

Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of sub-Saharan Africa

Volume I: Conference Summary

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Foreword

Achieving sustainable increases in agricultural production in sub-Saharan Africa is both a regional and a worldwide concern. High human and animal population densities in some areas have surpassed land-carrying capacities causing environmental degradation and undermining the long-term stability of these production systems. In attempts to meet the increasing food demands of larger populations, farmers are cultivating more land permanently, grazing lands have diminished and many traditional farming practices that formerly allowed land to rejuvenate are disappearing.

An efficient cycling of nutrients among crops, animals and soil is crucial to the sustained productivity of low-input mixed farming systems in sub-Saharan Africa. Access to agricultural inputs such as fertiliser and improved seed is limited. Nutrient balances, or the difference between nutrient inputs and harvests, are negative for many production systems. Although animal manures are perhaps the most important fertility amendment that many farmers apply to cropland, livestock can also contribute to these nutrient imbalances. Excessive removal of vegetation by grazing animals or harvesting feeds can deplete soil-nutrient reserves and result in decreases in soil productivity. A major portion of nutrients consumed by livestock may also be unavailable for recycling due to volatilisation, erosion and leaching losses, and uneven deposition of nutrients by animals in the landscape.

The climatic and socio-economic changes currently taking place in many parts of sub-Saharan Africa suggest that sustainable increases in agricultural production from an increasingly fragile ecosystem require new and innovative crop, livestock, and soil-management strategies. To further this objective, the International Livestock Centre for Africa (ILCA) and its cosponsors convened this conference to bring together national and international experts in livestock (cattle, sheep and goats) nutrition and management, ecology, agronomy, soil science and socio-economics to address fundamental issues of nutrient balances, agricultural productivity and the well being of the people, livestock and environment of sub-Saharan Africa.

The objectives of this conference were to:

- review the present state of knowledge on nutrient cycling in mixed crop–livestock systems
- identify research methodologies for investigating nutrient cycles in the plant/animal/soil interfaces of mixed farming systems
- identify future research priorities and integrated approaches for improving the role of livestock in the nutrient cycles of mixed farming systems.

Fifty-six national and international experts attended the conference. A total of 35 presentations from 18 countries reported on various livestock feeding and nutrient-cycling strategies in intensively and extensively managed mixed farming systems. The opening session provided an overview of the demographic and environmental changes and challenges facing sub-Saharan Africa today and the roles of livestock in mixed farming systems. Papers presented at the technical sessions addressed issues related to how animals acquire and utilise nutrients for their productivity, the fate of nutrients excreted by livestock, methods to improve nutrient capture and recycling and the social and economic processes that influence the availability of nutrient sources and flows in mixed farming systems. Issues related to resource management were examined at the field, farm, community and regional levels.

Volume I of the conference proceedings summarises the major discussions, findings and recommendations of the conference as gleaned from the rapporteur reports. The chairpersons provided guidance to the Plenary and Focus Group Sessions and the rapporteurs delivered comprehensive and punctual reports. Their efforts are gratefully acknowledged.

Programme

International Conference on Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa

International Livestock Centre for Africa (ILCA)
Addis Ababa, Ethiopia

22–26 November 1993

Monday 22 November

Opening Ceremony: Welcome addresses

Dr H A Fitzhugh, Director General, ILCA

Dr Awetahegn Alemayehu, His Excellency the Vice Minister,
Ministry of Agriculture, Ethiopia

Opening Session: Setting the scene

Chairperson: H A Fitzhugh Rapporteur: I Scoones

An overview of demographic and environmental issues in sustainable agriculture in sub-Saharan Africa.

M A Mohamed-Saleem and H A Fitzhugh*

An overview of mixed farming systems in sub-Saharan Africa.¹

J M Powell and T O Williams

Nutrient cycling and its importance in sustaining crop–livestock systems in sub-Saharan Africa: An overview.

P J Stangel

Technical Session I: Interactions between animals and plants

Chairperson: A A Agboola Rapporteur: P J Thorne

Animal/plant interactions: Nutrient acquisition and use by ruminants.

*J W Stuth, R K Lyons and U P Kreuter**

Relationship between nutrient content of the veld and production performance of the grazing ruminant in southern Africa.

C T Kadzere

Quantitative and qualitative estimation of nutrient intake and faecal excretion of zebu cattle grazing natural pasture in semi-arid Mali.

E Schlecht, F Mahler, M Sangaré, A Susenbeth and K Becker*

1. Not presented at conference but published in Vol. II of Proceedings.

Foraging behaviour of cattle grazing semi-arid rangelands in the Sahel of Mali

*L Diarra, * P Hiernaux and P N de Leeuw*

Feeding livestock for compost production: A strategy for sustainable upland agriculture on Java.

*J C Tanner, * S J Holden, M Winugroho, E Owen and M Gill*

Tuesday 23 November

Technical Session II: Interactions between animals and soils

Chairperson: M A Mohamed-Saleem Rapporteur: N Umunna

Manure as a key resource in sustainable agriculture.

K H Murwira, M J Swift and P G H Frost*

Faecal excretion by ruminants and manure availability for crop production in semi-arid West Africa.

*S Fernández-Rivera, * T O Williams, P Hiernaux and J M Powell*

Increasing the role of ruminant livestock in the maintenance of soil organic matter for sustainable production systems in southern Mali.**

*R Bosma, * M'Pie Bengaly and T Defoer*

Nitrogen intake and losses by sheep on *Medicago* spp and barley pastures in northern Syria.

*P White, A V Goodchild, * T T Treacher and J Ryan*

Carbon and potassium dynamics in grass/legume grazing systems in the Amazon.

*C E Castilla, * M A Ayarza and P A Sanchez*

Soil aspects of nutrient cycling in a manure application experiment in Niger.

J Brouwer and J M Powell*

Feed factors affecting nutrient excretions by ruminants and fate of nutrients when applied to soil.

*Z C Somda, * J M Powell, S Fernández-Rivera and J D Reed*

Technical Session III: Interactions between plants and soils

Chairperson: M J Swift Rapporteur: P J Stangel

Nutrient recycling in pasture, rangeland, fallow, and cut-and-carry feeding systems in SSA.

A A Agboola and A A Kintomo*

The role of forage legume fallows in supplying improved feed and recycling nitrogen in the subhumid zone of Nigeria.

G Tarawali and M A Mohamed-Saleem*

The benefits of forage legumes for livestock production and nutrient cycling in pasture and agropastoral systems of acid-soil savannahs of Latin America.

R J Thomas and C E Lascano*

Millet and cowpea in mixed farming systems of the Sahel: A review of strategies for increased productivity and sustainability.

*S V R Shetty, B R Ntare, A Bationo and C Renard**

A critical overview of crop residue use as soil amendment in the West African semi-arid tropics.

*A Bationo, A Buerkert, * M P Sedogo, B C Christianson and A U Mokwunye*

Nitrogen in dryland farming systems common in northwestern Syria.

*H Harris, J Ryan, * T T Treacher and A Matar*

The interactive effects of rainfall, nutrient supply and defoliation on herbage yields and quality of Sahelian rangelands in north-east Mali.

*P Hiernaux, * P N de Leeuw and L Diarra*

Wednesday 24 November

Technical Session IV: Nutrient cycling in mixed farming systems

Chairperson: C Renard

Rapporteur: P N de Leeuw

Socio-economic dimensions of nutrient cycling in agropastoral systems of dryland Africa.

I Scoones and C Toulmin*

Manure utilisation, drought cycles and herd dynamics in the Sahel: Implications for cropland productivity.

*T O Williams, * J M Powell and S Fernández-Rivera*

Nutrient flux between maize and livestock in a maize–coffee–livestock system in central Kenya.

*J K Ransom, * J Ojiem and F K Kanampiu*

Farmer and pastoralist strategies in Saurashtra, Gujarat: An analysis of landless pastoralism and dependence on the manure market.

*R P Cincotta and G Pangare**

The sustainability of rangeland to cropland nutrient transfer in semi-arid West Africa: Ecological and social dimensions neglected in the debate.

M Turner

Measuring the sustainability of crop–livestock systems in sub-Saharan Africa: Methods and data requirements.

S Ehui and M A Jabbar*

The role of livestock in sustainable agriculture and natural resource management.

J D Reed and J Burt*

Nutrient transfers from livestock in West African agricultural systems.

*P N de Leeuw, * L Reynolds and B Rey*

Technical Session V: Modelling nutrient cycles in plant/animal/soil systems

Chairperson: P N de Leeuw

Rapporteur: S Gavian

Modelling and simulation in the development of sustainable animal production systems.**

H Breman

Modelling the effects of livestock on nutrient flows in mixed crop–livestock systems.

P J Thorne

Myth and manure in nitrogen cycling: A case study of Kaloleni Division in Coast Province, Kenya.

*L Reynolds and P N de Leeuw**

A static model of nutrient flow on mixed farms in the highlands of western Kenya to explore the possible impact of improved management.

*K D Shepherd,** *E Ohlsson, J R Okalebo, J K Ndufa and S David*

African semi-arid agriculture cannot produce sustainable growth without external inputs.

*J McIntire and J M Powell**

Thursday 25 November

Group meetings

Group I: Animal–plant interactions

Chairperson: I Scoones Rapporteur: U P Kreuter

Group II: Animal–soil interactions

Chairperson: H Breman Rapporteur: K D Shepherd

Group III: Socio-economic dimensions in nutrient cycling research

Chairperson: T O Williams Rapporteur: M Turner

Field trip to ILCA Research Station at Debre Zeit

Friday 26 November

Group meetings

Closing Session

Chairperson: J M Powell Rapporteur: S Fernández-Rivera

Group reports

Concluding remarks

* Presenter

** French paper

Summary of the Plenary Sessions

Opening Session

Chairperson: H A Fitzhugh

Rapporteur: I Scoones

The challenges to the environment and agricultural productivity set by projected increases in population growth in sub-Saharan Africa are immense. The opening session provided a broad context for discussing the role of livestock in sustaining agricultural productivity. Cattle, sheep and goats contribute directly to household food needs and income and the gross domestic product. They also provide manure that sustains crop yields. The great demand on agriculture to produce more food and feed requires innovations that increase the efficiency of nutrient management. Given the current prohibitive costs of supplying external inputs such as fertilisers to crop and livestock producers, identifying the major points of nutrient loss and approaches for improving nutrient cycling are urgently needed.

The complementarity between crops and livestock, such as the use of crop residues for animal feed and animal traction and manure for crop production, make mixed farming attractive to producers. The degree of crop–livestock integration in farming systems and pathways to intensification are diverse and depend on an array of biophysical and socio-economic factors. These factors are mediated by the resources available and management practices of farmers. Appropriate technologies suited to the resources available to farmers continue to be needed as well as policies that provide incentives for more efficient resource use.

The session highlighted the variability in nutrient cycling patterns across sub-Saharan Africa. Differences occur across agro-ecological zones, among different livestock species and crop combinations, among different groups of farmers and over time, both between years and seasons. Research and development efforts to improve food production need to recognise the diversity of mixed farming systems and the potential for improving crop and livestock production within each system. Participatory research approaches involving appropriate scientific disciplines, policy makers and farmers are needed for developing ecologically sound, economically viable and socially acceptable technologies that improve nutrient cycling and enhance agricultural productivity.

