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CHANGES IN SOIL FERTILITY UNDER INDIGENOUS AGRICULTURAL INTENSIFICATION IN THE KANO REGION

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Preface

Drylands Research Working Papers present, in preliminary form, research results of studies carried out in association with collaborating researchers and institutions.

This working paper is part of a study which aims to relate long-term environmental change, population growth and technological change, and to identify the policies and institutions which are conducive to sustainable development. The study builds upon an earlier project carried out by the Overseas Development Institute (ODI) in Machakos District, Kenya, whose preliminary results were published in a series of *ODI Working Papers* in 1990-91. This led to a book (Mary Tiffen, Michael Mortimore and Francis Gichuki, *More people, less erosion: environmental recovery in Kenya*, John Wiley, 1994), which was a synthesis and interpretation of the physical and social development path in Machakos. The book generated a set of hypotheses and policy recommendations which required testing in other African dryland environments. Using compatible methodologies, four linked studies have been carried out in:

Kenya	Makueni District	
Senegal	Diourbel Region	
Niger	Maradi Department	*(in association with ODI)*
Nigeria	Kano Region	*(in association with ODI)*

For each of these study areas, there is a series of working papers and a synthesis, which have been reviewed at country workshops. An overall synthesis was discussed at an international workshop at London on 17 January, 2000.

Due to the limited number of working papers on Nigeria they are included in a combined Niger-Nigeria Series. The Research Leader for these studies is Michael Mortimore. He, Mary Tiffen or Frances Harris may be contacted at the following addresses.

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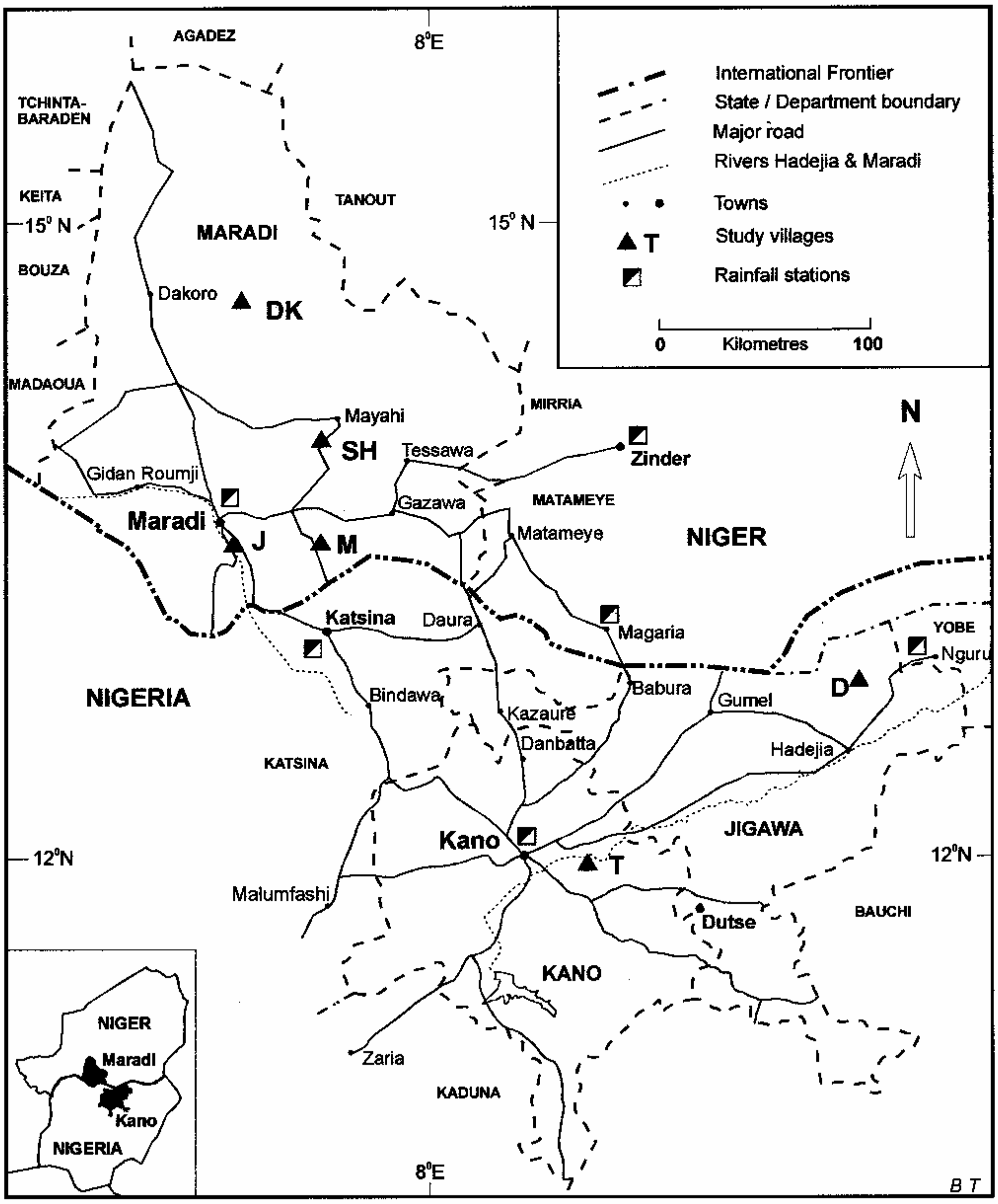
Preface map



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Abstract

Are smallholder farmers mining their soils and causing irreversible land degradation, or are they adapting soil fertility management practices to enable sustainable agricultural intensification? This report compares indigenous soil fertility management strategies in northern Nigeria and the Department of Maradi, Niger. Within this region there are variations in population density, rainfall, land tenure and economy (due largely to differing colonial agendas in Nigeria and Niger). This review aims to contribute to the debate concerning the effect of changes in agricultural production on soil fertility and land use management.

