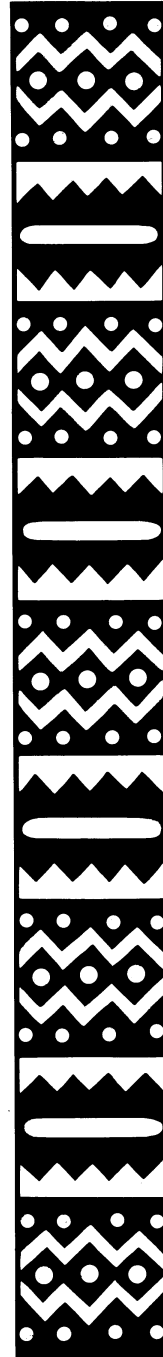


Managing Africa's Soils No. 6

Soil nutrient budgets and balances: What use for policy?

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About NUTNET

NUTNET stands for *Networking on soil fertility management: improving soil fertility in Africa-Nutrient networks & stakeholder perceptions*. 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.

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.

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Summary

This paper reviews the application of the nutrient budget and balance approach from a range of settings and scales in Africa. The paper asks: can such analyses help in the design of effective policy which supports improved soil fertility management by Africa's small-holder farmers? Through the examination of existing studies, the paper highlights some of the difficulties with nutrient budget analyses, including potential problems with a snapshot approach when trying to understand longer term dynamic processes; the danger of extrapolation to wider scales from limited locale-specific data sets; the challenges of understanding diversity, complexity and uncertainty within small-holder farming systems; and the importance of insights into the many socio-economic and institutional factors which influence decision-making at farm level and so mediate the processes of environmental change. The paper concludes by recognising the potential contribution of nutrient budget analyses to the policy process, but suggests caution over uncritical use; particularly the employment of aggregate studies to diagnose generalised problems and suggest blanket solutions. Instead, the paper highlights how nutrient budget analyses can be used as simple devices to encourage debate and dialogue between farmers, technical scientists and policy actors in a participatory process of negotiating interventions or policies for tackling issues of agricultural sustainability in Africa.

Keywords: Soil fertility; nutrient budgets; scale; sustainability; policy; Africa.



Quelles sont les contributions des bilans d'éléments nutritifs aux orientations des politiques agricoles ?

Résumé

Ce document examine l'application de l'approche adoptée en matière de bilan d'éléments nutritifs dans toute une série de milieux en Afrique et à différentes échelles. Il pose la question suivante : ces analyses peuvent-elles contribuer à concevoir des politiques efficaces améliorant la gestion de la fertilité des sols par les petits exploitants agricoles d'Afrique ?

Par l'examen des études réalisées, ce document met en lumière certaines des difficultés rencontrées lors de l'analyse du bilan des éléments nutritifs, y compris d'éventuels problèmes associés à une approche ponctuelle, lorsque l'on cherche à comprendre des processus dynamiques à plus long terme ; le danger d'extrapoler à des échelles supérieures des ensembles limités de données spécifiques à une situation locale ; la difficulté de comprendre la diversité, la complexité et l'incertitude inhérentes aux systèmes agricoles des petits exploitants ; et l'importance de prendre en compte les nombreux facteurs socioéconomiques et institutionnels qui influencent les prises de décision au niveau de l'exploitation agricole et, ainsi, d'accompagner les processus de changement environnemental.

Cet exposé conclut en reconnaissant la contribution que peuvent faire les analyses du bilan de d'éléments nutritifs au processus politique, mais il met en garde vis-à-vis d'une utilisation non critique ; notamment l'emploi d'études amalgamées pour diagnostiquer des problèmes généralisés et proposer des solutions toutes faites. Au contraire, il montre comment les analyses du bilan d'éléments nutritifs peuvent être une manière simple d'encourager le débat et le dialogue entre les agriculteurs, les chercheurs et les acteurs politiques dans un processus participatif de négociation des interventions ou des politiques pour traiter les questions relatives à la durabilité de l'agriculture en Afrique.

1 Introduction

In recent years, nutrient budget and balance approaches have become widely applied in the African context. Studies have been undertaken at a variety of scales: from plot and catchment to regional analyses and, sometimes, even continent-wide assessments. The conclusions emerging from many such studies point to widespread processes of 'nutrient mining' and soil fertility decline. Considering the urgent need to increase agricultural production in Africa, these are alarming conclusions. These, in turn, have prompted a variety of responses at a policy level, where conclusions from nutrient budget and balance assessments are increasingly used to justify policies and interventions, at both national and international levels (e.g. IFPRI, 1995; FAO, 1996; World Bank, 1996).

In this paper we ask: Do nutrient budgets give us the information we need to understand the status and dynamics of soil fertility across smallholder African farming systems? Can such analysis help design policy to support improved soil fertility management by Africa's small-holder farmers? The paper assesses, first, some of the difficulties with soil nutrient budget analysis, including potential problems with a snapshot approach to trying to understand a set of longer term processes, the dangers of extrapolation from very limited data sets, problems of handling diversity and uncertainty within small-holder farming systems, and the importance of understanding the many socio-economic and institutional factors which influence decision-making at farm level. Second, and more importantly, it challenges the methods and underlying assumptions of such forms of analysis, and the consequent need for care in translating their findings into policy. We want to point to both potential strengths and weaknesses in the use of soil nutrient budgets for framing policy decisions. In particular, we identify where complementary methods from the social sciences could strengthen the approach and provide the broader context within which the use of nutrient balances for policy making needs to be set.



Soil nutrient budgets: applications in Africa

General

Nutrient budgets have been used at a variety of levels and for a range of purposes. This section reviews some of these, focusing on their application in the African context.

Most nutrient budgeting studies follow a fairly simple routine, starting by the identification of the key inputs and outputs in various sub-components of a bounded system (cf. Stoorvogel and Smaling, 1990, Appendix III for methods and data sources commonly used). In most cases the system boundary, its sub-components and the various nutrient inputs and outputs are defined by the researcher (although see Defoer et al., 1998, for examples of farmer-led analysis). Estimation of flows of one or more nutrients (usually nitrogen, phosphorus and potassium, and ignoring secondary and micronutrients, organic matter status and carbon balances) then follows, either through direct measurement or through literature estimates based on standard functions (for instance, for volatilisation, deposition, erosion losses etc.). Where data is not being collected at that particular scale (notably for larger scale analyses), data from smaller scales are extrapolated. Budget analyses are thus essentially simple accounting exercises, whereby balances are calculated for each of the identified nutrient 'currencies' through summation.