Policy issues identified for further discussion

- The effect of property rights on resource management: Secure rights to land, whether under communal or private regimes, are required for long-term resource management.
- Economic incentives (e.g. subsidies) and policies that encourage well-functioning input and output markets can have a strong impact on the choices farmers make between alternative crop, livestock and nutrient management strategies.
- The role of focused interventions in providing incentives for sustainable management, either through reducing negative externalities or by encouraging resource-conserving practices.

Technical Session I: Interactions between animals and plants

Chairperson: A A Agboola

Rapporteur: P J Thorne

This session focused on factors governing nutrient acquisition and use by ruminants and the passage of nutrients in manure and urine. Two papers addressed nutrient harvesting by cattle from rangelands. Three papers extended this scope to include the effects of rangeland productivity, the nutritional status of the animal and diet supplementation on nutrient intake and excrement by grazing cattle. One paper

examined sheep feeding and composting strategies of intensively managed mixed farming enterprises in Indonesia.

It is clear that nutrient intake by livestock and its management by farmers can greatly affect nutrient cycling. A variety of research methods are available for estimating nutrient intake, yet the extent to which these capture the inherent variability of feed resources and the selective foraging behaviour of animals is limited. Approaches that encompass the seasonal and spatial variability in feed resources and animal foraging behaviour are needed if the wider consequences of nutrient intake and cycling through the system as a whole are to be addressed reliably.

The significance of “nutrient mining” in mixed farming systems is not well understood. A number of participants expressed the view that certain practices, such as the channelling of nutrients from one location to another when livestock graze rangeland and their manure is deposited on cropland, have long-term detrimental effects on mixed farming systems. Others, however, indicated that such practices may not necessarily be detrimental. It has been estimated that the cut-and-carry system in Indonesia which uses forages from field boundaries, roadsides etc has been operating for up to 200 years and a paper from Mali suggested that nutrient inputs and outputs were balanced for the rangeland studied. Where such nutrient equilibrium is found, there is a need to understand the internal checks and balances before embarking on research to improve them. In the absence of reliable information, it would be dangerous to assume that such examples of nutrient balances are widespread in sub-Saharan Africa.

Other issues arising from the presentations and discussions

- Relative terms such as “overgrazing” and “well-fed” can lead to confusion.
- The extent to which on-station trials reflect on-farm situations needs careful consideration. Assumptions based on improved breeds etc may be useful conceptually but require re-evaluation before being used to make quantitative predictions under sub-Saharan African conditions.
- Feeding interventions aimed at the manipulation of excreta or compost quality need to be considered in relation to animal production, labour availability and other constraints.
- Nutrient balance studies should be treated with care as they may not always identify the real inputs and outputs.

Technical Session II: Interactions between animals and soils

Chairperson: M A Mohamed-Saleem

Rapporteur: N Umunna

Most soils in sub-Saharan Africa are inherently infertile and require amendments in order to sustain crop yields. Fertilisers are costly and unavailable to most farmers. Since livestock are an integral part of many farming systems, the manure they produce, when applied to the soil, constitutes a low cost nutrient source that sustains the yields of many cultivated areas.

The potential fertiliser value of manure is dependent on a number of critical factors such as total nutrient content, which depends on fodder quality, manure storage practices and application strategies, and the mineralisation rates of manure-bound nutrients into inorganic forms for plant uptake. Since nutrient mineralisation and losses are highly influenced by manure handling, storage and land application techniques, improved animal manure and soil management practices that capture and recycle more nutrients could increase both crop and livestock productivity.

Highlights of the presentations and discussions

- In semi-arid environments, great seasonal and annual fluctuations in feed availability and quality affect the types and numbers of livestock farmers keep, manure availability and quality, and the impact of manure on crop production.
- Feed-quality factors such as nitrogen, cell-wall contents, lignin and polyphenols influence the amount and forms of nutrient excretion by ruminants and their fate when applied to soils.
- Applying both manure and urine to soils increases crop productivity more than applying either alone. Management practices such as corralling livestock on cropland return both manure and urine to soils and should be promoted.
- High rates of manure application on sandy soils cause leaching of organic carbon, nitrogen and phosphorus. The application of small amounts of manure regularly would be more efficient than the infrequent application of large doses.
- In the Amazon region of South America, soil bulk density increased with increasing stocking rate and decreased with decreasing stocking rate. This indicated that soil compaction due to trampling by cattle was reversible. Earthworm populations and activities in the upper soil profile appear to be better indicators of overgrazing than either chemical or physical soil properties.

Technical Session III: Interactions between plants and soils

Chairperson: M J Swift

Rapporteur: P J Stangel

This session addressed research issues pertaining to a variety of plant–soil interactions in the humid, subhumid, semi-arid and arid zones of sub-Saharan Africa, the semi-arid region of Syria, and the subhumid zone of Latin America. Various agronomic aspects of intercropping forage and food legumes with cereal crops were examined including the effects of legumes on forage quantity and quality, animal performance and soil fertility. Nutrient-management strategies for rangelands in the Sahel, and nutrient-cycling models for six distinct urban and rural situations prevailing in sub-Saharan Africa were presented.

Highlights of the presentations and discussions

- Poor soil fertility and low use of organic and inorganic fertilisers are the greatest constraints to agricultural productivity in the West African semi-arid tropics. Long-term application of fertiliser alone can adversely affect soil base saturation and pH and create aluminum toxicity leading to reductions in crop yields. These problems can be corrected through the efficient recycling of organic materials in combination with chemical fertilisers and by rotating nitrogen-fixing plants with cereal crops. Information is needed for the predominant soils, climate and mixed farming systems of sub-Saharan Africa on the long-term feasibility and economic benefits of using crop residues and animal manures to build soil organic matter reserves. It is also needed on the effect of the timing of organic matter application to soils and on mineralisation and nutrient release.
- Considerable debate prevails regarding the best use of crop residues. A review paper in this session indicated that cereal stovers must be applied to the barren soils of the Sahel to avoid severe erosion. However, the current strategy of farmers is to feed cereal stovers to animals and apply manure to the soil. The competition between livestock and soils for cereal stovers and other crop residues needs to be assessed in terms of the long-term trade-offs in plant, animal and soil productivity.
- *Stylosanthes*/grass mixtures containing 40–60% legume, if intensively managed, and 10–30% legume if extensively managed perform well on acid soils in the subhumid tropics and fix enough nitrogen to sustain the production of associated grasses. *Stylosanthes*/grass mixtures

also provide significant amounts of residual nitrogen for cereals such as acid tolerant rice varieties, maize and millet that follow in rotation. Livestock grazing *Stylosanthes*-based pastures produce more milk, lose less weight and have shorter calving intervals and greater calf survival compared with animals grazing natural pastures.

- Rangelands and degraded soils need to be reclaimed in the Sahel where pastures provide vital seasonal feed for livestock belonging to pastoralists and agropastoralists. Forage legumes are, however, less well suited to this ecological zone. In the Sahel, cowpeas are the predominant grain legume and the hay is used as feed. Strip rows of millet and *Stylosanthes* show promise as a food/forage cropping system in the Sahel and *Medicago* is considered a promising legume for the dry regions of Northern Africa–Western Asia.

Technical Session IV: Nutrient cycling in mixed farming systems

Chairperson: C Renard

Rapporteur: P N de Leeuw

This session encompassed nutrient cycling in such diverse mixed farming systems as the extensively managed low input millet systems of the Sahel to the intensive, high input maize–coffee–milk production systems in the highlands of Kenya. At the extensive end of this continuum, increasing aridity and drought and population pressures are transforming the types and numbers of livestock kept by farmers which in turn affects manure outputs and crop yields.

As human and animal population densities increase, more intensive methods of crop and animal management are adopted. Manure accumulated in corrals is spread on cropland and animal-powered transport is used for hauling feed to the homestead and manure and other nutrient sources (leaf litter from savannah land and soils from termite mounds) to cropland. Intensive dairying provides cash for purchasing fertiliser that, when combined with manure, sustains high maize yields.

The biological processes that regulate nutrient flows in mixed farming systems are mediated mainly by socio-economic factors. The manure supply is affected by factors such as herd size, grazing rights to communal rangeland and access to manure exchange contracts with mobile herders. Most aspects of intensified manure management depend on available labour to collect, process, transport and spread manure on cropland and cash to build corrals and to purchase animals and carts for transport. Viable returns from these investments depend on market prices and adequate infrastructure to ensure delivery of inputs and marketing of farm produce.

Two complementary scenarios for improving nutrient cycling were envisaged. One is based on improving the efficiency of nutrient cycling by mobilising resources internal to the farming system such as better manure management, legume fallows and soil conservation practices. The other consists of a greater reliance on external resources such as inorganic fertilisers, mechanised cropping and small-scale irrigation. Both scenarios may converge when population density increases the value of land, making investments in soil conservation and fertility maintenance profitable. This process of intensification is further accelerated by better access to markets and greater inflows of non-farm income.

Other issues presented and discussed

- Various aspects of soil fertility management including the reliance of many mixed farming systems on nutrient transfers from rangelands to croplands were discussed. It was generally agreed that when nutrient outflows continuously exceed inflows, reductions in rangeland and livestock production and manure output (and crop production) occur.
- A methodology was proposed for measuring the ecological sustainability and economic viability of crop and livestock production in mixed farming systems by assessing intertemporal and interspatial total-factor productivity. This approach evaluates and quantifies changes in

stocks and flows of soil nutrients and the effect of material inputs and outputs on the productivity of different farming systems.

- At the local level, more efficient nutrient management could be promoted as an integral part of community-based resource management of small watersheds using the “farmer-back-to-farmer” approach of participatory research.

Technical Session V: Modelling nutrient cycles

Chairperson: P N de Leeuw

Rapporteur: S Gavian

This session presented various techniques for modelling nutrient cycles in mixed farming systems. The basic question behind most of the models is how plants, animals and soils can be managed to replenish nutrient losses from cropland. Based on technical parameters borrowed from production systems in Europe, the Sahel and Kenya, the models estimated the nitrogen input/output relationships between livestock, trees and crops by tracing the movement of organic materials within various components of the mixed farming systems.

While most models tried to simulate the complexity of mixed farming systems, each emphasised a slightly different component. Included are the effects of animal diet on nutrient excretion by livestock, of various animal-management practices on the accessibility of these nutrients for recycling, and of agroforestry on soil-nutrient stocks and degradation. In addition to simulating the effects of various input combinations on the soil nutrient status, the models also predict the productivity of croplands and the amount of range required to support the number of livestock needed for obtaining adequate manure. Models can be used to assess the financial returns to various combinations of physical and biological inputs, and thus farmer incentives to adopt alternative crop, animal and soil-management practices.

The usefulness of modelling

Models are useful for simulating the effects of different climatic, economic and technical conditions on crop and livestock productivity in instances where actual data may not be available. The models presented in this session simulated nutrient flows as affected by boundary plantings of trees, hedgerow intercropping, zero grazing, and chemical fertilisers. A bio-economic model incorporated major components of crop–livestock production activities with differing price scenarios to predict the level of external inputs that might be needed to support sustainable agricultural production in the Sahel.

Although models can be effective tools for understanding complex interactions among various system components and for educating decision makers, many are poorly suited to the highly site-specific needs of farmers.

Closing Session

Chairperson: J M Powell

Rapporteur: S Fernández-Rivera

The reports from the Focus Group Sessions were presented in this session.

