali. Such an export of nitrogen requires 600 kg of organic matter to be mineralised each year from the zone 0-20 cm below the surface. With a C:N ratio of 12, and initial soil organic matter contents of 1%, the thirty year limit for the farming system represents the point at which mineralisation has reduced organic matter to the "critical level" of 0.6% (Pieri, 1992).

A similar calculation, using my sample-wide nitrogen deficit of 8.2 kg/ha predicts that present farming practices would take just over 95 years to mineralise and consume the 775 kg of organic matter present per hectare (assuming that average organic matter content is 1.2% and its C:N ratio averages 13.5). Given the significantly different regional balances shown in Table 4, this calculation would predict an effective "life" of 65 years for the village and 150 years in the hamlets, with Fulani farming seemingly sustainable well into the future.

The problems with calculating soil "life" in this linear and deterministic equation are that neither spatial nor temporal variability can be accommodated. It ignores possible agency on the part of the soil-mining farmers, such as potential and on-going responses to soil fertility change. As well, in any such "back of the envelope" type of calculation, even small errors in the estimation of any of the variables (i.e.: soil depth, organic matter content, C:N ratio, mineralisation rate) can radically alter the ultimate estimate of soil "life".

Environmental transfers

Several of the "environmental" variables contributing to the nutrient balance calculations had to be estimated from secondary literature (as mentioned above). This short-coming is common to most nutrient budgets, but is rarely addressed. The values retained for calculations in Lanfiéla (Table 6) represent the conservative "best-estimates" that could be obtained for all the nutrient transfers based on existing literature relevant to sub-humid West Africa.

However, this literature does not necessarily agree on the scale or the importance of the "environmental" nutrient transfers. Substituting the transfer equations of other studies for those used in the Lanfiélan calculations produced a wide range of results. Table 7 shows the effects of such a substitution in terms of kg/ha of nitrogen transferred by "environmental" fluxes.

Table 6. Mean nutrient values retained for "environmental" transfers.

Transfer		N	P_2O_5	K_2O
IN3 - Atmospheric Deposition		5 kg / ha	1.2 kg / ha	3.5 kg / ha
IN4 - Biological Fixation (Symbiotic)		50% of uptake		
IN4 - Biological Fixation (Asymbiotic)		2 kg / ha		
IN5 - Weathering			1 kg / ha	5 kg / ha
Total		**9.5 kg / ha + fixation**	**2.2 kg / ha**	**8.5 kg / ha**
OUT3 - Leaching	{Cotton	7 kg / ha	1 kg / ha	16 kg / ha
	{Legumes	15 kg / ha	1 kg / ha	16 kg / ha
	{Maize	6 kg / ha	1 kg / ha	16 kg / ha
	{Millet/Sorghum	1.5 kg / ha	1 kg / ha	16 kg / ha
OUT4 - Volatilisation		(soils too acid)		
OUT4 - Denitrification		10 kg / ha + 30% applied – 10% uptake		
OUT5 - Erosion		0.76 kg / T sediment	0.26 kg / T sediment	0.46 kg / T sediment

Table 7. Value contributed by "environmental" transfer functions to the 1996 nitrogen balances (kg / ha), substituting different authors' functions.

Author	Nitrogen		Transfers included
Van der Pol (1992)	- 28.3	± 12.4	IN: biological fixation, rain/dust, leaf-fall,mineral weathering OUT: leaching, denitrification, erosion
Camara (1996)	- 15.4	± 24.8	IN: none OUT: leaching, denitrification
Stoorvogel *et al*. (1993)	- 13.6	± 26.8	IN: biological fixation, rain/dust OUT: leaching, denitrification, erosion
Duivenbooden (1992)	+ 4.1	± 28.2	IN: biological fixation, rain/dust OUT: leaching, denitrification
Lanfiélan calculations	**-16.9**	**± 28.7**	

In the most detrimental case (van der Pol, 1992), the strongly negative impact results from assumptions about higher soil mineral content and erosion rates than appeared to hold true for Lanfiéla. Denitrification in van der Pol's model was also a constant 12 kg N/ha, whereas the Lanfiélan calculations used a base of 10 kg /ha that was influenced by both nutrient application and crop uptake.

The most favourable case (Duivenbooden, 1992) was not designed to calculate nutrient balances for existing farming systems as such, but to calculate all of the variables that would have to be considered to keep "imports" equal to "exports" at different production levels. It has rather high values for asymbiotic fixation and atmospheric input, all of which account for the (surprisingly) net positive impact of environmental factors.