An interest in resource balances in agricultural science dates back to the early experiments of Boussingault who, in the 1830s, set out to draw up balance sheets to show how far manure and other sources of nutrient supply (air, rain and soil) had satisfied the crop (Wild, 1988). Subsequently, approaches to input-output analysis became a major focus of systems ecology from the 1950s, when energy, mineral nutrient and other cycles were identified, and static balance studies of different ecosystems carried out (Odum, 1968). Simple accounting approaches to ecosystem management have since become widespread, including important applications in agricultural systems in Europe and North America, initially for identifying nutrient shortfalls and appropriate fertilisation regimes (e.g. Frissel, 1978). More recently, in areas

of high nitrate pollution, nutrient budgets are increasingly being used to monitor and control levels of discharge and limit adverse effects from high levels of use (Conway and Pretty, 1991). However, it has only been in the last decade, as concerns for soil fertility decline have increased and the limitations of standard chemical fertiliser testing programmes have been recognised, that nutrient budget and balance analyses in Africa have come to the fore (Van Duivenbooden, 1992; Smaling and Braun, 1996).

Farm and field-level studies

At a relatively small scale nutrient budgeting has been used as a means to assess the level of nutrient sources and flows, opportunities for improved use efficiency and scope for possible interventions. Such studies have been carried out at a variety of scales from patch and plot to farm level. For example, detailed plot-level studies have been carried out in Zimbabwe (FSRU, 1996) and Niger (Brouwer et al., 1993), where differences in nutrient flows over small areas were examined. Such studies highlight just how varied nutrient availability is within the field, and how farmers' management of nutrients and crops, is attuned to this (e.g. Carter and Murwira, 1995; Scoones et al., 1996 for Zimbabwe; De Steenhuijsen Piters, 1995 for northern Cameroon).

Most studies take a plot-based approach whereby different cropping units are distinguished according to crop type, landscape position or intensity of management (often comparing dryland outfields with homesteads and gardens). In southern Ethiopia, for example, comparison of enset (false banana) plots close to homesteads with intensively managed maize gardens and outfields reveals important differences in patterns of fertility management, types of nutrient cycling and levels of nitrogen and phosphorous balance at plot level (Eyasu et al., 1998). Similarly, the banana fields in the *kibanja* homegarden in Bukoba district, Tanzania, directly and indirectly receive nutrients from the common *rweya* grasslands further away (Baijukya and De Steenhuijsen Piters, 1998).

Other studies take the farm, rather than the plot or field, as the basic unit of analysis and calculate inputs and outputs accordingly. For example, a study in the Lake Zone in Tanzania estimated all inputs and outputs for an average type of narrow valley farming system (Budelman et al., 1995). A comparable approach has been used in Kenya (Shepherd et al., 1995), and in northern Nigeria (Harris, 1998). While all these studies recognised that farms are made up of different sub-components, with different landscape positions, soil types and management regimes, the farm unit as a production and management unit was taken for the purposes of diagnostic assessment of soil fertility issues.

Ultimately, the purpose of the study guides the scale of analysis and the data collection strategy, although the level of detail at which such studies are undertaken is always the result of a trade-off between cost and measurement intensity. All farm, field and plot-



level studies reviewed here have been geared towards identifying possible interventions for improving the efficiency of nutrient management. For example, in Kenya a range of agroforestry interventions were identified for testing (Shepherd et al., 1995); in Ethiopia testing of different manuring and composting techniques was proposed (FARM-Africa, 1996); and in Tanzania improved manure management techniques linked to home gardening were suggested by nutrient budget studies (Budelman et al., 1995).

The degree of farmer participation in the process of diagnosis varies between the studies reviewed here. In Mali, for instance, farmers were fully involved in the process of resource flow diagramming and analysis, leading to a range of interventions designed and implemented by farmers, including improved management of cut and carry livestock systems, composting, and contour ploughing (Defoer et al., 1996). In Zimbabwe and Ethiopia, a similar process has evolved where farmer research groups lead a process of problem identification, analysis and experimentation, which is supported by more detailed nutrient budgeting and soil sampling (FSRU, 1996; FARM-Africa, 1996). The purpose of involvement by the farmer in such diagnosis is two-fold: first to provide information and understanding regarding local conditions and farmer strategy and, second, to support a longer term process of experimentation, research and adaptation firmly located at farm level. Such examples provide valuable material for the development of farmer-led analysis and action to improve soil fertility management (Deugd et al., 1998).

Landscape and village territory studies

The influence of scale on nutrient balance analysis is also highlighted by those studies which take a watershed, village or 'terroir' approach, including arable, fallow and grazing areas. In a study in northern Burkina Faso, for instance, field level budgets were negative due to the export of crops for consumption or sale, but, at a village level, nutrient budgets were positive due to the import of manure from surrounding rangelands (Krogh, 1995). In the agro-pastoral settings typical of many African farming systems, the relationship between crop and range land is key. For this reason, many studies attempt to calculate the area of rangeland required to support the livestock which will provide enough manure to balance the nutrient offtake from crop harvests and other outputs from cropped areas. This requires looking beyond the farm and field to the broader landscape or village territory. A number of studies of this sort have been undertaken, including work in Mali (Bremner and Traore, 1987; Van Duivenbooden and Gosseye, 1990; Van Keulen and Bremner, 1990; Van der Pol, 1992; Toulmin 1992), Niger (Powell and Williams, 1993; Williams et al., 1995; Powell et al., 1995), Burkina Faso (Quilfen and Milleville, 1983; Prudencio, 1993); Nigeria (Powell and Mohammed-Saleem, 1987; Bourn and Wint, 1994); and Zimbabwe (Swift et al., 1989).

Ratios of the area of rangeland needed to supply sufficient livestock feed and so manure for one hectare of crop land are hugely variable, ranging from effectively zero in sites



such as the Kano Close Settled Zone (Harris, 1995) to up to 45ha in much more extensive systems (Turner, 1995). Modelling such systems is subject to considerable difficulties given the assumptions which must be made about such variables as livestock carrying capacity, watering frequency and the associated area which can be grazed, seasonal variation in grazing intensity and species composition, all of which have a major influence on the conclusions reached (Turner, 1995). For example, in many Sahelian agro-pastoral systems, transhumant herds make use of pastures around farming settlements for only a few months in the dry season. The animals forage on crop residues and the dry hay of annual grasses, transforming them and depositing them in the form of dung onto farmland. Once such pastures have been heavily grazed, the herds move on elsewhere. By contrast, the herds belonging to villagers are much more constrained in their pattern of movement, and thus risk making a more intense and potentially damaging impact on grazing resources around the settlement (Toulmin, 1992).