Plant–animal interactions

Insufficient supply of feeds for livestock and low returns from the use of soil fertility amendments were identified as the main problems facing nutrient cycling in many mixed farming systems. The research goals included the development of technologies that improve the management of natural vegetation and forage reserves and the nutritive quality of feeds, the fate of nutrients consumed by livestock and the reduction of nutrient losses from manure and urine. Applied and strategic research on issues related to vegetation dynamics and feed availability from natural pastures as well as site-specific research on resource management were also suggested.

Animal–soil interactions

The problem identified by this group was the declining productivity of both cropland and rangeland caused primarily by inappropriate resource use and management. The research goal for this theme was to devise resource-management strategies to increase the efficiency of internal and external nutrient inputs and to guide policy makers on long-term strategies for sustainable nutrient cycling. Research should quantify nutrient flows, processes and balances and develop models that predict the trends of existing and improved production systems.

Social and economic dimensions of nutrient cycling

The main problems identified were low agricultural productivity, poor communication among farmers, researchers and policy makers, inappropriate policies and lack of focus on agriculture by governments. Socio-economic research needs to address ways to alleviate impediments to a wider distribution and use of agricultural inputs and how markets can be developed to assure farm profitability. Applied and adaptive research techniques such as rapid rural appraisal and the use of indigenous knowledge are needed to involve the farmer in the research process. Dynamic models, nutrient budget analyses and geographic information systems (GIS) are valuable tools for determining specific local/regional nutrient demands and aggregating local-level studies to a regional scale. This aggregation is needed in order to present a more global picture and bring the magnitude of nutrient imbalance (which at the village level may appear insignificant) to the attention of policy makers.

Key discussions during the closing session

- Some participants felt that strategic issues of nutrient-cycling research were neglected by the focus groups. Others were more optimistic arguing that researchable issues and approaches were identified from a multidisciplinary perspective, including policy.
- The benefits of integrated approaches to nutrient-cycling research involving farmers, interdisciplinary teams of scientists and policy makers were stressed. The wide range of participant expertise and the fruitful discussions and recommendations of this conference attested to the necessity of such research approaches.
- Papers and discussions during the conference highlighted the importance of livestock nutrition and management in the movement of nutrients in mixed farming systems.
- There is a need for research on the combined use of organic and inorganic sources of nutrients, the flows of nutrients from rural to urban areas as well as at regional and intercontinental scale.
- It was argued that general models have failed to predict local or specific situations and it was suggested that site-specific research is needed.

At the end of the session, participants proposed the formation of a network or association of scientists interested in nutrient cycling. Some participants suggested that the various existing opportunities should be utilised more fully for forging professional collaboration and communicating the recommendations of this conference to others. It was recommended that a conference summary be written and transmitted expeditiously to other colleagues, institutions, policy makers and donors.

Summary of Focus Group Sessions

Introduction

This conference brought together a variety of scientific and technical expertise in nutrient cycling research from many parts of sub-Saharan Africa and other regions of the world. The Focus Group Sessions provided an ideal occasion for participants to share their diverse perspectives on how best to improve the role of livestock in nutrient cycling for various types of mixed farming systems.

The goal of these sessions was to identify key research issues, constraints, goals, approaches and indicators in nutrient cycling research for the mixed farming systems of sub-Saharan Africa.

Conference participants were divided into three multidisciplinary groups from different geographic regions corresponding to three research areas:

- Animal–plant interactions
- Animal–soil interactions
- Socio-economic dimensions in nutrient cycling.

A workbook was developed to guide participants through three tasks:

Task I: List and prioritise the issues and constraints that research should address and define research goals.

Task II: Identify relevant research approaches, the most appropriate type(s) of research to accomplish research goals and identify gaps in available research methodologies.

Task III: Identify indicators for monitoring the attainment of goals.

Approximately six hours were devoted to the Focus Group Sessions. The tasks and expectations of the sessions were presented and discussed for a half hour at the end of the second day of the conference. An array of issues, constraints, goals and possible approaches in nutrient cycling research was gleaned from the compilation of conference abstracts and used as examples during this preparatory session.

It was no doubt difficult to accomplish the ambitious goals of the sessions in such a short time. The guidance and recordings of the chairpersons and rapporteurs is gratefully acknowledged. The following summary shows that the groups rose well to their challenges and took different paths to accomplish their goals. As expected, there was considerable overlap among the research issues and approaches that were identified by the three groups. This attests to the fact that nutrient cycles of mixed farming systems involve great interaction among biological, social and economic components.

Group I: Animal–plant interactions

Chairperson: I Scoones

Rapporteur: U P Kreuter

Research imperatives were established and used as a framework for identifying research issues and constraints and defining research goals and approaches:

- Research must focus on nutrient losses and gains in the production system.
- Research must emphasise ecological and sociological issues related to the use and conservation of the natural resource base.

- Research must be directed by the potential adoptability of findings in terms of meeting producer requirements and values.

Research issues and constraints

Issue I: Insufficient feed of high quality, a situation that is growing worse for many mixed farming systems.

Constraint: Animal numbers are excessive and/or forage yield and quality is decreasing due to the depletion of soil nutrients through the removal of animal and crop products without adequate nutrient replenishment.

Issue II: Returns to investments in research aimed at enhancing soil productivity in sub-Saharan Africa have frequently been low or negative.

Constraint: Technologies that improve forage productivity and nutrient cycling are not being applied in many areas, either because they are not applicable to local biophysical conditions and/or management constraints have not been adequately addressed.

Other research issues that were identified

- Exploit the synergisms between fertilisers, legumes and other soil amendments.
- Regional assessment of nutrient flows such as nutrient export from farm to urban areas in the form of produce.
- Policies and effective extension tools that facilitate the adoption of sustainable technologies that provide long-term gains in agricultural productivity.

Research goals and approaches

Goal I: Increase feed supply and quality

Greater animal numbers can be supported in areas where natural pastures are underexploited, especially in the more humid areas of sub-Saharan Africa where trypanosomiasis risks are low. In areas of feed shortages, additional forages and diet supplements must be provided to support existing and any future increases in animal numbers. Inadequate feed and nutrient supplies in many mixed farming systems is due to large spatial and seasonal variabilities in feed resources.

An understanding of area-specific natural resource management practices and the key factors that influence farmers' adoption of alternative practices is critical to the design of research that targets long-term gains in forage productivity. The effective dissemination of research results also requires links between research and local resource management groups at the community level and with the efforts of non-government organisations and extension services.

Approaches

- Implement strategic research and monitoring to determine site-specific vegetation dynamics linked to forage management.
- Use farming systems research techniques to capture farmers' knowledge and practices relevant to the animal–plant interface, especially with respect to local knowledge of landscapes, natural-resource use and livestock management.
- Develop systems that monitor, over time, the feed supply and demand by livestock and feed allocation to specific components (e.g. cows, oxen and small ruminants) of the livestock subsystem.
- Evaluate animal response to vegetation characteristics, determine influence of management on foraging behaviour and nutrient deposition and develop management practices that optimise nutrient retrieval from natural vegetation.

- Strategically supplement animal diets with nutrients that limit animal production.
- Assess the productivity and nutrient value of new feeds.
- Introduce improved plant types into existing grasslands to enhance forage production and soil fertility.
- Improve indigenous animal breeds for increased efficiency of nutrient use.

Goal II: Minimise nutrient losses from dung and urine

The limited availability of nutrient resources in mixed farming systems requires their efficient use. The relative returns of nutrients from manure and urine are not well known. There is also insufficient information on:

- the effects of animal diet and watering regimes on nutrient retention by animals
- partitioning of excreted nutrients into manure and urine
- the fate of excreted nutrients in the mixed farming system as a whole.

Such information is required to quantify the impact of current and alternative animal-, plant- and soil-management practices on nutrient cycling and long-term agricultural productivity.

Approaches

- Assess farmers' perceptions and practices and local research and extension information related to nutrient cycling.
- Determine the types and amounts of nutrient inputs and outputs and develop integrated models that explain nutrient partitioning in animal and plant components on a year-long basis.
- Assess trade-offs between feeding biomass (nutrients) to livestock versus alternative uses (e.g. soil-fertility amendment, building material and fuel).
- Assess the effects of animal diet on the fertiliser value of manure and evaluate how alternative feeding strategies affect animal productivity and nutrient cycling.
- Conduct site-specific experimentation with treatments (manure, straw, bedding materials, pit storage, corralling and tethering systems, anaerobic and aerobic conditions and other local and imported nutrient sources) chosen according to local conditions.

Indicators

- Quantifiable reduction in nutrient loss
- Long-term increases in forage productivity
- Improved manure quantity and quality for recycling
- Increased dissemination of information on forage production to clients (producers, extension services etc)
- Use of research outputs by researchers, farmers, community institutions, non-government organisations working in rural communities in collaboration with national agricultural research and extension services.

Group II: Animal–soil interactions

Chairperson: H Breman

Rapporteur: K D Shepherd

The causes and effects of soil degradation are often interdependent. Research to improve nutrient cycling in mixed farming systems must, therefore, identify and target the key mechanisms that mediate nutrient flow between animals and soils. The key nutrient-cycling processes need to be identified and understood not only from a biophysical point of view, but also from the view of farmers, consumers and decision makers.

Issue I: Declining productivity of rangeland and arable land and, therefore, animal and crop production.

Constraints

- Unbalanced flow of biomass and nutrients caused by people and animals at the farm, community and regional levels.
- Degradation of soil structure, leading to decreased water and nutrient availability for plants.
- Short-term vision and/or awareness of farmers themselves and of policy makers who fail to create either positive incentives for appropriate resource use or negative incentives for misuse.
- Lack of interchange between farmers, scientists, and policy makers.

Soil degradation and declining crop and animal productivity are due to an excessive removal of biomass and nutrients from the land. This leads to soil erosion, an exhaustion of soil organic-matter content, nutrient leaching, and the disappearance of perennial species from natural pastures. For extensively managed mixed farming systems the problems and their causes change in relation to the pressure on natural resources and access to external inputs.

The integration of crops and livestock in mixed farming systems can extend the possibility of soil degradation beyond cropland to rangeland, fallow land and waste land. As more intensive modes of crop and livestock production are initially adopted, natural resources can be overexploited. Livestock can speed-up organic matter and nutrient cycling thereby increasing the possibility of nutrient loss. Incentives for conservative resource use do not exist in many mixed farming systems.

Goal I: Devise resource-management strategies that efficiently use internal and external nutrient inputs.

Approaches

- Initial diagnosis of farm, local, regional and national impediments to more efficient nutrient cycling is needed. Farmers, consumers and policy makers often have different points of view on how to manage natural resources for more sustainable agricultural production. Diagnosis should quantify nutrient flows, processes and balances for key farming systems.
- Provision of external nutrient sources is necessary where nutrient harvests in grain, forages and other losses are greater than nutrient returns by farmers and the natural nutrient-recharge capacity. Fertiliser use will not, however, be profitable in all mixed farming systems. Fertiliser costs for systems with inherently low biological production potential are likely to exceed the benefits in terms of increased crop and livestock output. Fertiliser use will be most profitable in mixed farming systems with high production potential and where there are well developed markets for the purchase of inputs and the sale of produce.
- Modelling. The long-term implications of existing and improved nutrient-management strategies have to be evaluated and compared. Both *ex ante* and *ex post* evaluations of the impact of intervention on animal and plant productivity and soil quality at field, farm and regional scales are needed. Models should answer such questions as where external inputs can be most economically applied within the system (e.g. to the crop or animal component, food or cash crop and rangeland or cropland).
- Reducing nutrient losses via leaching, run-off and volatilisation etc can enhance the profitability of using external nutrient sources. The timing and placement of nutrients, effects of nutrient application on soil properties and whether water or nutrients are more limiting to plant growth are but a few research areas where information is lacking. The use of deep-rooting perennials and woody species to enhance nutrient cycling needs further evaluation. Recommendations aimed at enhancing nutrient cycling must account for the costs and alternative uses of external inputs, and the interactive effects of organic and inorganic nutrient use on animal and soil productivity.