It is important to recognise that the environmental transfers are themselves large enough to account for the overall negative nitrogen balance of the sample. In their absence, "management"-only partial balances are positive, as has been more qualitatively observed in work by ESPGRN for southern Mali (Defoer *et al*, 1998; Kanté *et al*., 1997). This is largely attributable to the application of nutrients from "external" sources to cropland, whether gathered from the bush and pastures by grazing animals, or from further afield as inorganic fertilisers (see the next section).

It is also worth noting that "environmental" transfers are all at least as big a removal of nutrients as that represented by the harvested products. The increase in biomass production is a function of greater application of fertiliser and manure, whose contributions to leaching and gaseous losses also increase linearly with increasing doses. Nutrients lost to harvest and environmental processes will, therefore, continue to be considerable even if greater "integration" of crop and livestock systems occurs. The "recycling" of crop residues through grazing or stabled animals for manure production may in fact increase these "environmental" nutrient losses, by converting nutrients into more mobile and volatile forms (Pieri, 1992).

6 Time-related issues

Organic matter balances

The "flux mapping" exercises with farmers demonstrated quite strikingly the divergence between plots which contributed the most organic matter to household compost and manure supplies (generally cereals), and those which had received the most (cotton). For any given plot, we can calculate an "organic matter balance" that is the difference between (a) all the imports made to the plot from within the household's herd-household-field system and (b) the sum of all the exports that this plot made to the same pool of household nutrients. Only gross tonnages of organic matter are of interest in this balance. The relevant fluxes are "stocking", "composting", "left in the fields", and "grazing by own animals" for the exports. The imports are all the compost, household waste, and manure inputs coming from the household's own resources.

Within a household, it is possible to identify the plot that received the greatest quantity of organic matter from household piles, pits, or corrals (the "favoured" plots), and the plot(s) that contributed the greatest exports of residue nutrients that ended up in household piles and pits (the "exploited" plots). The other plots that were neither "favoured" nor "exploited" can be considered "ordinary".

Table 8. Organic matter balances (kg / ha) compared for "favoured", "ordinary", and "exploited" plots, 1996.

	Favoured plots (greatest organic imports)	**Ordinary plots**	**Exploited plots (greatest organic exports)**
Organic Matter Balance (kg/ha)	+ 2108 ± 450 **c**	- 66 ± 88 **b**	- 719 ± 198 **a**
Average plot size (ha)	1.08 ± 0.85 **b**	0.68 ± 0.65 **a**	1.42 ± 1.11 **c**
Total area (ha) within sample	72.4	88.3	96.3
% of Total	28%	34%	38%

Letters indicate significantly different means (a = 0.05, one-way ANOVA)

On average, the positive organic matter balance of favoured plots was more than twice the deficit removed from an exploited plot (Table 8). Indeed, for the sample as a whole, organic matter balances were marginally positive: +301 kg/ha ±2517. This implies that the manure that was applied was generated from sources other than simply the grazing or stocking of the household's own crop residues. If more residues were stocked as litter or fodder, more of the livestock diet would be from on-farm sources and this balance would actually tend to be lower. It is therefore not evident that greater crop-livestock integration (in terms of increasing the recycling of crop products through animal digestive tracts) would be able to improve on these balances.

The "favoured" plots were mostly cropped with cotton, the exploited plots predominantly cropped with cereals. With only three exceptions, most or all of the organic matter in cotton farming (i.e.: non-Fulani) households was applied to the cotton crop (Table 9). While this demonstrates the priority given to cotton, the cereal crops (maize in particular) do maintain favourable nutrient balances despite this internal flux by receiving significant doses of inorganic nutrients from off-farm. The transfer of nutrients as "crop residue to waste pit" also takes place in one year, and the "pit to cotton plot" transfer the following year (at least), meaning that the possibility exists that the nutrients return to the same plot of land after all.

Table 9. Organic Matter Balances (kg/ha) by crop and plot type, 1996.

Crop	O.M. Balance (when favoured plot)	O.M. Balance (when not favoured plot)	Overall O.M. Balance (averaged by Household)
Cotton	+ 1837 ± 1951 **a**	-545 ± 1118 **b**	1006 ± 2046
Maize	+ 1433 ± 1827 **a**	- 250 ± 541 **b**	+ 458 ± 1492
Millet	+ 1619 ± 2629 **a**	- 324 ± 414 **b**	+ 486 ± 1951
Sorghum	+ *4050* [n=1] **a**	- 240 ± 378 **b**	+ 374 ± 1658
Cowpea	+ 915 ± 721 **a**	- 422 ± 416 **b**	-179 ± 703
Groundnut	(not favoured)	- 248 ± 496	-248 ± 496

Letters indicate significantly different means (a = 0.05, two-tailed t-test, comparing columns)

Crop rotations

One way to suggest the "sustainability" of the cropping system is to combine the nutrient balances of crops that would normally follow each other in the typical rotations. The rotations presented in Table 10 are the most common ones followed in the study area. They represent the summation of the nutrient balances as if the same management regime as was observed in 1996 were followed year after year. The rotations that involve cotton are calculated only using data from cotton-growing

Table 10. Annual Nutrient balances (kg / ha / year) of the principal crop rotations.