In addition, as with other scales of analysis, spatial and temporal variability are key to such nutrient flows and budget calculations. At a village or landscape level, the spatial relationship between the relatively dry toplands and the relatively wet bottomlands is often central to the agroecology of a farming system. This is influenced by nutrient flows and erosion dynamics at a landscape level, whereby some areas may be nutrient sources and others nutrient sinks or transition zones (Scoones, 1991). Thus losses through erosion in one part of the landscape provide benefits elsewhere, making the extrapolation of results from measurements at one site highly problematic (Stocking, 1996). Too often, budget analyses assume uniform patterns of soil loss across a landscape, which, if added up, result in large negative losses from erosion, ignoring the likelihood of considerable redistribution of soil and nutrients within the landscape (cf. Böjo and Cassells, 1996, for Ethiopia). Farmers may consciously manipulate erosion and run-off processes, increasing rates of loss in some areas as a means of concentrating moisture and nutrients in desired places.

Temporal dynamics may also have major influences on balance results. In many agro-pastoral settings, temporal variation in livestock populations and related manure production (Williams et al., 1995) or migration, and so farm-level labour or cash availability (David and Ruthven, 1993), can have significant impacts on levels of manure input, amounts of fertiliser purchased, and areas of land left fallow over time. Thus the negative balances in certain years may be compensated by higher level of inputs in other years. Nutrient budget dynamics need to be examined over several years as, for example, when drought causes a collapse in livestock numbers, after which a number of years are required for herd size to recover. However, despite acknowledging such spatial and temporal dimensions, most studies retain a snap-shot view which offers an average ratio of crop:rangeland, one that may have little meaning in the real world (Turner, 1995).



District, national and continental scales

Many similar problems arise when the scale is enlarged yet further to a district, national or continental scale. A number of district level studies have emerged recently which make use of data from farm and village level analyses and attempt to extrapolate to a wider scale. For example, one such study from Kisii district, Kenya found consistently negative balances for all major nutrients at the aggregate district level (Smaling et al., 1993). Similar results have been found in Mali, where aggregate nutrient losses are reported for all districts, except the cotton growing zone where imports of inorganic fertilisers compensate for harvest exports and other losses (Van der Pol and Traore, 1993; Powell and Coulibaly, 1995).

At national and regional levels a similarly gloomy story emerges: unless significant inputs of external inputs in the form of inorganic fertilisers are supplied, negative balances of nutrients are inevitable (McIntire and Powell, 1995). For Africa as a whole, the low level of inputs (including fertiliser) relative to outputs results in a consistently negative balance (Stoorvogel and Smaling, 1990; Stoorvogel et al., 1993). These larger scale estimates have become increasingly influential in policy discussions around soil fertility management and the prospects for sustainable agriculture in Africa (cf. IFPRI, 1995; FAO, 1996; World Bank, 1996) and numerous other government and agency documents on this subject). Almost all conclude that, because of aggregate deficits of nutrients, interventions must focus on increasing nutrient inputs through processes of nutrient 'recapitalisation', often involving major fertiliser programmes.

But, as discussed earlier, given the issues of spatial and temporal variability raised by studies carried out at smaller scales (indeed, the very studies on which these larger-scale assessments are based), we must ask: how reliable a guide for policy decisions are these aggregate nutrient balance estimates? It may be the case that "scale-inherent simplifications were inevitable" (Smaling et al., 1993, 237), but what are the implications of these acknowledged weaknesses? And finally, a more fundamental puzzle: if things are so bad at an aggregate level (and apparently have been for some time - agriculture after all has been practised in many areas of Africa for centuries, without external inputs of chemical fertiliser), how is it that farming persists at all?

In the next sections, we will first look at the way nutrient budget and balance studies at these different scales have been used in recent policy debates. We will then go on to review some of the conceptual, methodological and practical dilemmas raised by the use of nutrient budget and balance studies at different scales. We return in the final section to a discussion of why farmer participation in the soil nutrient debate is critically important if the insights raised by nutrient budgets and balances are to be translated into improved practice at farm level.



Nutrient budgets and policy: Getting a simple message across or misrepresenting a complex story?

During the last decade, both individually and together, nutrient balance studies have managed to highlight effectively the issue of soil fertility, pointing to possible future scenarios and implications for agricultural development intervention. Such simple messages provide a spur to action by governments and the international community, through raising the profile of the topic.

Nutrient budget analyses share a certain amount in common with earlier high profile surveys of environmental problems, which caught the imagination of the general public and policy makers alike. From the 1970s, environmental debates have been dominated by a set of arguments about resource depletion based on projected gaps between demand and supply, usually derived from static systems models of inputs and outputs, assuming a particular, usually linear, relationship between population and resources. Such accounting or budgeting procedures, often known as 'gap analysis', resulted in prescriptive statements about future outcomes, but little insight into the dynamics or processes involved. Gap analysis, for instance, was central to the debate around the so-called 'woodfuel crisis', and, more broadly, the 'energy crisis' of the 1970s (Leach and Mearns, 1988). Similarly, gap models have been employed effectively to argue for the imminence of wider resource depletion crises, due to population pressures (e.g. Ehrlich and Ehrlich, 1990) or more generalised 'limits to growth' (e.g. Meadows et al., 1972). While such arguments reached their zenith during the 1970s, when aggregate resource



scarcity was perceived as the greatest threat to the environment, they continue to maintain a strong hold on both policy makers' and the general public's views of the environment (Adams, 1992). Indeed, as the millennium approaches, gap analyses seem to have come back in vogue as futurologists project into the next century a vision of global collapse (e.g. Brown and Kane, 1995 among others).

All these models project forwards likely levels of demand and supply for certain critical resources, under constrained assumptions of what constitutes the 'carrying capacity' of a given system. But the past two decades have demonstrated the errors underlying many such scenarios. For example, patterns and levels of demand for particular resources have changed substantially from those predicted; technology has wrought big shifts in how resources are used, and the supply of many resources has expanded at rates far in excess of those anticipated (Beckerman 1995). Such flexibility and capacity to adapt to new circumstances is also found amongst African farmers who have had to cope, over recent decades, with major challenges, such as increased land shortage, changing input-output prices, new technologies and, in some places, a marked reduction in rainfall.

The process of creating a consensus between science and policy and enlisting a range of actors committed to action, requires a clear, compelling and simple message. However, in the process, key uncertainties are often ignored (cf. Latour, 1987; Wynne, 1994). As with other forms of gap analysis, aggregate nutrient budgets tell only a partial story. Yet, because of the effectiveness of their presentation and the apparent simplicity of the 'narrative' (Roe, 1991), their limitations are often played down, or are not even mentioned at all.



4 Challenges for nutrient balance analyses

In this section we identify some of the emerging challenges for nutrient budget analyses raised by our review of current practice elaborated above. These include the need to understand the dynamics of change; the need to address scale issues seriously; the need to recognise uncertainties in any analyses; and, finally, the need to incorporate socio-economic factors into nutrient cycle assessments at all scales.