Goal II: Guide policy makers on long-term strategies for sustainable nutrient cycling.

Approaches

- Improve communications. The decision-making processes and behaviour of farmers in relation to their agro-ecological and socio-economic context needs to be understood by researchers and policy makers. Researchers need to conduct targeted economic studies at the household, community, national and international levels to provide pertinent information to farmers and policy makers on appropriate practices that enhance productivity while conserving natural resources.
- Policy initiatives. Lack of awareness or knowledge at the level of farmers, policy makers or the population as a whole requires new initiatives in education, extension, public awareness etc. Legislation that creates positive incentives can be effective in mitigating overexploitation of natural resources and degradation.
- Population pressures on the environment can be relieved by migration and by the creation of alternative employment. However, migration from overexploited areas is not a viable alternative in most areas of sub-Saharan Africa as there are limited employment opportunities outside agriculture. For many regions, the provision of fertiliser is unavoidable if sustainable crop and livestock production is to be achieved and natural resources are to be conserved.

Indicators

- Soil-quality parameters such as improved soil structure, organic matter and nutrient content, base saturation, pH and positive changes in available nutrients in relation to available water
- Balanced nutrient budgets for major farming systems
- Increased farmer income.

Group III: Socio-economic dimensions in nutrient cycling

Chairperson: T O Williams

Rapporteur: M Turner

Overall goal

Improve the welfare of rural people by increasing the availability and distribution of agronomically important nutrients that are needed to ensure adequate food production and income.

Research issues and constraints

Issue I: Low agricultural productivity

Constraints

- Inherently low soil fertility
- Inadequate use of soil-nutrient amendments
- Inefficient nutrient cycling
- Inability of farmers to take remedial action due to lack of secure land tenure, lack of access to inputs and information to effectively use inputs and lack of appropriate technologies for integrated use of indigenous and external inputs.

Constraints to more effective nutrient cycling can be grouped into the factors of production and incentives that affect the investments of capital and labour that are often required to improve soil-fertility management. These factors of production include:

- lack of capital due to low rural incomes
- labour shortages preventing timely application of nutrients
- lack of livestock and manure

- inadequate fodder for livestock
- agro-ecological constraints which limit the range of crops that can be grown
- inadequate skills/knowledge on combining manure and fertilisers
- market and infrastructure constraints that inhibit timely supply of fertilisers
- lack of adequate extension services to advise on methods of fertiliser use
- lack of plant responsiveness to nutrients.

Issue II: Inappropriate policies and lack of government focus on agriculture

Constraints

- Poor infrastructure at farm and regional level (e.g. lack of markets and transportation)
- Lack of income and credit to purchase inputs
- Lack of market information to make decisions on nutrient use
- Inappropriate input and output prices.

Issue III: Poor communication among farmers, researchers and policy makers

Communication problems can be major impediments to efficient nutrient cycling and increased agricultural productivity. The causes of poor communication are not so much due to disinterest on the part of farmers, researchers and policy makers but a result of institutional constraints.

Constraints to communication between researcher and farmer

- The researcher does not fully understand either the goals or the agronomic and animal husbandry problems of the farmer.
- Demands of experimental design versus farmers’ practices often differ. Agronomists attempt to reduce variability and the number of independent variables in their experiments. The resulting experimental conditions can diverge greatly from the on-farm situation.
- Disregard of the variation in farmers’ practices and the validity of “indigenous knowledge”.
- The demands of a researcher’s discipline for scientific rigour may require more detailed scrutiny (time and equipment) than may be needed to respond to the problems of the farmer.
- Researcher’s perception of risk may be different from that of the farmer.

Constraints to communication between policy maker and researcher

- Researchers have difficulty conveying or showing clearly the impact of research investment.
- Inability of policy makers to use research results and therefore, lack of appreciation of research by policy makers.
- Researcher’s inability to indicate the range of variation and uncertainty of results. This can be viewed as a credibility problem in that researcher predictions often do not come to pass.
- Researchers are unable to conceptualise problems of national importance (e.g. socio-economic researchers doing village-based studies without conceptual or practical linkages to the priorities of national policy).

There are few communication pathways between researcher and policy maker.

Research goals and approaches

Goal I: Improve the efficient utilisation of indigenous and external nutrient sources.

Approaches

- Utilise dynamic models, nutrient budget analyses, and GIS techniques to identify “pressure points” or stressed areas from a nutrient cycling perspective.

- Use conceptual models to aggregate local level socio-economic studies to a regional scale.
- Understand farmers' perceptions of soil fertility by using a hybrid of social, anthropological, economic and agronomic studies of indigenous nutrient cycling practices.
- Determine the possibility of introducing fertiliser responsive crops and/or crops with high input/output price ratios in cases where the price of existing crop is too low to justify fertiliser expenditure.
- Conduct research on appropriate combinations of manure, residue, and fertiliser applications for specified localities.
- Decrease risk aversion associated with nutrient uses (e.g. crop burning at high application rates).

Goal II: Improve access to nutrient supply

Approaches

- Conduct studies to identify why markets are unable to provide fertilisers.
- Solve problems that impede the proper functioning of markets.
- Examine policy issues as they affect input demand and supply.
- Understand how social relations condition resource exchange and access (e.g. farmer–pastoralist relations).
- Create information-management systems to monitor nutrient-exchange relationships at the farm level.

Goal III: Improve the efficient use of labour in nutrient cycling

Approaches

- Improve the control over benefits of labour investment (e.g. land tenure security).
- Improve labour returns to fertiliser use through appropriate pricing incentives.

Goal IV: Improve communications

Approaches: Farmer and researcher communications

- Use a bottom-up demand-driven approach to problem identification.
- Conduct on-farm trials to improve researcher and farmer communication.
- Resolve conflicting goals of farmers and researchers (e.g. with respect to the relative importance each group attaches to soil fertility maintenance issues *vis-à-vis* the goals of animal and crop husbandry).
- Improve institutional organisation of extension services to make them more effective.
- Identify approaches to institutionalise participatory research approaches that include farmers, researchers and technology transfer agents in all phases of research.

Approaches: Policy maker and researcher communications

- Include researchers in policy-making units.
- Engage scientists to act as liaison officers between researchers and policy makers.
- Put local and regional issues into a national perspective.
- Use information management units for disseminating scientific findings and minimising the confusion and other problems caused by multiple lines of communication.

Indicators

- Favourable benefit: cost ratios arising from the use of indigenous and external nutrient sources. To obtain meaningful ratios, a monitoring network may be needed to collect information on

input and output prices, barter exchanges, increases in crop and livestock productivity and their impact on the environment.

- Farmer uptake of technologies that enhance nutrient cycling.
- An efficient and equitable distribution of nutrients to producers.
- Increased funding of nutrient-cycling research (signifies a greater recognition of its importance by policy makers).

Appendix I: Abstracts

An overview of demographic and environmental issues in sustainable agriculture in sub-Saharan Africa

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Ever-increasing human population and urbanisation are intensifying the demand for agricultural commodities in sub-Saharan Africa (SSA). As a result, the traditional balance between people, their habitat and socio-economic systems is fast disappearing. Excessive deforestation, land clearing and cultivation are occurring in an attempt to meet rising food demands. Land degradation and pollution threaten sustainable increases in agricultural productivity and endanger the survival of present and future generations. Changes in agricultural production are needed soon in sub-Saharan Africa to avert large-scale human suffering. Despite the rapidly growing population and enormous production constraints, SSA can become agriculturally self sufficient. This will require imaginative food production techniques and management approaches that protect the environment at unprecedented scales. These changes can only be realised through changes in political will and national attitudes.

An overview of mixed farming systems in sub-Saharan Africa

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Mixed farming systems, involving complementary interactions between crops and livestock such as using animal traction and manure for cropping and feeding crop residues to livestock, are increasing in importance in sub-Saharan Africa (SSA). Traditional specialised production systems of shifting cultivation and nomadism are being replaced by more sedentary forms of crop and livestock production that involve permanent cultivation and reduced grazing. The full integration of crop and livestock production into the same unit is an evolutionary process mediated principally by regional differences in climate, population densities, disease, economic opportunities and cultural preferences. Mixed farming is well developed in the highlands of SSA and poorly developed in the humid zone, due to pests and diseases, and in the arid zone, due to lack of cropping. The greatest potential opportunity for increasing agricultural productivity exists through mixed farming in the subhumid and wetter parts of the semi-arid zone of SSA. This paper provides an overview of mixed farming systems in SSA by first examining their evolution and current distribution by agro-ecological zone. It examines socio-economic constraints to crop–livestock integration, animal feed issues and the use of animal manure in intensively and extensively managed mixed farming systems and ends with a synopsis of strategies for attaining sustainable improvements in crop and livestock production.

Nutrient cycling and its importance in sustaining crop–livestock systems in sub-Saharan Africa: An overview

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Nutrient cycling in crop–livestock systems requires major improvements before it is considered sustainable under sub-Saharan conditions. This is due in part to the inherent low fertility of the soils within the region. However, the major impediments are the intense levels of soil erosion and the common practice of diverting large amounts of crop residue and animal manure to non-farm uses (e.g. energy and building materials) rather than returning them to the soil. In addition, significant quantities of nutrients are lost due to leaching, volatilisation and off-farm transit of grains, meat and livestock by-products. Preliminary estimates of net losses of nutrients annually from all sources average 49 kg/ha per year or 9.3 million t/yr of nutrients for the entire region. This is four times as high as the average use of fertiliser in sub-Saharan Africa and one-half the world rate of use. A strategy to reduce nutrient losses by at least one-half and build soil fertility to improve nutrient cycling in crop–livestock systems is advanced in this paper. This includes the creation of pilot areas to verify and adapt already known research findings to local conditions. The specific areas include establishment of soil fertility reserves, creation of agricultural input centres, establishment of agroforestry zones and development of land-use centres. Research areas identified deal with nutrient balance studies, finding ways to increase soil organic matter in agricultural soils to levels attained under native conditions, and examining ways to reduce nutrient losses in crop–livestock systems. Also considered is an assessment of the impact of landless livestock enterprises on the environment in and around urban areas.