Rotation	N	P_2O_5	K_2O
Cotton-Maize (2 yr)*	- 0.6 ± 16.0	+39.5 ± 11.2	+ 16.5 ± 20.0
Cotton-Maize-Millet (3 yr)*	- 6.8 ± 13.5	+18.7 ± 6.5	+ 9.3 ± 14.8
Maize-Millet (2 yr)	- 6.6 ± 43.3	+ 23.1 ± 19.8	+ 12.6 ± 45.1
Groundnut-Millet (1 or 2 yr)	- 21.1 ± 22.4	+ 14.1 ± 8.9	- 0.2 ± 26.6

* Excludes Fulani maize from the calculation (see text)

households, excluding therefore the Fulani and with them their heavily fertilised maize fields.

Most striking from the table is that the heavy inorganic fertilisation of maize that follows cotton in the first rotation is sufficient to raise the nitrogen balance back to near zero. This was the most common rotation in the region and is usually found on the largest plots of the household fields. Applying manure and fertiliser to the cotton, and following this with maize and more fertiliser, effectively splits the costs of fertilisation over two years and appears to be an effective strategy. Ignoring this rotational practice and examining only the 1996 cotton balance (-11.7 kg N/ha) in isolation would easily lead to incorrect assumptions about the sustainability of cotton farming.

The cotton-maize-millet rotation is more typical of households that have been planting cotton for less than ten years. The cotton crop is planted "experimentally" on different plots over succeeding years, and the habitual maize-millet follows. It is a rotation that depletes soil nitrogen of an average of nearly seven kg/ha per year, but often is preceded by the clearance of a long-term fallow (i.e.: the crops would benefit from higher "natural" fertility inputs than the balance model quantifies). It is also not a balance that differs significantly from that of the maize-millet rotation, which is the most common sequence of crops on the smaller, ancillary plots of most household fields that do not ever bear cotton.

The last two rotations (maize-millet and groundnut-millet) are, however, ill-served by the mere summation of region-wide balances. The results portrayed in the table may indeed reflect the nutrient status of the minor plots that support these rotations in most cotton-farming households. However, for the five non-cotton farming households who accord these rotations pride of place in their fields, the organic matter balances (and the nutrient balances) of maize, millet, and groundnut are significantly higher than the sample-wide average. The maize-millet rotation, as practised by Fulani households gives +59.2 kg N/ha per year, while the groundnut-millet rotation (the primary cultivation of the Minianka hamlet-resident) leads to a minor deficit of -3.4 kg N/ha.

7 Space-related issues

Rangeland to cropland ratios

In extensive grazing systems, most of the nutrients found in the manure that is applied to fields originated in plants grazed either in the woody savannah areas, or the meadows near the watering points, and not from the crop residues left in the fields (Swift *et al*, 1989). To reflect this, many studies cite a "Rangeland to Cropland Ratio" (RCR) indicating the amount of grazing land that "supports" the production of manure that could then be applied to crop land (cf. Turner 1995).

Such a ratio does not always account for seasonal variation of ranges, or the different herd management strategies co-existing in a region. From interviews and field visits, RCRs were determined for village cattle: 3½:1 in the rainy season and as low as 2½:1 in the dry season, during crop stubble-grazing. In Miniankabougou, the ratio was nearly 50:1 and Fulani ratios were 120:1 and 190:1 in the wet and dry seasons respectively. The discrepancy between these figures arises from differences in herd management and watering issues. Village animals are herded by small children and are kept nearer to home (for fear of theft or injury) than the "professionally"-herded Fulani animals. The village animals are also principally watered at the dam nearby, while Fulani herds are not allowed to use it and must visit streams and associated pastures further to the south and east of the territory.

An RCR of 20:1 is often suggested as sufficient to maintain fertility under fallow conditions (Ruthenberg, 1980), which is close to the ratio found for the whole grazing range of the herds (16:1). The two Fulani settlements, and Miniankabougou, have far higher RCRs, but the villagers do not. This suggests that fertility maintenance using cattle manure is an option available only outside of the village farming system, unless substantial reallocation of manure takes place within the region.