Capturing dynamic processes

As the studies reviewed in earlier sections of this paper demonstrate, most balance models provide only a snap-shot view, based on a few seasons' data collection. But can such estimates tell us anything about the dynamics of soil fertility change? The answer is: not very much. Realistically, most balance models are little more than limited time-frame accounting sheets. But analysts using such models do, however, implicitly or explicitly, make assumptions about the dynamics of the system in both its current and 'ideal' state. These usually derive from input-output equilibrium ecosystem modelling, and assume that with sufficient feedback loops, a steady and sustainable state can be achieved.

Such equilibrium thinking permeates much of the debate on nutrient cycling and soil fertility management, and is rarely questioned, as such concepts are deeply embedded in much mainstream ecological theory and method. But, it must be asked, is this the right approach to understanding environmental change in African farming systems? For the analysis of soil fertility change, we must therefore ask: how can you situate the particular data observed in a budget analysis within a dynamic sequence? What evidence do we have of past levels and changes in nutrient availability? What assumptions are being made about trends - is a linear decline the right model for describing what has happened to soil fertility or are other more complex dynamics a possibility?



Clearly gaining insights into longer-term dynamic processes is a major task, especially given the limited presence of long-term trials in Africa (Greenland, 1994; Powelson and Johnston, 1994; Wooster and Swift, 1994). However, such trials, combined with other, more qualitative observations derived from the historical study of agricultural systems (Scoones, 1997a, b), can provide important insights into key dynamic characteristics.

Micro-level diversity, sampling and the problems of scaling up

The landscapes in which African savanna farming systems have evolved are often very diverse, in terms both of their physical attributes and the history of their management and use. Within a watershed, topland and bottomland areas provide contrasting soils, slopes, patterns of drainage and crop growing conditions and, hence are managed differently by farmers. At a field level, scarce labour, capital, nutrient and other inputs are distributed between different plots with the aim of balancing increased yield against exposure to risk. As a consequence, sandy soils are planted to particular crop types, and with different fertilisation practices than heavier clays, while diversity of cropping patterns and practices help ensure reduced vulnerability to crop failure. Diversity at a village level is also important, and distance from the farming settlement often provides a major axis along which patterns of soil fertility vary, with much higher levels of investment being made close to the homestead (Prudencio, 1993). Higher potential patches are usually managed intensively, with soil structure and nutrient status being improved over time. This is particularly the case for gardening of high value crops, involving investment in enclosures, fertility inputs, and watering for dry season production. In dry areas, farmers may accelerate erosion and runoff from slopes to concentrate water, soil, and nutrients in lower lying crop lands, or may create terraces, bunds, strips, basins, mounds or planting pits in which to capture water runoff in combination with small additions of organic fertiliser (see Table 1).

An effective sampling strategy must be able to identify the major land types used by farmers, techniques and processes of soil conservation and improvement, and the inter-relationships between the various parts of the landscape (Fresco and Kroonenburg, 1992). A simple summation of areas covered by major soil types will miss several essential attributes of these farming systems, in which farmers value and exploit diversity. At the same time, there are serious challenges for analysis where different parts of the landscape are linked through processes of runoff and run-on of moisture and nutrients (Brouwer and Powell, 1998). Nutrient budgets tend to generate average estimates, whereas farmer strategy and management makes use of and develops diversity, constituting a major difference in paradigm. This has significant implications for the relevance of interventions stemming from the analysis undertaken.



Table 1. A selection of soil and water conservation techniques used by farmers in Africa (derived from a continent-wide review, reported in Reij et al (eds.), 1996).

| Technique | Soil/water management |
|---------------------------|---|
| Bench terrace | Fixed structure, built up over many years, usually on steep slopes; results in holding of soil, reducing erosion and leaching; often combined with agroforestry. |
| Fixed bund/contour ridge | Fixed structure built along the contour with wide range of designs; results in capture or slowing or diversion of water, with consequences for distribution of soil and fertility in field. |
| Moveable bunds | Bunds which are placed strategically to direct the movement of water and soil within a field; avoids the build up of rich soil behind fixed structures. |
| Gulley plug/ small dam | Harvesting of soil and water behind a small dam structure; often built up over time to capture maximum alluvium on surface. |
| Basin | Various designs, including round, demi-lune etc, result in the spatially focussed harvesting of water and soil for improved plant growth. |
| Planting pit | Pit dug often into hard soil to encourage infiltration of water; often combined with mulching and termite action. |
| Mound | Raised planting beds in variety of shapes combined with plant matter incorporation to improve growing conditions for crops. |
| Vegetation strip | Strip of grass or other vegetation to reduce water flow and collect soil deposited; may be fixed or moveable. |
| Mulching | Addition of surface vegetation (or sometimes stones) to reduce water loss and improve soil fertility. |

Sampling therefore presents a recurrent set of problems for calculating nutrient budgets for which there are no simple answers. Usually limits of data collection capacity and laboratory analysis facilities severely constrain sample sizes for detailed budget studies, making a case study approach more likely than full statistical sampling of a range of plot, farm or catchment types.

Recognising uncertainties

Any modelling exercise must make assumptions about boundaries, components and relationships. Nutrient budget and balance models, which attempt to capture the basic elements of highly complex systems, must make a lot of assumptions. This means making choices about which elements are to be investigated in detail and which are not. For instance, many nutrient budgeting exercises take within-soil processes as a



'black box', a horrifying approach for some soil scientists. But not everything can be measured, and in most of the examples described earlier, researchers chose to focus on assessing the inputs and outputs of different farm components, leaving soil processes aside.

The data sources used for such analyses have different confidence limits attached to them. This is particularly the case when data derived from actual measurement and those from literature estimates are compared. The type of input and output data which are relatively easy to measure include flows of materials, such as fertiliser, manure, crop residues and harvested grains. But other data, such as volatilisation, deposition or denitrification, are much more difficult to measure. For this reason, many researchers use literature estimates for such flows. But these have often not been validated for the study areas, and estimates commonly have wide confidence limits. This is problematic, especially if the error levels associated with these estimates outweigh the magnitude of the flows measured in the field. Another level of uncertainty about data estimates emerges when resource flows (measured as weight of materials) are translated into nutrient contents, as there are major differences in laboratory estimation procedures, making comparison problematic.

A simple, accurate and fully objective measure of nutrient flows is therefore largely impossible, and the careful use of sensitivity analyses is essential. This is inevitable, since all measurement and modelling exercises have to assume some 'black boxes', otherwise the data collection task would be almost infinite. Science always involves judgement regarding the right trade-off between time, cost, effort and accuracy. But choice of system boundaries, which sub-components will be investigated, which elements of the system are the black boxes, and which factors are subject to uncertainty all have important implications. It is crucial to recognise such subjective judgements and data uncertainties. Instead of seeing nutrient budget or balance results as definitive statements on the basis of which policies can be made, they should be regarded simply as foci for debate and discussion, where assumptions and uncertainties are made explicit.