Animal/plant interactions: Nutrient acquisition and use by ruminants

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Nutrient intake constitutes the interface between animals and plants within the soil–water–atmosphere–plant–animal–human (SWAPAH) continuum. This interface also represents a major impact point of human management decisions affecting the animal’s well being, ecosystem productivity for human endeavours, biodiversity of plants and animals, nutrient cycling, water quality/yield and soil stability. The hierarchical nature of herbivore diet selection processes and associated physiological needs, relative to the spatial configuration of natural and man-made landscape features, sets limits regarding where animals harvest nutrients and how effectively nutrients are ingested, absorbed and recycled in the ecosystem. The selected mix of animal species and their dietary requirements, relative to the available diversity of plant species, determines how efficiently nutrients are acquired at the landscape level. The nutritional balance of the grazing ruminant is determined by a complex set of factors regulating dry-matter intake, diet quality/composition, and nutrient requirements for critical animal physiological processes. To understand the factors influencing dry-matter intake requires knowledge of a species’ sex/age class and breed attributes, physiological stage, effects of terrain on foraging energetics, environmental conditions (temperature, wind, mud/snow), forage quality/availability, and use of supplemental feeds, minerals, hormones and ionophores. The amount of nutrients harvested relative to the animal’s requirements determines the potential of the animal to convert critical nutrients, particularly crude protein and energy, for weight gain, milk production, reproductive performance and offspring performance. This paper presents a “whole-animal-system” perspective of nutrient acquisition in the context of the SWAPAH continuum. Emerging nutritional decision support systems and faecal near-infrared reflectance spectroscopy (NIRS) monitoring technologies are emphasised.

Relationship between nutrient content of the veld and productive performance of the grazing ruminant in southern Africa

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Over 75% of the cattle, sheep and goat population in southern Africa are kept under smallholder farming conditions. The nutritional base for these livestock and for those under commercial ranching systems is the natural pasture. This nutrient base is subject to seasonal nutrient fluctuations which have direct and indirect influences on the productivity of the grazing ruminant. The paper reviews the relationship between the nutrient content of the veld and its implications on the productivity of ruminant livestock.

Quantitative and qualitative estimation of nutrient intake and faecal excretion of zebu cattle grazing natural pasture in semi-arid Mali

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From 1988 to 1992, 30 zebu bulls and 8 oesophageally-fistulated oxen, initially weighing between 150 and 200 kg, were grazed on natural pastures in central Mali. During dry seasons, 15 bulls and 4 oxen were supplemented with local crop by-products. Based on *in vitro* digestibilities of extrusa samples from four oxen in each treatment group, and on estimations of total faecal excretion, the intake of organic matter (IOM), nitrogen (IN) and metabolisable energy (IME) were calculated. Retention of body protein and fat were determined *in vivo* using the deuterium dilution technique. Average dry season IOM of unsupplemented animals varied from 63 g/kg $W^{0.75}$ (± 11) to 88 g/kg $W^{0.75}$ (± 17), IME varied from 512 kJ/kg $W^{0.75}$ (± 93) to 719 kJ/kg $W^{0.75}$ (± 135) and IN from 516 mg/kg $W^{0.75}$ (± 144) to 1629 mg/kg $W^{0.75}$ (± 469). Rainy season IOM was not different from that observed during the dry season. Supplementation increased total IOM, IME and IN but tended to substitute for intake from pasture with increasing vegetation quality. While the additional weight gain of supplemented cattle on pastures with low vegetation density and quality was 53% higher than that of unsupplemented animals, it decreased to 33% on pastures with high densities of good-quality vegetation. There were no significant differences between treatment groups in the relative proportions of empty body water, protein and fat. For an unsupplemented animal of 250 kg body mass, average faecal excretion of organic matter (FOM) and nitrogen (FN) varied within a range of 1.8 kg OM/d (± 0.3) to 2.4 kg OM/d (± 0.5) and 20 g N/d (± 3) to 47 g N/d (± 9), respectively, in the dry season. Supplementation did not increase FOM and FN. During the wet season total-N excretion increased due to greater urine excretion caused by a surplus of N relative to energy in the diet. The transfer of nutrients from pasture to cropland through manure and urine can contribute considerably to the maintenance of soil fertility in mixed farming systems of the Sahelian zone. Supplementing the diet of free ranging animals has little effect on nutrient cycling.

Foraging behaviour of cattle grazing semi-arid rangelands in the Sahel of Mali

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Cattle nutrition studies in the Sahel have shown inter-seasonal differences in feed intake and markedly higher nitrogen concentrations in selected feed than in forage on offer, indicating efficient grazing selectivity. In this study, seasonal changes in feeding behaviour by cattle were related to the standing

units were first inferred from differences between the relative extent of units along grazing routes and in the area accessible to the herd. Cattle preferences were further rated using a chi-square test of the relative frequency of the bites recorded in one landscape unit with the relative extent of that unit along the daily grazing route of the herd. Similar preference ratings were calculated for classes of herbage standing mass within landscape units. The relative frequency of plant species recorded as dominant in randomly sampled bites provided an estimate of cattle seasonal preferences for plant species. Early in the wet season, high selectivity was observed between landscape units with herbage mass ranging from 200 to 1500 kg DM/ha, but there were no significant differences in selectivity between mass classes. Later in the wet season, the selectivity was more influenced by herbage mass than by landscape unit. Cattle avoided patches of low and high mass and selected less common species, including forbs and some browses. Early in the dry season, no clear trend was detected in selectivity for landscape unit or herbage mass. As the dry season progressed, herbage mass and quality decreased, the few remaining high-mass patches became increasingly selected and the diet included an increased number of species and a higher proportion of browses. Seasonal changes in foraging, therefore, do not depend only on the standing mass and protein content of the herbage on offer, but are also influenced by the spatial distribution of the vegetation organised in a hierarchy of scales from plant communities down to patches and individual plants. The impact of such foraging behaviour on vegetation and nutrient cycling is discussed.

Feeding livestock for compost production: A strategy for sustainable upland agriculture on Java

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Ruminant livestock are an integral part of smallholder farming systems in Indonesia. However, the extent and continuous nature of cropping on densely populated islands such as Java leaves very little land suitable for grazing. The majority of livestock are therefore permanently housed in backyards and fed indigenous forages cut from field margins and roadsides. Cut-and-carry feeding is labour-intensive and the supply of forage is often the most expensive input to ruminant production. Surprisingly, farmers collect quantities of forage greatly in excess of the requirements of their livestock. In an experiment, indigenous forage dominated by *Axonopus compressus*, was fed to sheep at increasing rates: 25, 50 or 75 g DM/kg live weight (W) per day. The results showed that although DM intake and liveweight gain rose with increasing offer rate, the incremental improvements from 50 to 75 were non-significant ($P < 0.05$) and less than from 25 to 50. It is unlikely that farmers justify their excess-feeding strategies on the basis of these marginal gains in animal productivity alone. The rationale for excess feeding may lie in manure-compost production. Farmers collect uneaten feed in pits beneath their animal barns. The uneaten feed combines with faeces and urine falling through the slatted floors to produce manure-compost. In the above experiment, the quantity of manure-compost made from refused forage mixed with sheep excreta increased markedly as the forage offer rate rose. It is possible that farmers adjust their feeding rates to optimise total output, i.e. including manure-compost, as opposed to animal production *per se*. Manure-compost is ranked by farmers as one of the most important outputs from livestock production. In the upland regions of Java, 90% of the fertiliser used on smallholdings is manure-compost. It is hypothesised that livestock are used to produce high-quality compost and that their integration into Javanese agriculture is essential to the sustainability of some of the most intensive cropping cycles in the world.

Manure as a key resource in sustainable agriculture

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Mixed arable–livestock farming systems are characteristic of large areas of Africa. In these systems manure from livestock is commonly used as a fertiliser in arable fields. In this paper the importance of manure from herbivores as a key ecosystem resource for agricultural intensification and change is evaluated. Two aspects are examined: first the value and utility of manure as a source of nutrients under current circumstances; and second the significance of manure as a fertiliser within the whole farming-system context. Manure has traditionally been an important source of nitrogen (N) and other nutrients. However, current trends in agricultural intensification tend towards a progressive decrease in the availability and quality of this resource suggesting that the continuing use of manure confers little benefit as a nutrient fertiliser. There are, however, a number of possibilities for manure utilisation which will maintain its management. Where possible, joint application of manure and inorganic fertilisers and manipulation of the relative amounts and times of application can synchronise N release and availability in the soil with demand for, and uptake by, crop plants. This is potentially the most productive approach, combining the short-term benefits of inorganic fertiliser with the long-term value of manure. This multiple-fertiliser approach can be extended. One of the major deficiencies in current research and extension is the failure to use indigenous knowledge and practice as a starting point for scientific intervention. Small-scale farmers in Zimbabwe commonly use four or five different fertilisers and apply them differentially across field types. The number of potential combinations and possible outcomes in terms of both long- and short-term effects on soil fertility provide the basis for a flexible and cost-effective soil nutrient management strategy. Additional increases in efficiency can be gained from modification of the storage stage of the system. With increasing pressure on land it is necessary to look beyond the traditional free range communal grazing systems to more intensive alternatives. In this respect moves towards cut-and-carry and zero-grazing practices such as are being adopted in Kenya and other countries in East Africa would seem to be a sensible option. It is nonetheless necessary to also consider the inclusion of alternative sources of fodder nutrients, such as those from N-fixing trees and other legumes.

Faecal excretion by ruminants and manure availability for crop production in semi-arid West Africa

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Livestock manure is an important source of nutrients for crop production in semi-arid West Africa. An assessment of the potential of manure to sustain crop production calls for an estimation of the amounts of manure that could be produced and captured and the feed resources required to maintain livestock used for manuring. This paper presents estimates of the amounts of manure produced by

cattle, goats and sheep fed *ad libitum* under confinement. A model is presented to predict the yearly faecal output by grazing ruminants under fluctuating feed supplies. Statistics on livestock population and cultivated areas are used to evaluate the effects of livestock to cropped area ratios and the spatial location of livestock at manuring time, on the potential amounts of manure available for crop production. The number of cattle, sheep and goats needed to manure different proportions of a 10-ha farm and the amounts of feed required for herds used for manuring are estimated. Model results indicate that the potential of manure to continuously sustain crop production in semi-arid West Africa is limited by livestock population, spatial location of livestock at manuring time, manure excretion per animal, efficiency of manure collection, and the amounts of feed and land resources available. Since the relative importance of these limiting factors and the possibilities for realising this potential vary both spatially and temporally, it is suggested that these technical factors should be taken into consideration when evaluating the potential of manure to support crop production at national, regional, or farm level.

Increasing the role of ruminant livestock in the maintenance of soil organic matter for sustainable production systems in southern Mali

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The maintenance of soil organic matter (SOM) in cultivated soils is a major constraint to sustainable crop production in southern Mali, especially with reduced fallow periods. Population growth, increasing cultivated areas and livestock numbers, and frequent bush fires are the major factors contributing to inefficient natural fallows. In some areas, 20 to 45% of the land is cultivated, about 60% is arable, and stocking rates range from 19 to 30 TLU/km². Two methods for maintaining SOM have been evaluated using a model and data from three studies conducted by DRSPR/Sikasso. Intensification of manure production all year round while using litter was more effective than improved fallows ungrazed during the rainy season. However, given the present land use rate, no sustainable production can be achieved without increasing ruminant livestock numbers. More cattle increase the profitability of improved fallows. These provide dry-season feed and hence improve the sustainability of the production system. Stall-feeding cattle in the hot dry and early wet seasons helps optimise the cycling of crop residues and the use of dry-season labour. It also improves the early growth of vegetation and makes it possible to increase carrying capacity over 30 TLU/km². Socio-economic measures should be considered at farm, village and regional levels to drastically change the livestock management system.