Zones of grazing intensity and manure distribution

One of the consequences of extensive grazing systems is that the nutrients collected in manure are redistributed, not just from bush to crop land but also predominantly within the bush itself. Assessing the frequency of grazing and the on-farm manuring by passing herds is, however, notoriously difficult (Msumali *et al*, 1995). Direct measurements of the manure dropped "in passing" tend to find that it is a relatively small and dispersed resource (i.e.: Harris, 1995). System-wide studies, however, appear to over-estimate such manuring by assuming that large fixed percentages of the biomass consumed – 50, 60 or even 90 % (Krogh, 1995; Smaling *et al*, 1993; Camara, 1996) – are returned to the crop land by livestock. Such assumptions are at odds with not only my findings, but also the observations of Powell and Williams (1993) that animals remove more biomass in grazing than they return via manure or urine.

In Lanfiéla, we classified sample fields into five categories based on field measurement of manure dropped "in passing", other observations of grazing frequency, and the statements of herders and land-owners (Table 11). With the day-time manure measures obtained from the *culotte* study, a knowledge of the different seasonal grazing orbits from corral to watering points, and the time spent grazing, we then estimated the spread of manure (and nutrients) along these orbits and across the landscape (Figure 3).

Table 11. Quantities of dung dropped "in passing" by grazing herds, dry season 1996-1997

Level	Type of site	Average kg DM of dung found in five 25 m² frames	Manuring rate (kg DM/ha)
None	• ungrazed fields, only stray animals	[no measures made]	<< 1
Low	• grazed ~1 week immediately post harvest by village plough oxen only	0.05 ± 0.08	19
Medium	• grazed all dry season by village oxen • grazed ~1 week by transhumant herds	0.60 ± 0.04	240
High	• grazed all dry season by Fulani herds • major "corridors" to watering points	1.35 ± 0.84	540
Very High	• Fulani crop-land near corrals • immediate vicinity of watering point	2.44 ± 0.77	980

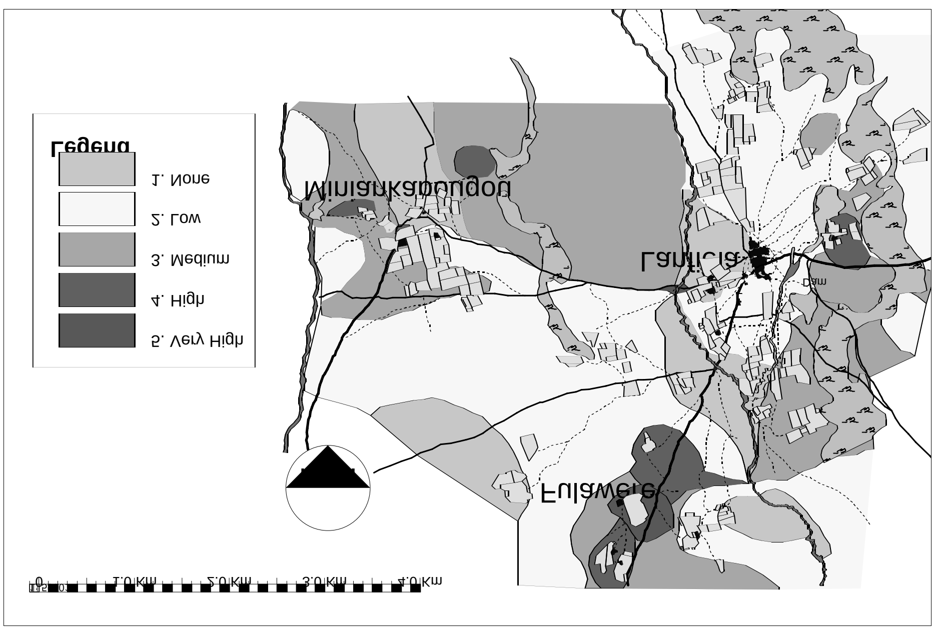
DM = dry matter

The uneven concentration of grazing intensity over the crop land (shown as silhouettes of the 1996 sample fields) is striking. Manure dropped by grazing animals was concentrated along several herding "corridors" near to Fulawere. The southern portions of the Miniankabougou crop-land also appeared to benefit from this resource, being surrounded by "grazeable" bush that was exploited in the wet season. A region of village cropland to the south and east of the stream also benefited from considerable herd traffic in the dry season.

The zones of lowest grazing intensity reflect regions where gardening and rice cultivation were important. The soil immediately to the west of the village is easily compacted by cattle herd movements. It was also the site of an increasing number of fruit orchards (mango, orange, and cashew) that their owners did not want disturbed.