Integrating socio-economic issues affecting soil nutrient management

Much of the current soil nutrient debate ignores the role that farmers play in shaping processes of environmental change. Yet farmers are key actors in the cycling of nutrients within agricultural areas, and are also an important source of information and knowledge regarding local soils and crop performance. Farmers face a range of economic opportunities for investment of labour and capital, of which agriculture is only one and, within agriculture, soil fertility is only one constraint among many. Social



and economic factors therefore are critical in understanding patterns of soil fertility management in different contexts, over time and from one farmer to another.

Management by farmers is critical to each of the flows and boxes in any nutrient budget model. Marked differences often exist within a single setting in the efficiency with which soil fertility is handled by different farmers, despite broadly similar access to resources and opportunities. This is due to a combination of personal characteristics - such as an interest in innovation - and differential access to resources, such as labour, cash income, livestock, markets, and the security of landholdings.

The relative value of land, labour and capital endowments over time, among different farmers and between areas, may have important implications for the form and efficiency of any farm-level nutrient cycle. For example, rising prices for land and crops, provide both an incentive and a means for investment in improving land. As land becomes scarcer, its implicit price rises, and it becomes more worthwhile to invest in it, thereby raising its value further. Similarly, as land becomes scarcer, farmers become more aware of the need to make best use of what they have. In many parts of savanna Africa, land has become increasingly short and this has led to a re-assessment by farmers of their options and farming practices. Efficient management of soil fertility tends to be labour intensive, even where a farmer has equipment like a cart to help transport manure from stable to field. In areas of low population density, extensive systems of nutrient management are possible, through grazing of village pasture lands and kraaling of animals on the farmer's field. However, as grazing becomes scarcer and manure of higher value, animals are often guarded within the compound and fodder brought to them, requiring far higher labour inputs.

In central Mali, for example, a combination of population growth and spread of ploughs has meant that many villages have now reached the edge of their terroir and there is very little land in fallow. But this is a relatively recent event here, of perhaps only the last 20 to 30 years and, hence, farmers are only now starting to come to grips with the implications of such changes for how they ensure that their plots remain fertile. By contrast, in the Kano Close Settled Zone of northern Nigeria, population densities have been very high for generations and systems for ensuring that soil fertility can be maintained are well-established (Mortimore 1989, Harris, 1995). Rising population density and the perception by farmers that land has indeed become scarce is probably a necessary, although insufficient, condition for achieving more efficient management of soil fertility.

The prices and availability of agricultural inputs and outputs are also key elements in the calculation farmers must make regarding which crops to grow and the quantity of different inputs to be added. Such decisions are often made under conditions of great uncertainty, since the timing and variability of rainfall, incidence of pests, and



performance of prices in the post-harvest period will all be subject to considerable risk against which farmers can only partially insure themselves.

Devaluation and structural adjustment policies have had a major impact on price ratios of inputs and outputs, dramatically affecting nutrient management practices. In many instances, subsidies on fertiliser purchase and distribution have been abandoned, and the private sector has been encouraged to take over supply systems. In many cases, there has been a fall in amounts of fertiliser used, given its higher price, and a return to biomass as a source of nutrients. However, in some instances, higher crop prices have provided sufficient margins to maintain input levels (Winpenny et al., 1995; Gakou et al., 1996).

Security of tenure and access to land is also a critical factor in the ways farmers manage soil fertility. People invest in improving a particular asset where they have some assurance they will gain a stream of benefits into the future. Where such benefits are subject to risk or uncertainty, this is liable to depress the level of investment. Farmers must decide how much time, effort, and capital to invest in improving their land, by comparison with alternative use of their resources, given likely levels of return in each activity. Security of access to land varies between countries and farmers, depending for example on whether one is from a founding lineage of a particular village or a settler from elsewhere, whether land is being loaned, and whether the country is undergoing a major revision of legislation and administration of land (Lund 1993).

Ignoring such socio-economic factors in the analysis of nutrient budgets and balances misses many of the key driving forces influencing outcomes and setting the framework within which improvements can be developed (Scoones and Toulmin, 1995).



5 Negotiating sustainability: The challenges of participation

The discussion of the previous sections point towards perhaps the most important challenges for work in this field: the need to move away from defining sustainability simply in technical terms, and how best to support processes of change and adaptation at farm level. Addressing these challenges will demand a shift towards a more participatory approach to research, action and the policy debate in which uncertainties are recognised, complexity appreciated and the combination of views from different stakeholders sought as a central plank in planning for the future.

If presented without the full range of caveats, nutrient balances may give a false sense of certainty about the nature and trend of soil fertility change at all scales, leading, on occasions, to simplistic and inappropriate interventions. Data collection difficulties, scale-dependence and inherent uncertainties mean that nutrient budgets are not simple, uncomplicated, objective indicators of agricultural sustainability.

The concept of sustainability is laden with many assumptions and means different things to different people, so that a single, objective, 'scientific' definition will be eternally elusive (cf. Jacobs, 1995; McNaghten et al., 1995). This acceptance of diversity is important, as it shifts our attention from trying to discover a single answer, to recognising that different actors will have different perspectives informed by their interests and experiences, and rooted in their own particular worldviews. Policy and other forms of intervention must start from this realisation, and move forward through debate and discussion on points of agreement and disagreement. Interventions are not optimal solutions to a scientifically well-defined problem, but attempts at adaptive learning in a complex, uncertain and sometimes perplexing world (cf. Holling, 1993, Thompson, 1993).



Fundamental to such a shift in approach is the acknowledgement that tools of analysis must fit the needs of a particular decision maker. Linked to this is the recent acceptance that in practice governments and other agencies often have very limited capacity directly to affect how land is used, and bring about changes in farmer behaviour. As a consequence, the ambitions of governments around the world have been scaled back and attempts made to harness local energies and initiatives. Designing the appropriate tools for improving soil management must aid, as a first priority, a process of reflection, analysis and experimentation by farmers.

In recent years, there have been some major steps forward with the development of methods which attempt to provide bridges between different worlds of understanding, trying to link scientists' understandings with farmers' insights through simple modelling approaches, workshops and joint experimentation. For example, on-farm work to develop an interactive approach where farmers and researchers can work together is being attempted as part of on-going work in Ethiopia, Mali and Zimbabwe (IIED, 1996). Dialogue between researchers and farmers is encouraged as part of a participatory process to analyse resource flows and from which collaborative experiments on soil management questions can be derived. Diagnostic work - employing a range of participatory rural appraisal techniques (Chambers, 1994), including mapping, diagramming and ranking, as well as farmer-led experimentation - provides opportunities for joint analysis and dialogue, from which a common understanding can be reached regarding what is happening to the various elements of the system under study. Such fora may be important settings for different actors to identify their own indicators, allowing each to talk with and learn from the other, to see what alternatives exist for improvement. Perspectives on intervention options from different actors are thus exposed, interrogated and opened up for debate and adaptive testing.