Nitrogen intake and losses by sheep on *Medicago* spp and barley pastures in northern Syria

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Farming systems of the semi-arid rainfed West Asia and North Africa regions are characterised by cereal cropping, mainly barley, integrated with sheep and goats. Recent emphasis on sustainability and the environmental implications of losses of nitrogenous gases to the atmosphere underscore the

need to quantify the role of the grazing animal in nutrient cycling. While the nitrogen (N) and phosphorus (P) contents vary between faeces and urine, they are modified by stage of plant growth and by the physiological status of the animals. In field trials using total faecal collection from lactating ewes at ICARDA (International Center for Agricultural Research in the Dry Areas) in northern Syria (mean annual rainfall 330 mm), total daily N excretion on annual *Medicago* spp pastures fell from April to September (40 to 13 g/d) while the equivalent drop in intake from barley pastures was from 25 to 8 g/d. A large proportion of that N appeared in the urine (about 70% falling to 50% on *Medicago* and 50% falling to 10% on barley). The largest nitrogen output in milk was 8 g/d, on the medic pasture in April. Soil samples were held in controlled laboratory environments to examine the influence of soil type, temperature, moisture and organic debris on volatile loss of ammonia from urine.

Carbon and potassium dynamics in grass/legume grazing systems in the Amazon

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Pastures in the Amazon are mismanaged. Adapted low-input pastures can, however, be sustainable, productive and ecologically sound. Two separate trials were undertaken to study the effects of grazing on potassium (K) and carbon (C) dynamics on a *Brachiaria humidicola* x *Desmodium ovalifolium* mixture in the Amazon region. For K, despite high rainfall conditions, losses (below 100-cm depth) in bare plots were detected only at high application rates of K (300 kg/ha). Losses were minimised by K retention in specific absorption sites in small quantities of 2:1 minerals. Retention mechanisms included high dry matter production and K luxury consumption; residues were also an efficient recycling mechanism. Without animals K losses appeared to be negligible. The animals modified the amount and composition of returned K, especially in urine. They therefore disrupt rather than enhance K cycling. Uneven and localised spots of high K return (465 kg K/ha) occurred and annual leaching losses of 30 to 94 kg K/ha may occur. For C, under a wide range of grazing conditions, maximum faecal C inputs were 3.9 t/ha per year and compared to leaf litter, were the main source of C above ground. Stocking rates did not affect root-distribution patterns with depth, grazing stage and rainfall patterns. Grazing, however, increased the amount of dead roots which increased the estimate of root productivity (2.4 t/ha per year). Soil physical and biological properties were affected by stocking rate but soil chemical properties were not. Bulk density increased with increasing stocking rates but decreased when the animals were removed, suggesting that trampling is a reversible and temporary effect. Increasing stocking rates did not affect root biomass, suggesting that trampling *per se* is not detrimental to plant production. However, earthworm biomass dropped precipitously when the pasture was overgrazed. Earthworms may be better indicators of soil damage or degradation than soil physical or chemical properties.

Soil aspects of nutrient cycling in a manure application experiment in Niger

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Lack of nutrients is one of the main factors limiting crop production in the Sahel. Livestock play an important role in the transfer of nutrients from grazing land to cropping land through deposition of manure and urine. In 1990, a six-year study was initiated in semi-arid Niger, West Africa, to study the effects of application of various amounts of cattle and sheep manure, with and without urine, every one, two or three years, on the efficiency of nutrient use in the production of pearl millet. Intensive soil sampling was only possible during the first 12 months because of the plot size. There were a number of indications from the results of this intensive sampling. Regular sampling of soil, instead of the more usual regular sampling of soil water, can be useful in quantifying components of the soil nutrient balance. Pre-experiment sampling on a plot basis, to determine the spatial variability of soil characteristics, should help reduce the effects of spatial variability on experimental results. Since soil chemical parameters can show seasonal, cyclical fluctuations, temporal comparisons of soil properties should be done over (multiples of) 12-month periods, preferably at the start of the cropping season. Incorporation of organic matter by termites, decomposition in deeper soil layers, and leaching of nutrients continued during the dry season. Application of manure increased crop growth, may have accelerated decomposition of organic matter, increased termite activity, and possibly increased fixation of nitrogen. However, the results also showed that application of high rates of manure can give rise to leaching of organic carbon (C), nitrogen (N) and phosphorus (P). Within 12 months of application of the equivalent of 13 000 kg/ha of cattle manure, the equivalent of 1070 kg/ha of C, 91 kg/ha of N and 19 kg/ha of P had been translocated to beyond a depth of 1.5 m. It may therefore be more efficient to apply small amounts of manure frequently, than to apply a lot of manure less frequently.

Feed factors affecting nutrient excretion by ruminants and the fate of nutrients when applied to soil

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Mixed farming systems in semi-arid West Africa rely on recycling organically bound nutrients to maintain soil productivity. The passage of plant biomass through ruminant livestock plays a major role in the nutrient cycles of this region. The feeding value of crop residues and browses and their impact on nutrient excretion by sheep, and the decomposition of and nutrient mineralisation from crop residues, browse leaves and manure derived from these feeds were studied during the dry, wet and cool seasons in the Sahel of West Africa. The total amount and proportion of nutrients excreted in faeces and urine varied with the lignin:neutral-detergent fibre (NDF), lignin:nitrogen (N) and polyphenol:N ratios of the diets. Feeding browse shifted N excretion from urine to faeces, and from

faecal microbial- to undigested feed-N. Initial organic-matter decomposition was more rapid and greater in manure than in browse leaves. Manure decomposition was fastest during the dry and cool seasons. Mineralisation and immobilisation patterns of N and phosphorus (P) in leaves and manure varied considerably. Whereas N and P were released more quickly from manure, browse leaves initially immobilised N and P, particularly during the cool season. Mineralisation of N and P from manure varied seasonally and was highly influenced by the sheep diet. This study showed that the passage of feed through ruminants can be an important regulator of nutrient cycling in this semi-arid region.

Nutrient recycling in pastures, rangeland, fallow and cut-and-carry systems in sub-Saharan Africa

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Sustainable agriculture is viewed as a long-term goal that seeks to overcome problems and constraints confronting the economic viability, environmental soundness and social acceptance of agriculture production systems. Improved nutrient cycling is one of the soil conservation practices that may increase soil productivity in sub-Saharan Africa (SSA). Six agricultural models with different nutrient recycling mechanisms are identified for the ecological zones of SSA. These models are for distant farms, compound farms, crop, livestock, crop–livestock, and urban production systems. Nutrient recycling efficiency is highest in compound farms, followed by crop–livestock, crop, livestock, and urban farms. It is estimated that 102 million tonnes of refuse are generated annually, and 27 million tonnes of human waste dry matter from the urban centres are not utilised. Higher nutrient recycling efficiency could be attained by integrating human–crop–livestock segments in each respective model for sustainable agricultural development in SSA. Such an objective can be achieved by educating the populace on the advantages of nutrient recycling. Short- and long-term research should be planned and executed to accomplish such goals.

The role of forage legume fallows in supplying improved feed and recycling nitrogen in subhumid Nigeria

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Sub-Saharan Africa is experiencing substantial land degradation and declining soil fertility. This has led to decreasing total agricultural productivity. Introducing forage legume rotations into crop–livestock systems can stabilise agricultural productivity. In addition to providing high-quality forage for animals, legumes can improve soil characteristics for crop production. Research conducted to test the impact of forage legumes on livestock productivity in the subhumid zone of Nigeria showed that cattle grazing *Stylosanthes*-based pastures in the dry season produced more milk, lost less weight, had shorter calving intervals and there was greater calf survival when compared with natural pastures. Leguminous pasture grazing by goats significantly reduced weight losses in the wet season. Both observations were attributed to the greater nutritive value of the forage legume relative to the natural pasture. The nitrogen (N) recycled by legume leys to subsequent crops was assessed in bioassays. Results showed that N supplied by *Stylosanthes* to subsequent crops varied from 30–80 kg N/ha. Grain yields from areas preceded by the legume were always higher and in some cases were double those from natural pasture. The superior performance of crops following *Stylosanthes* was associated with improvement in soil physical and chemical properties caused by the legume. The incorporation of forage legumes into cropping systems shows great potential for the maintenance of sustainable farming systems.

The benefits of forage legumes for livestock production and nutrient cycling in pasture and agropastoral systems of acid-soil savannahs of Latin America

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Agricultural production must increase to match population growth in Latin America. However, the region is already witnessing a decline in productivity due to soil loss, compaction, overgrazing and inappropriate cropping systems. The vast savannah areas of infertile acid soils offer some hope for sustainable increases in agricultural production. Animal liveweight gains have doubled per head and increased tenfold per hectare with improved grass/legume pastures when compared with managed native savannahs. Similarly, milk production and calving performances can be improved with legumes. Grass/legume pastures combined with acid-soil tolerant upland rice are examples of input-efficient sustainable systems. Inputs of N from different forage legumes via biological nitrogen (N) fixation were quantified using ^{15}N isotope dilution techniques. The proportion of legume-N derived from fixation was greater than 85%. Thus the amounts of N_2 fixed may be calculated from simple estimates of legume biomass. A legume content of at least 20% of the above-ground dry matter was estimated to be sufficient to maintain the N balance in these tropical pastures. Decomposition of legume residues is a key route for the cycling of N and other nutrients in under-utilised tropical pastures. Litterbag studies demonstrated wide variation in rates of nutrient release among forage legumes and grasses (litter half-lives ranging from 26–173 days during the wet season). Apparent transfer of legume-N to a companion grass was rapid during the first year of grass/legume pasture establishment on a sandy Oxisol, and depended on legume persistence under grazing. The ability of forage legumes to improve soil quality was investigated using ^{13}C measurements of soil organic matter, potential N mineralisation rates, soil physical measurements and yields of upland rice crops after a grass/legume pasture, a grass only pasture, or native savannah.

Millet and cowpea in mixed farming systems of the Sahel: A review of strategies for increased productivity and sustainability

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In the Sahel, pearl millet (*Pennisetum glaucum* (L.) R.Br.) and cowpea (*Vigna unguiculata* (L.) Walp.) are an integral part of the farming systems and contribute to both human food and livestock feed. The traditional production system relies on the arrangement of these crops in time and space with both having implications for crop and livestock productivity, and sustainability. This paper reviews agronomic research and suggests ways and means of improving the productivity and sustainability of this system. The effects of different agronomic factors and cropping systems on grain and fodder yields and their implications on nutrient cycling and soil productivity are emphasized. Research at the ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Sahelian Center on such

factors as cultivar choice, soil fertility and water management, crop management and cropping patterns is highlighted. Components of millet production systems found to be promising include application of small amounts of phosphorus (P), improved varieties of pearl millet and cowpea, sowing at higher densities, use of animal traction for ridging and weeding and rotation of millet and cowpea. The role of cowpea and forage legumes such as *Stylosanthes* in the improvement of soil fertility and the key link of crop residues as a source of livestock feed and soil amendment are stressed. Future research priorities on the integration of livestock into millet/land legume-based production systems are proposed.