Owing to the extensive grazing movements of the local herds, and the concern of herders to avoid damaging crops, much of the manure that could conceivably be dropped “in passing” on cropland is in fact dispersed fairly widely back into the bush. It is a significant resource only for those fields that lie along major grazing routes, and of only marginal importance to most other fields.

Figure 3. Distribution of zones of “grazing intensity", used for nutrient balance calculations, 1996-1997.



Rings of cultivation intensity: space as history

The intensification of West African agricultural systems is often described as following a “ring-management” system (Prudencio, 1993; Sedogo, 1993; Ruthenberg, 1980). The greatest inputs of labour and nutrients are applied to locations close to the home, sustaining annual cultivation. More distant, “bush” fields are less intensively managed, and so long as space allows, are re-fertilised by fallowing.

In Lanfiéla, the different settlement histories of the three sub-regions have created a more organic overlapping of this ideal concentric ring system. Hamlets have sprung up and begun to manage land intensively in the midst of what was for village residents the fallow "bush". The intensity of management in the hamlet's "core" is demonstrated by its only modestly negative nutrient balance (-4.7 kg N /ha), whereas the adjacent land managed as "bush" fields for villagers receive few inputs and lost 21.8 kg N /ha.

The longer settlement history of the village has meant that older, wealthier households have claimed the best field sites on the plain surrounding the village. Newly established, or poorer households, must therefore resort to clearing and cultivating "bush" field sites that are farther from the village. Many of the "bush" regions are difficult to access due to rocky paths or the flooding of the river during the rainy season, which make effective management of these fields that much harder.

However, "bush" fields for villagers also represent a means of exploiting local soil and climatic variability. Village households do not have as much livestock as those in the hamlets or Fulawere, and so are unable to generate as much manure for their fields. The clearance of old fallows in the "bush" is therefore an alternative means of tapping soil nutrients that might otherwise be gathered through grazing animals. The competition each dry season for cart owners to be paid in manure for the borrowing of their cart is another expression of this quest for bush nutrients.

7 Concluding remarks

Behind the image of Africa's long dry seasons of environmental degradation and soil-mining agriculture lie stories of incredible local variability. In Lanfiéla, three distinct regional farming systems were sustained by different degrees of reliance on livestock, inorganic fertilisers obtained with cotton revenue, and soil variability.

It is tempting to conclude that since both crops and livestock play roles in all three systems, that productivity (or soil fertility) could be improved by more complete crop-livestock integration. However, recurring themes in this paper urge caution in this regard. The diversity of actors and situations imply that no standard prescription will be available. The temporal and spatial issues that enriched the study of the nutrient balances will also influence the potential for integration.

Firstly, as discussed in the sections on organic matter balances and on grazing intensity, the positive organic matter balance for sample fields results from animals' grazing off-farm resources, not crop residues. An organic matter balance will tend towards zero the more crop residues are a part of the animal's diet. Secondly, a greater cycling of residues through livestock could increase the "environmental" nutrient losses like volatilisation and denitrification. But thirdly, the co-existence of several farming systems in the region does offer hope. By identifying how each exploits slightly different aspects of the "bush", cropland, and organic matter more generally, points of potential collaboration can be found. The manure from Fulani herds, for example, that collects in wet season corrals and is never spread on fields could become the means with which these most recent immigrants to Lanfiéla make themselves valued members of the community.

Nutrient balances helped in developing these details, but are not simple tools to master. A calculated balance is essentially an ahistorical snap-shot of a given year's agricultural practices. Interpreting it as some more profound window on a system's "sustainability" misrepresents the soil fertility dynamics of the region, and risks feeding into an unrealistic "crisis narrative".

Too many of the components in nutrient balances are environmentally determined, and difficult to evaluate properly even though they contribute enormously to the end result. Balances are also affected by such off-farm factors as the seasonal fluctuations in the rangeland to cropland ratio that supports livestock and manure production. Socio-cultural differences, and economic differentiation between actors, lead to systematic impacts on cropland agro-ecology and deviations from the "big picture". Finally, rotational practices and the legacy of previous years' balances provide crucial contextual information, without which "snap shot" balances become meaningless.

In the local context, soil fertility decline is only one factor of many seeming to influence the "sustainability" of the farming systems. Most of the old farmers claimed that crop yields have not declined over their lifetimes, but that rainfall has diminished and become more erratic (cf. Pieri, 1992). The Fulani, whose farming system appears the most viable from the nutrient balance perspective, are the most recent settlers in the area and would cite land tenure and watering rights as issues more likely to influence their futures than soil fertility decline.

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