Nutrient budgets and balances can serve as useful devices in this setting - encouraging debate about soil fertility issues between policy-makers, scientists and farmers. Set within a participatory framework for field research and policy analysis, involving dialogue and open debate, nutrient budget analyses can be one route (among others) to providing a 'platform' (cf. Röling, 1996) for negotiation around the nature of soil fertility and, more broadly agricultural and environmental sustainability.



Discussion and conclusions

So what use are nutrient budget and balance approaches to policy? Do they help answer the key policy question - is nutrient imbalance a problem in Africa? Our review of experience suggests that such approaches, if sensitively applied, can make important contributions to the on-going debate on appropriate policies, strategies and interventions to encourage sustainable forms of agriculture in Africa. But in applying such approaches we must be cautious about extrapolation from limited data sets, avoid making claims at inappropriate scales, reflect critically when inferring types of dynamic process from snapshot views, and resist imposing technical solutions, without understanding complex social, cultural or economic contexts.

An alternative approach, as discussed above, would take local contexts seriously, understanding both the historical dynamics of change and the role of social and economic processes in environmental transformation. The disadvantage of such an approach is that it offers up no headlines; no neat and simple narratives on which policy statements and programmes can be hung. Instead, it points to the importance of differentiated patterns of soil fertility management over space and time.

How can such particularism articulate with processes of national policy making and the design of global initiatives, which almost inevitably must seek generalisations appropriate to wider scales? In our view, the answer must lie in adopting the principle of subsidiarity, which argues that tasks should be carried out as near to the level of actual users of resources or beneficiaries of administration as is compatible with efficiency and accountability (Swift, 1995). Thus a broader national and international policy setting is required which encourages farmers to develop locally appropriate solutions.

1. At a local level, we must start from the assumption that farmers have an understanding of soil nutrients and their impact on crop and pasture production. There may be, however, considerable opportunities for improving the efficiency with which nutrient flows are managed on-farm, by investigating losses and inefficiencies within the system, as well as economic, institutional and technical constraints.



However, ultimately, it is farmers who are the land users and decision-makers. Innovating farmers exist in all communities, yet opportunities for wider sharing with others may be constrained. More thought needs to be given to ways of supporting farmer-led experimentation and innovation, as well as processes of farmer-to-farmer extension (cf. Chambers et al., 1989; Scoones and Thompson, 1994).

2. At a national level, a shift is needed from seeing policy and decision making as a mechanistic, linear process in which decisions are made at the centre, then filtered down through levels of administration and extension before being delivered to the farmer. Coping with rapid change and high levels of local diversity demands a more pluralistic approach, that makes use of a wider range of views, information and knowledge. This would imply a more experimental and iterative approach to policy-making (Thompson, 1993; Juma and Clark 1995), in which feedback between field and national levels is a critically important element to monitor progress and make adjustments. It would also imply that farmers be taken as allies in the process of achieving more sustainable land use, allies from whom useful information, ideas, and perceptions can be sought. Such an approach would acknowledge current realities; the very limited reach of governments to directly influence how land is used, and the poor record of policies based on coercion.
3. At international level, greater care is needed to qualify the headline approach to characterising African agriculture, emphasising instead the opportunities and difficulties faced in different places. It must be asked: can the global system only respond to simplistic generalisations? Must we always deal in the debased currency of crisis and disaster, in order to get the resources needed to address the real and diverse problems of soil fertility management? Or does this approach only set the agenda at national and local levels in a way which saps local initiative, and discourages the capacity for innovation and adaptation upon which the future of African agriculture must depend? While recognising the value of global initiatives in focusing attention and funds on a particular issue, we need to tailor such approaches to address local perspectives and realities, and avoid the very real dangers of such initiatives closing down debate and discussion, and forcing inappropriate blueprint solutions on local settings.



References

- Adams, W. M.**, 1992. *Green Development: Environment and Sustainability in the Third World*. Routledge, London.
- Baijukya, F. B., De Steenhuijsen Piters, B.**, 1998. Nutrient Balances and their Consequences in the Banana-Based Land Use Systems of Bukoba District, Northwest Tanzania. *Agric. Ecosyst. Environ.* 71, 149-160.
- Beckerman, W.**, 1995. *Small is Stupid: Blowing the Whistle on the Greens*. Duckworth, London.
- Böjo, J., Cassells, D.**, 1996. Land Degradation and Rehabilitation in Ethiopia: A Reassessment. AFTES Working Paper, 17. World Bank, Washington.
- Bourn, D., Wint, W.**, 1994. Livestock, Land Use and Agricultural Intensification in Sub-Saharan Africa. Pastoral Development Network Paper 37a. ODI, London.
- Breman, H., Traore, N. (Eds.)**, 1987. *Analyse des Conditions de l'Elevage et Propositions de Politiques et de Programmes*. République du Mali. Sahel D(86)302, Club du Sahel/CILSS/OCED, Paris, 243p.
- Brouwer, J., Powell, J. M.**, 1998. Increasing Nutrient Use Efficiency in West-African Agriculture: Impact of Microtopography on Leaching from Cattle and Sheep Manure. *Agric. Ecosyst. Environ.* 71, 231-241.
- Brouwer, J., Fussell, L., Herrmann, L.**, 1993. Soil and Crop Growth Micro-Variability in the West Africa Semi-Arid Tropics: A Possible Risk Reducing Factor for Subsistence Farmers. *Agriculture Ecosystems and Environment*, 45, 229-238.
- Brown, L., Kane, H.**, 1995. *Full House: Reassessing the Earth's Carrying Capacity*. Earthscan, London.
- Budelman, A., Mizambwa, F., Stroud, A., Kileo, R.**, 1995. The Application of the Nutrient Flow Analysis in Land Use Diagnostics: The Case of North Sukumaland, Land Zone, Tanzania. In: Workshop on Nutrient Cycling and Soil Fertility Management in Africa, Soddoo, Ethiopia, 26 November - 2 December 1995. IIED, London.
- Carter, S., Murwira, H.**, 1995. Spatial Variability in Soil Fertility Management and Crop Response in Mutoko Communal Area, Zimbabwe. *Ambio*, 24, 77-84.
- Chambers, R.**, 1994. Participatory Rural Appraisal PRA: Analysis of Experience. *World Development*, 22, 1253-1268.
- Chambers, R., Pacey, A., Thrupp, L-A. (Eds.)**, 1989. *Farmer First. Farmer Innovation and Agricultural Research*. IT Publications, London.
- Conway, G., Pretty, J.**, 1991. *Unwelcome Harvest: Agriculture and Pollution*. Earthscan, London.
- David, R., Ruthven, O.**, 1993. The Effects of Male Out-Migration on Women's Management of the Natural Resource Base in the Sahel. SOS-International, London.
- De Steenhuijsen Piters, B.**, 1995. *Diversity of Fields and Farmers. Explaining Yield Variations in Northern Cameroon*. PhD thesis, Wageningen.