A critical review of crop residue use as soil amendment in the West African semi-arid tropics

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Poor soil fertility and low use of organic and inorganic fertilisers are the greatest constraints to increasing agricultural productivity of farming systems in the West African semi-arid tropics (WASAT). Results from long-term field experiments showed that the use of mineral fertilisers alone in the long-run leads to decreasing base saturation, decreasing pH and increasing aluminium (Al) toxicity in soils which might be limiting crop yields. The soil fertility in intensified farming in the WASAT can only be maintained through efficient recycling of organic material such as millet crop residues (CR) or manure in combination with mineral fertilisers and using of rotations with legumes such as groundnut and cowpea or *Stylosanthes*. The mechanisms responsible for the positive effects of CR on crop yields are multiple. They include local conditions such as rainfall, wind speed, soil type, and temperature regime. Thus, at some sites an increase in available phosphorus (P) or potassium (K) may be the most important mechanism while at other sites, the protection against sand coverage and water erosion, a loosening of the upper soil layers, soil microbiological effects or a decrease of soil surface temperature and soil resistance may be dominant. In mixed crop–livestock systems, the issue of competing uses for CR needs to be addressed to understand the current mechanisms of resource allocation by farmers and to design economically and ecologically sound alternatives which ensure the sustainability of current farming systems at a higher output level. The complementary effects between livestock and crop production in the Sahel also suggests that research efforts should not only take into account ways to increase crop biomass at the farm level, but also how to increase the quantity and quality of fodder.

Nitrogen in dryland farming systems common in north-western Syria

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Farming systems in West Asia–North Africa involve rotations of cereals with fallow or food/forage legume crops depending on location and rainfall. Barley (*Hordeum vulgare* L.) tends to dominate in the drier zones and bread (*Triticum aestivum* L.) and durum (*T. turgidum* L. var *durum*) wheat in the more favourable areas. Sheep and goats are integral parts of the systems, particularly those dominated by barley. The International Center for Agricultural Research in the Dry Areas (ICARDA) is developing improved cultivars and management practices, and needs to critically examine several systems in terms of efficiency, costs and sustainability. Therefore, a long-term trial was established in 1983/84 at ICARDA's main research station at Tel Hadya, near Aleppo in northern Syria, to evaluate the productivity of systems in which durum wheat is rotated with vetch (*Vicia sativa* L.), lentil (*Lens culinaris* Medik.), chickpea (*Cicer arietinum* L.), medic (*Medicago* spp) pasture, wheat, water-melon (*Citrullus vulgaris* L.), and fallow. Varying nitrogen (N) levels (0, 30, 60, 90 kg/ha) and intensities of grazing stubble (heavy, moderate, none) were imposed on the wheat phase. Both the wheat and the alternative phase were included each year. While seasonal rainfall, which ranged from 210 to 486 mm, and residual soil moisture after the alternate phase dictated the magnitude of wheat yields, N increased water-use efficiency. Soil N levels (mineral and total) varied with the system and were highest for medic and least for wheat and fallow. Similar differences were evident for organic matter (OM), which also tended to increase with increasing N level. The concentration of N in grain and straw as well as total N uptake varied with the rotation and crop yield. Though the trial needs to continue for several more years, the impact of some crops (i.e. medic) on soil quality is already apparent.

The interactive effects of rainfall, nutrient supply and defoliation on the herbage yields of Sahelian rangelands in north-east Mali

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In the Sahelian rangelands biomass production is constrained by soil moisture in the drier (100–250 mm) parts and by soil nutrients in the wetter parts. Similarly, for a given Sahelian range, nutrient deficiency would be more prominent in good than in poor rainfall years. To test this hypothesis, fertiliser trials were carried out at sites distributed along the bioclimatic gradient in the Gourma (Mali) over contrasting rainfall years between 1988 and 1992. In good rainfall years, adding 100 kg nitrogen (N) and 38 kg phosphorus (P)/ha increased herbage production by approximately 30%, whereas the response to fertiliser was inverted in poor years. Plant uptake of N and P increased with biomass yield,

but at a lower rate. Fertiliser N and P increased biomass and nutrient yields but the nutrient content in biomass decreased due to nutrient dilution. In the pastoral context of the Sahel, grazing further influences the interactive effects of moisture and nutrient supply on herbage production and quality. To elucidate these interactions, cutting experiments were conducted with and without fertilisers. The effects of defoliation without fertilisers depended on rainfall and frequency of cuttings. In fair rainfall years early cuttings increased total yield whereas early cutting reduced yield in poor rainfall years. In good rainfall years total yield was reduced by 50 and 25% when repeated cuttings were at 15- and 30-day intervals, respectively. Reductions in yields were less severe in poor rainfall years. N and P uptakes changed little with repeated cuttings due to higher nutrient contents in regrowth. Adding fertilisers increased regrowth yields so that cumulative yields of repeated cuttings equalled or exceeded the control yield, depending on the rainfall conditions. Redistribution of rainfall in the landscape by run-off/run-on, and livestock grazing behaviour diversify the quantity and quality of range resources. Thus, recognising that soil nutrients provide a constraining ceiling for primary and secondary productivity on a regional scale, exploiting the quality gradient on a local scale through range management provides room for production improvement with little risk for this ecosystem.

Socio-economic dimensions of nutrient cycling in agropastoral systems in dryland Africa

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Most research on nutrient cycling to date has focused on its biological dimensions. However, social and economic processes mediate the volume, pattern, and distribution of different nutrient flows. This paper presents a number of questions which need to be addressed, including: how sustainable are nutrient flows within agropastoral systems? and how can nutrient management be intensified as pressure on resources increases? Case studies are taken from five areas to provide details of how nutrients are managed in practise. These cover Burkina Faso and Senegal, Kenya, Mali, Nigeria and Zimbabwe. The case studies illustrate how important it is to understand the social and economic processes underlying the availability of nutrient sources and flows to different people. For example, access to manure depends on herd size, and the existence of manuring contracts whereby farmers can gain access to water and crop residues in exchange for the manure from visiting herds. Tenure relations will condition rights of access to grazing resources, while access to chemical fertiliser will depend on whether the farmer has market access and cash income. Rising human population density is likely to lead to increasing problems of soil fertility maintenance. However, in some areas, rising populations may provide both an incentive and the means to intensify land use. Political relations between herding and farming populations will determine the terms on which farmers can gain access to manure. Management skills and availability of farm labour will affect the care with which fertility inputs are applied in relation to crop growth in the rainy season. There are currently two basic policy alternatives for nutrient-cycle management within African agropastoral systems. The first involves the more effective management of resources internal to the agro-ecosystem (e.g. mulching, composting and intercropping with leguminous plants), while the second is based on the use of external inputs (e.g. chemical fertilisers). Future research needs to identify the costs and returns of each strategy, and the conditions are likely to include sufficient pressure on resources to prompt intensification, market conditions which bring reasonable returns to investment on-farm and assured access to land and other resources.

Manure utilisation, drought cycles and herd dynamics in the Sahel: Implications for cropland productivity

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Animal manure is of vital importance to soil-fertility maintenance in semi-arid West Africa due to its intrinsic value as a soil amendment and because of the low level of inorganic fertiliser use. This paper provides a regional overview of manure utilisation for food crop production. Results of experimental trials and on-farm studies are reviewed to evaluate the agronomic and economic effectiveness of livestock manure as a source of nutrients for millet and sorghum production. The potential and actual

amounts of manure available for crop production during normal rainfall years are estimated, and the effect of drought-induced changes in livestock population and species composition on manure availability and cropland productivity are assessed. In doing this, on-station and on-farm data from Niger are used to assess nutrient losses from croplands and to estimate the amount of manure required to maintain crop production at various yield levels. The number of animals needed to produce this level of manure and the feed resources required to maintain them are estimated and compared with the level of livestock holdings and feeds found in village studies. The influence of drought on the structure of national and village herds are evaluated and the amounts of different types of manure that are likely to be available in the years immediately preceding and following a drought are estimated. These estimates and feed availability parameters are used to assess the adequacy of available manure for food crop production, and the role that manure and other soil amendments can play in the future intensification of agricultural production in semi-arid West Africa.

Nutrient flux between maize and livestock in a maize–coffee–livestock system in central Kenya

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Soil productivity has been declining in the central highlands of Kenya due to intensive cropping. To obtain information on potential points which could be managed to better conserve nutrients within the farming system, the flux of nitrogen and phosphorus was monitored in four randomly selected farms in Embu District during the 1990/91 short rainy season and in three farms during the same season in 1991/92. Grain yield, stover production, stover removal, and fertiliser and manure use were measured. Maize yields on average were nearly 4 t/ha in the 1990/91 and 5 t/ha in 1991/92. Measured stover production averaged 2.9 t/ha and 4.9 t/ha in the 1990/91 and 1991/92 seasons, respectively. Averaged across all farms and years, 72% of all stover was fed to animals. Nitrogen and phosphorus removal by grain averaged 50.7 kg/ha and 17.5 kg/ha, respectively, and by stover 4.9 kg/ha and 1.9 kg/ha, respectively. All four farms received chemical fertiliser in 1990/91 but only one received fertiliser in 1991/92. Fertiliser supplied more than 50% of the phosphorus. Manure was applied in five of the seven farm-years and supplied most of the nitrogen in the system. Inputs of nutrients by manure far exceeded their removal by stover. Due to the importance of manure in maintaining the productivity of the soil, sustaining the production of fodder and developing improved manure-handling techniques are suggested as key elements in sustaining maize productivity in this area.

Farmer and pastoral strategies in Saurashtra, Gujarat: An analysis of landless pastoralism and dependence on the manure market

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Over the past 40 years, Bharavad pastoralists from Saurashtra in Gujarat State, India, have found themselves divested of rangelands and village commons that were formerly the primary source of nutrition for their ruminant livestock. To adjust to the changing socio-economic and biotic–edaphic environments, Bharavad pastoralists in this region have de-emphasised the production of more nutrient-demanding livestock products and focused on co-existing with farm production through marketing livestock manure. A model that was used to examine the economics of farmers' involvement in the agropastoral production system predicts that farmers with improved dairy cattle will profit most from (a) utilising high quality on-farm crop residues for their own milk production, and (b) trading low quality crop residue to pastoralists for manure. Other researchers have suggested [in response to our own analysis] that farmer–pastoralist relationships focusing on nutrient cycling can often be over-emphasised. This paper argues that in Saurashtra (and most likely in other areas where pastoral groups are politically marginalised), manure trade is the only production activity available to herders that utilises pastoral skills and is remotely sustainable.

The sustainability of rangeland to cropland nutrient transfer in semi-arid West Africa: Ecological and social dimensions neglected in the debate

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The integration of crops and livestock has often been cited as a model for agricultural development in semi-arid West Africa. Recent formulations treat the adoption of more intensive forms of manuring as a critical step in agricultural development. These analyses have been criticised for ignoring or underestimating the possible negative consequences of such management on rangeland and livestock productivity. This paper critically examines this debate. It is argued that the agronomic benefits of manuring depend largely on nutrient transfers from non-cropped grazing lands. In this respect, the ecological critiques are correct in arguing that, except in sparsely cultivated areas, the livestock required to support continuous cropping cannot be maintained by local pastures without external inputs. Over the long-term, such nutrient transfers cannot be sustained; nutrient outflows from pastures will exceed inflows resulting in a combination of reductions in livestock productivity, manure quality, pasture productivity and local livestock presence. However, these analyses have ignored the large influence of village-level agronomic and livestock management on the parameters used in such calculations. Once the temporal and spatial aspects of rangeland–cropland nutrient transfer are considered, it is shown that the dynamic sustainability of the process is determined, not simply by rangeland/cropland ratios and livestock stocking rates, but by differences in grazing and manure management at the village and household levels. Village-based livestock management is an area of

active concern and experimentation by crop–livestock producers in semi-arid West Africa. More efficient nutrient management can be promoted through a combination of policy and extension efforts.