- Defoer, T., Kanté, S., Hilhorst, T., de Groote, H.,** 1996. Towards More Sustainable Soil Fertility Management. Paper prepared for the Nutrient Cycling Project Workshop, IIED/FARM-Africa, Soddo, Ethiopia, Nov. 1995.
- Defoer, H., De Groote, H., Hillhorst, T., Kanté, S., Budelman, A.,** 1998. Increasing Nutrient Use Efficiency in West-African Agriculture: Impact of Microtopography on Leaching from Cattle and Sheep Manure. *Agric. Ecosyst. Environ.* 71, 217-230.
- Deugd, M., Röling, N., Smaling, E.M.A.,** 1998. A new praxeology for integrated nutrient management, facilitating innovation with and by farmers. *Agric. Ecosyst. Environ.* 71, 269-284.
- Ehrlich, P., Ehrlich, A.,** 1990. *The Population Explosion*. Simon and Schuster, New York.
- Eyasu E., Morse, S., Belshaw, D.R.G.,** 1998. Nitrogen and Phosphorus Balances of Kindo Koisha Farms in Southern Ethiopia. *Agric. Ecosyst. Environ.* 71, 95-116.
- Fresco, L., Kroonenberg, S.,** 1992. Time and Spatial Scales in Ecological Sustainability. *Land Use Policy*, 9, 155-168.
- FARM-Africa,** 1996. Annual Report of the Soil Fertility Management Project. Unpublished report, FARM-Africa, Awassa.
- FAO,** 1996. Recapitalisation of Soil Productivity in Sub-Saharan Africa. TCI Occasional Paper Series, 5. FAO, Rome.
- Frissel, M.,** 1978. *Cycling of Mineral Nutrients in Agricultural Ecosystems*. Elsevier, London.
- FSRU,** 1996. Report on the Nutrient Cycling Project: 1995-96 Season in Chivi and Mangwende. Farming Systems Research Unit, DRSS, Harare.
- Gakou, A., Kebe, D., Traore, B.,** 1996. *Soil Management in Mali*. Final Report. ODA, London/World Bank, Washington.
- Greenland, D.,** 1994. Long-Term Cropping Experiments in Developing Countries: The Need, the History and the Future. In: Leigh, R., Johnston, A. (Eds.). *Long-term Experiments in the Agricultural and Ecological Sciences*. CABI, Wallingford, pp. 187-209.
- Harris, F.,** 1995. Intensification of Agriculture in Semi-Arid Areas: Lessons from the Kano Close-Settled Zone, Nigeria. IIED Gatekeeper Series, SA59. IIED, London.
- Harris, F.,** 1998. Farm Level Assessment of the Nutrient Balance in Northern Nigeria. *Agric. Ecosyst. Environ.* 71, 203-216.
- Holling, C.S.,** 1993. Investing in Research for Sustainability. *Ecological Applications* 3, 552-555.
- IFPRI,** 1995. *A 2020 Vision for Food, Agriculture and the Environment*. IFPRI, Washington DC, 56pp.
- IIED,** 1996. Annual Report of the Project 'Soil Fertility Management in Africa'. Unpublished Report, Dryland programme, IIED, London.
- Jacobs, M.,** 1995. *Sustainable Development: Faultlines of Contestation and the Radical Model*. CSEC, Lancaster.
- Juma, C., Clark, N.,** 1995. Policy Research in Sub-Saharan Africa: An Exploration. *Public Administration and Development* 15, 121-137.



- Krogh, L.**, 1995. Field and Village Nutrient Balances in Millet Cultivation in Northern Burkina Faso: A Village Case Study. SEREIN Working paper 4, Copenhagen.
- Latour, B.**, 1987. *Science in Action. How to Follow Scientists and Engineers through Society.* Harvard University Press, Cambridge, Mass.
- Leach, G., Mearns, R.**, 1988. *Beyond the Woodfuel Crisis.* Earthscan, London.
- Lund, C., 1993. Waiting for the Rural Code: Perspectives on a Land Tenure Reform in Niger. IIED, Drylands Programme Issue Paper No 44. IIED, London.
- McIntire, J., Powell, J.**, 1995. African Semi-Arid Agriculture Cannot Produce Sustainable Growth without External Inputs. In: Powell, J., Fernandez-Rivera, Williams, T., Renard, C. (Eds.),
- Mcnaughten, P., Grove-White, R., Jacobs, M., Wynne, B.**, 1995. Public Perceptions and Sustainability in Lancashire: Indicators, Institutions, Participation. CSEC, Lancaster.
- Meadows, M., Randers, D., Behrens, W.**, 1972. *The Limits to Growth.* Pan Books, London.
- Mortimore M.**, 1989. *Adapting to Drought: Farmers, Famines and Desertification in West Africa,* Cambridge University Press.
- Odum, E.**, 1968. Energy Flow in Ecosystems: A Historical Review. *American Zoologist*, 8, 11-18.
- Powell, J., Mohamed-Saleem, M.**, 1987. Nitrogen and Phosphorous Transfers in a Crop-Livestock System in West Africa. *Agricultural Systems*, 25, 261-277.
- Powell, J., Williams, T.**, 1993. Livestock, Nutrient Cycling and Sustainable Agriculture in the West African Sahel. Gatekeeper Series, 37. IIED, London.
- Powell, J., Coulibaly, T.**, 1995. The Ecological Sustainability of Red Meat Production in Mali: Nitrogen Balance of Rangeland and Cropland in Four Production Systems. Report to PGRN, Bamako, Mali.
- Powell, J., Fernandez-Rivera, P., Hiernaux, P., Turner, M.**, 1995. Nutrient Cycling in Integrated Rangeland-Cropland Systems of the Sahel. In: Vth International Rangelands Congress, Salt Lake City.
- Powelson, D., Johnston, A.**, 1994. Long-Term Field Experiments: Their Importance in Understanding Sustainable Land Use. In: Greenland, D., Szabolcs, I. (Eds.), *Soil Resilience and Sustainable Land Use.* CABI, Wallingford, pp. 367-394.
- Prudencio, C.**, 1993. Ring Management of Soil and Crops in the West African Semi-Arid Tropics: The Case of Mossi Farming System in Burkina Faso. *Agriculture, Ecosystems and Environment*, 47, 237-264.
- Quilfen, J., Milleville, P.**, 1983. Résidus de Culture et Fumure Animale: Un Aspect des Relation Agriculture-Elevage dans le Nord de la Haute-Volta. *Agronomie Tropicale*, 38: 206-212.
- Reij, C., Scoones, I., Toulmin, C.**, 1996. *Sustaining the Soil: Indigenous Soil and Water Conservation in Africa.* Earthscan, London.
- Roe, E.**, 1991. Development Narratives, or Making the Best of Blueprint Development. *World Development*, 19, 2287-300.



- Röling, N.**, 1996. Creating Human Platforms to Manage Natural Resources: First Results of a Research Programme, pp. 149-158. In: Budelman, A. (Eds.), *Agricultural R and D at the Crossroads. Merging Systems Research and Social Actor Approaches*. KIT Press, The Netherlands
- Scoones, I.**, 1991. Wetlands in Drylands: Key Resources for Agricultural and Pastoral production, *Ambio*, 20, 366-371
- Scoones, I.**, 1996. Hazards and Opportunities: Farming Livelihoods in Dryland Africa Lessons from Zimbabwe, Zed Books, London.
- Scoones, I.**, 1997a. The Dynamics of Soil Fertility Change: Historical Perspectives on Environmental Transformation from Zimbabwe. *Geographical Journal*, 163, 161-169.
- Scoones, I.**, 1997b. Landscapes, Fields and Soils: Understanding the History of Soil Fertility Management in Southern Zimbabwe. *Journal of Southern African Studies*, 23, 615-634.
- Scoones, I., Thompson, J. (Eds.)**, 1994. *Beyond Farmer First. Rural People's Knowledge, Agricultural Research and Extension Practice*. IT Publications, London.
- Scoones, I., Toulmin, C.**, 1995. Socio-Economic Dimensions of Nutrient Cycling in Agropastoral Systems in Dryland Africa, pp. 353-370. In: Powell, J., Fernandez-Rivera, S, Williams, T., Renard, C. (Eds.), *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems in Sub-Saharan Africa*. ILCA, Addis Ababa.
- Shepherd, K., Ohlsson, E., Okalebo, J., Ndufa, J., David, S.**, 1995. A Static Model of Nutrient Flow on Mixed Farms in the Highlands of Western Kenya to Explore the Possible Impact of Improved Management. In: Powell, J., Fernandez-Rivera, S, Williams, T., Renard, C. (Eds.), *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems in Sub-Saharan Africa*. ILCA, Addis Ababa.
- Smaling, E., Braun, A.** 1996. Soil Fertility Research in Sub-Saharan Africa; New Dimensions, New Challenges. *Commun. Soil Sci. Plant Anal.*, 27: 365-386.
- Smaling E., Stoorvogel, Windmeijer, P.**, 1993. Calculating Soil Nutrient Balances in Africa at Different Scales II. District Scale. *Fertiliser Research*, 35: 237-250.
- Stocking, M.** 1996. Challenging Conventional Wisdoms about Soil Erosion in Africa, pp. 140-154. In: Leach, M. and Mearns, R. (Eds.), *The Lie of the Land: Challenging Received Wisdom in African Environmental Change and Policy*. James Currey, London.
- Stoorvogel, J., Smaling, E.**, 1990. Assessment of Soil Nutrient Depletion Sub-Saharan Africa: 1983-2000. The Winand Staring Centre, Wageningen.
- Stoorvogel, J., Smaling, E., Janssen, B.**, 1993. Calculating Soil Nutrient Balances in Africa at Different Scales. I. Supra-National Scale. *Fertiliser Research*, 35, 227-235.
- Swift, J.** 1995. Dynamic Ecological Systems and the Administration of Pastoral Development, pp. 153-173. In: Scoones, I. (Ed.), *Living with Uncertainty. New Directions in Pastoral Development in Africa*. IT Publications, London.
- Swift, M., Frost, P., Campbell, B., Hatton, J., Wilson, K.**, 1989. Nutrient Cycling in Farming Systems Derived from Savannah, pp. 63-76. In: Clarholm, M., Berstrom, D. (Eds.), *Ecology of Arable Lands: Perspective and Challenges*. Kluwer Academic Publishers.



- Thompson, M.**, 1993. Good Science for Public Policy. *Journal of International Development* 5, 669-689.
- Toulmin, C.**, 1992. *Cattle, Women and Wells: Managing Household Survival in the Sahel*. Clarendon Press, Oxford.
- Turner, M.**, 1995. The Sustainability of Rangeland to Cropland Nutrient Transfer in Semi-Arid West Africa: Ecological and Social Dimensions Neglected in the Debate. In: Powell, J., Fernandez-Rivera, S., Williams, T., Renard, C. (Eds.), *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems in Sub-Saharan Africa*. ILCA, Addis Ababa.
- Van der Pol, F., 1992. Soil Mining. An Unseen Contributor to Farm Income in Southern Mali. *KIT Bulletin*, 325. KIT, Amsterdam.
- Van der Pol, F., Traore, B.**, 1993. Soil Nutrient Depletion by Agricultural Production in Southern Mali. *Fertilizer Research*, 36, 79-90.
- Van Duivenbooden, N.**, 1992. Sustainability in Terms of Nutrient Elements with Special Reference to West Africa. CABO-DLO Report, 160. Wageningen.
- Van Duivenbooden, N., Gosseye, P. (Eds.)**, 1990. *Compétition pour des Ressources Limitées: Le Cas de la Cinquième Région du Mali. Raport 2. Productions Végétales, Animales et Halieutiques*. CAP-DLO, Wageningen.
- Van Keulen, H., Breman, H.**, 1990. Agricultural Development in the West African Sahelian Region: A Cure Against Land Hunger? *Agriculture, Ecosystems and Environment*, 32, 177-197.
- Wild, A. (Ed.)**, 1988. *Russell's Soil Conditions and Plant Growth*, 11th ed. Longmans, Harlow.
- Williams, T., Powell, J.M., Fernandez-Rivera, S.**, 1995. Manure Utilisation, Drought Cycles and Herd Dynamics in the Sahel: Implications for Cropland Productivity, pp. 393-410. In: Powell, J., Fernandez-Rivera, S., Williams, T., Renard, C. (Eds.), *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems in Sub-Saharan Africa*. ILCA, Addis Ababa.
- Winpenney, J., Malga, A., Teme, B., Coulibaly, B., Diarra, L., Kergna, A., Tigana, K.**, 1995. *Structural Adjustment and Sustainable Development in Mali*. Draft Working Paper, ODI/WWF.
- Woomer, P., Swift, J. (Eds.)**, 1994. *The Biological Management of Tropical Soil Fertility*. John Wiley, Chichester.
- World Bank**, 1996. *Recapitalization of Soil Productivity in Sub-saharan Africa*. World Bank, Washington.
- Wynne, B.**, 1994. Scientific Knowledge and the Global Environment, pp. 169-189. In: Redclift, M., Benton, T. (Eds.), *Social Theory and the Global Environment*. Routledge, London.



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