Measuring the sustainability of crop–livestock systems in sub-Saharan Africa: Methods and data requirements

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Livestock are an important component of farming systems in sub-Saharan Africa. They are raised mainly for meat, milk and skin and provide a flexible financial reserve in years of crop failure. They also play a critical role in the agricultural intensification process by providing draft power and manure for crop production. With increasing human population and economic changes, cultivated areas in many sub-Saharan African countries have expanded on to marginal lands and fallow periods are being shortened. As a result, large areas of land have been degraded and crop and animal yields have fallen. Improved crop–livestock production systems and technologies are currently being developed in response to the growing demand for food and the degradation of the natural resource base. These technologies must enhance food production; they also need to maintain ecological stability and preserve the natural resource base, i.e. they must be sustainable. However, the notion of sustainability has been of limited operational use to policy makers and researchers attempting to evaluate new technologies and/or determine the effects of various policies and technologies. This paper discusses a methodology for measuring the sustainability and economic viability of crop–livestock systems. The approach is based on the concept of intertemporal and interspatial total factor productivity, paying particular attention to the valuation of natural resource stock and flows. The method is applied to a data set available at the International Livestock Centre for Africa (ILCA). Intertemporal and interspatial total factor productivity indices are computed for three farming systems in south-western Nigeria. Results show that the sustainability and economic viability measures are sensitive to changes in the stock and flow of soil nutrients as well as to material inputs and outputs. The advantage of this approach is that intertemporal and interspatial total factor productivity measures are computed using only price and quantity data, thus eliminating the need for econometric estimation.

The role of livestock in sustainable agriculture and natural resource management

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The objectives of this paper are to introduce the reader to the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM/CRSP) and the Landscape Approach to Sustainability in the Tropics (LAST) and discuss the role of livestock in these projects. LAST uses landscape ecology to research the interactions among ecosystems within a watershed. The farmer-back-to-farmer research approach and gender analysis are integral tools which are used throughout the design and implementation of the project. The results of a Participatory Landscape Lifescape Appraisal conducted in collaboration with LAST researchers and the farmers in

the watershed which encompasses the village of Donsin in Burkina Faso are used to illustrate the role of livestock in SANREM. Livestock in the Donsin watershed have a direct impact on: conservation of soil and water resources; management of soil fertility and the soil's physical and biological characteristics; nutrient cycles within the watershed; cultural practices for controlling erosion; maximising biological production potential; the management of forest resources; and the introduction of agroforestry projects. The people of Donsin are heavily dependent on the natural resource base within their watershed but these resources are undergoing rapid transformations due to drought and increased exploitation. The LAST approach will use participatory research in SANREM to assist the people of Donsin improve their standard of living by developing tools which can be used for appropriate management of natural resources. Interdisciplinary research on the role of livestock needs to be incorporated into broader research themes within the context of human and agricultural ecology to assist farmers in Donsin manage natural resources.

Nutrient transfers from livestock in West African agricultural systems

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The potential supply of nutrients from excreta voided by livestock and what is potentially available for transfer to cropland are examined within a West African context. Nutrient output from cattle is derived from a simulation model that predicts nutrient intake in relation to animal performance and monthly feed supplies; it subsequently links intake to excreted output of lactating and dry cows and young growing stock, as well as of entire cattle herds. The supply side of potential nutrient transfers is addressed at several scales, from agro-ecological zones to that of individual farmers, by analysing ratios between livestock and farmed and non-farmed land. At a regional scale, focus is on Nigeria and on the cottonbelt in Francophone West Africa. The Nigerian situation elucidates the relationships between livestock and land along the rainfall gradient and brings out the multiple interactions between settled smallholder farmers and more mobile agropastoral and transhumant herders. Farming systems in the cottonbelt demonstrate the importance of animal traction and cash cropping as determinants of nutrient-transfer patterns. At the farm level, three case areas are analysed: two in the cottonbelt of Mali and Côte d'Ivoire and one in the closely-settled zone in semi-arid Nigeria. These analyses highlight the variable scenarios of nutrient transfers at the farm and village level, demonstrating that heterogeneity among farmers is as much at play as differences between zones and countries. The implications of these nutrient-transfer scenarios are discussed with emphasis on crop-livestock interactions at increasing levels of population pressure and how they may affect pathways of land-use intensification and soil-fertility maintenance.

Modelling and simulation in the development of sustainable animal production systems

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Various approaches to nutrient-cycle modelling in the plant–animal–soil system were presented. An (incomplete) inventory of available approaches and models was carried out. Their practical utilisation was then analysed and the problem of their limited use was discussed. Several causes for this limited use were identified including lack of adequate training, low level of reliability and problems encountered by third parties seeking to assess their applicability and hence their validity. Some causes are much more difficult to address including the negative attitude towards models and suspicion with regard to undesirable results. Fortunately, limited use does not mean that modelling and simulation are totally absent in Africa. The systems approach has largely contributed to strategic changes in rural development, including increased concern for soil fertility, natural resource management and livestock nutrition. The approach and philosophy of «Production Soudano-Sahaliennne Project – Exploitation optimale des éléments nutritifs en élevage (PSS)» were also presented to underline the need for modelling and simulation in developing sustainable animal production systems. This scientific collaboration project between Mali and The Netherlands examines the feasibility of intensifying Soudano-Sahelian agriculture through introduction of chemical fertilisers for improved forage production. A systems approach is essential for such an analysis because: the value of trials is limited in a changing environment characterised by overexploitation; long-term trials are necessary to determine the optimal rate of response of fertilisers on poor soils; time is needed to establish the efficiency of the integration of biological and intensive agriculture; synergism of integration is difficult to assess mentally; too many parameters affect the cost efficiency of livestock supplementation; and the most promising options can be selected using simulation.

Modelling the effects of livestock on nutrient flows in mixed crop–livestock systems

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Some of the effects of the passage of biomass through livestock on the dynamics of whole-system nutrient cycles are relatively clearly defined. However, processes in the livestock component may have other far-reaching effects that are less readily accounted for. For example, changes in diet composition can affect the partitioning of excreted nitrogen between manure and urine. Such changes can interact with animal and compost management practices to affect the dynamics of processes occurring in soil organic matter. A model based on digestive processes in ruminants is described which has been developed to assist in resolving these effects and interactions. Initial simulations with the basic Animal Production/Manure (APM) model have been conducted, both alone and in conjunction with the SCUAF (Soil Changes Under Agroforestry) model. These have been based on a system in which livestock are fed crop residues but may also graze or receive concentrate supplementation to highlight a number of issues, in particular that: animals may, depending on access to grazing and concentrate supplements, act as importers of nutrients into more intensively cropped land; and optimum production from the animal component may not necessarily be associated with maximum

losses of nutrients from this land, even when the use of concentrate supplements is limited. Apart from improving our understanding of whole-cycle nutrient dynamics, the approach used in developing the APM model might also allow a unified approach to questions of whole-system productivity in mixed crop–livestock systems. Future efforts will concentrate on defining the parameters of the processes on which APM is based and the validation of the model against field data.

Myth and manure in nitrogen cycling: A case study of Kaloleni Division in Coast Province, Kenya

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A simulation model was developed that predicts dry-matter (DM) and crude-protein (CP) intake and associated cattle performance based on live weight, age, pasture conditions and supplementary feeding. Intake data were used to estimate the amount of nitrogen (N) retained by cattle and that excreted in faeces and urine. The N levels in excreta were varied according to the nature, quantity and quality of the diet. Dietary CP level and degradability further influences N excretion in urine and faeces. The availability of excreted nutrients for recycling through soils depends on the livestock management system. The model was also used to examine the effects of on- and off-farm feed supplies and differences in livestock holdings on the on-farm nutrient inputs from livestock in Kaloleni Division of coastal Kenya. Nutrient requirements for the entire livestock population were calculated and matched with feed resources to predict how rural population density affects the balance between feed demand and supply. The model showed that cattle owners are able to provide a net input of 25 kg N/ha to their maize, sufficient to maintain a grain yield of 1.8 t/ha. Farmers without cattle suffered a net outflow of N from grazing of crop residue by cattle from other farms. As human population density increases and farm size declines, cattle owners obtain a decreasing proportion of animal feed from their own farms, and cattle spend more time grazing elsewhere. Hence, the net inflow of N will rise at the expense of the rest of the community. Purchased concentrates, an economically viable alternative for dairy cattle, are another external nutrient source for raising the N levels in excreta and can help maintain soil fertility.

A static model of nutrient flow on mixed farms in the highlands of western Kenya to explore the possible impact of improved management

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Currently there is much interest in the potential role of agroforestry in the mitigation of nutrient depletion in sub-Saharan Africa. Using data from farm surveys and trials static models of nutrient flow for existing farm systems and improved agroforestry systems were constructed. These included boundary plantings of trees, hedgerow intercropping for green manure or fodder, and a well-managed zero-grazing system with moderate fertiliser inputs. The objective was to explore the possible impact on nutrient budgets of improved management options. Major nitrogen (N) losses (70% of total farm loss) occurred in the field and hedgerow compartments, principally through leaching and denitrification, which exceeded 60 kg N/ha per annum in all systems. However, there was uncertainty in predicted net mineralisation and the potential amounts of soil-N losses, and the study indicated substantial potential for N mineralisation in deep subsoils. In contrast, phosphorus (P) was efficiently conserved in the farm system, and moderate additions of inorganic P fertilisers could maintain soil-P stocks. Net soil nutrient balances ranged from -39 to -118 kg N/ha per annum and from -7 to +31 kg P/ha per annum in the different simulated systems. N inputs through biological N fixation and deep N capture were significant in agroforestry systems (up to 122 kg N/ha per annum), but when trees were used for production purposes these additional inputs were offset by increases in consumable N harvested (grain, wood and milk) which ranged from 35 to 195 kg N/ha. Improved manure management reduced soil-N deficits by 70 kg N/ha per annum in a zero-grazing system with a high manure flux. Research priorities for the humid highland farming systems include the quantification and dynamic modelling of (1) N mineralisation and N dynamics throughout soil profiles, (2) spatial and temporal patterns of N uptake by trees in agroforestry systems, and (3) nutrient budgets in long-term systems trials.

African semi-arid tropical agriculture cannot grow without external inputs

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A multi-period non-linear optimisation model was constructed of a mixed millet and cattle producing area in the semi-arid tropics of Niger, a poor West African country which is largely agricultural. The model compared the economics of "low-input sustainable" (LIS) agriculture, with animal manure but without mineral fertilisers, to those of agriculture using mineral fertilisers and manure subject to a

minimum soil fertility constraint. Agriculture using mineral fertilisers was superior at average fertiliser prices, at fertiliser prices 50% higher than average and at a higher fertiliser response to LIS agriculture. LIS agriculture was not more stable than agriculture with mineral fertilisers and did not grow more rapidly. A low economic interest rate did not affect the results significantly. LIS agriculture is inferior because it requires very high pasture area per unit of crop area — at least in a ratio of 10:1 — in order to produce enough manure to maintain soil fertility in the absence of mineral fertiliser. Such pasture area would only be available at very low population densities; at higher population densities, competition for land between crops and livestock without mineral fertilisers necessarily results in low income or exhaustion of the soil.

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