Analysis of empirical data from several sites in north-east Nigeria and the Department of Maradi in Niger show that the range of soil fertility management technologies practised in each village increases with the intensity of the farming system. All of the farming systems studied are low input-low output farming systems.

Individual farmers and farming communities must be responsive to their environments, resulting in a dynamic process of soil fertility management. Crop-livestock integration overcomes the initial constraints to agricultural intensification by providing organic matter, transportation, income diversification (through production of livestock as well as crops) and animal traction (McIntyre, Bourzat and Pingali, 1992). Successful integration also involves an increase in legume production within the system, which provides fodder for livestock (and organic matter to be recycled to the fields as manure), increases inputs of nitrogen through nitrogen fixation, and, through the sale of legume grain, provides cash which may be used to invest in inorganic fertilisers. Integrated nutrient management uses all the resources available to farmers, such as labour (depending on family size and ability to hire labour), livestock manure, draught animal power, crop varieties, fertilisers and knowledge, to work on the land to which they have access. The availability of these resources will vary according to the prevailing natural and socio-economic environment: rainfall, availability of purchased inputs, economics of the farming system, and population pressure.

Due to economic conditions in the study area, low external input strategies are more common than those requiring high investment or cash expenditure. Strategies which are highly dependent on external inputs are not viable at present in this region. Fertiliser is scarce, and its availability at appropriate times in the agricultural calendar unreliable. Low external input farming systems are more suited to the economics and infrastructure under which smallholder farmers operate in Africa. Unless the constraints to increased use of inorganic fertiliser can be resolved, these farming systems can only rely on low-external input strategies to maintain soil fertility.

Résumé

Est-ce que les petits exploitants appauvrissent les sols et causent une dégradation des terres irréversible, ou bien sont-ils en train d'adapter les techniques de gestion de la fertilité des sols qu'ils utilisent afin de permettre le maintien de l'intensification de l'agriculture? Dans ce rapport les stratégies de gestion de la fertilité des sols utilisées par les populations indigènes du nord du Nigeria et du département de Maradi au Niger sont comparées. Il existe dans cette région des variations au niveau de la densité de la

population, de la pluviométrie, de la propriété foncière et des conditions économiques (qui sont dues principalement aux politiques coloniales différentes mises en place au Nigeria et au Niger). Cet examen a pour objectif de contribuer au débat concernant les effets sur la fertilité des sols et sur la gestion de l'utilisation des terres des transformations affectant la production agricole.

L'analyse de données empiriques concernant plusieurs sites situés au nord-est du Nigeria et dans le département de Maradi au Niger indique que l'éventail des techniques de gestion de fertilité des sols pratiqué dans chaque village s'accroît avec l'intensification des systèmes agricoles utilisés. Tous les systèmes agricoles étudiés sont du type faible niveau d'intrants - faible niveau de production.

Les agriculteurs, et les communautés agricoles, doivent être sensibilisés par rapport à leur environnement, ce qui a pour conséquence la mise en œuvre d'un processus dynamique de gestion de fertilité des sols. L'intégration de l'élevage à la culture permet de satisfaire les contraintes initiales liées à l'intensification agricole en fournissant la matière organique, les moyens de transport, et la diversification des sources de revenus (grâce à la production animale aussi bien que celle des cultures) ainsi que la traction animale (McIntyre, Bourzat and Pingali, 1992). Une intégration réussie suppose également une augmentation de la production de légumineuse dans le cadre du système de production de fourrage pour le bétail (et de matières organiques qui sont recyclées et utilisées comme engrais pour fertiliser les champs), un apport accru d'azote grâce à l'absorption d'azote, et la vente des graines de légumineuses, laquelle permet de générer des revenus en argent liquide qui peuvent être investis dans l'achat d'engrais minéraux. Une gestion intégrée des éléments nutritifs permet d'utiliser toutes les ressources dont disposent les agriculteurs, telles que la main- d'œuvre (qui varie selon la taille du ménage et sa capacité à employer de la main- d'œuvre salariée), la fumure animale, la force de traction animale, les variétés de plantes cultivées, les engrais et les connaissances des agriculteurs, ainsi que leur capacité à exploiter les terres auxquelles ils ont accès. La disponibilité de ces ressources varie en fonction du milieu naturel dominant et des conditions socio-économiques: la pluviométrie, la disponibilité des intrants qu'il faut acheter, les facteurs économiques caractérisant le système agricole et la pression démographique.

Étant donné les conditions économiques de la zone étudiée, les stratégies nécessitant un faible apport d'intrants extérieurs sont plus utilisées que celles nécessitant des investissements élevés ou des apports d'argent liquide. Les stratégies qui nécessitent une forte utilisation d'intrants extérieurs ne sont pas viables à l'heure actuelle dans cette région. Les engrais sont rares et leur disponibilité aux moments appropriés dans le calendrier agricole n'est jamais certaine. Les systèmes agricoles basés sur une faible utilisation d'intrants extérieurs sont mieux adaptés aux conditions économiques et à l'infrastructure caractérisant le milieu dans lequel évoluent les petits exploitants. Lorsque la contrainte d'augmenter les apports d'engrais minéraux n'est pas satisfaite, ces systèmes agricoles dépendent pour leur survie de l'adoption de stratégies permettant de maintenir la fertilité des sols tout en utilisant peu d'intrants extérieurs.

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Acronyms and abbreviations

CSZ:	Close-settled zone
CEC:	Cation exchange capacity
EC:	Electroconductivity
WHC:	Water holding capacity

1 INTRODUCTION

Over the past decade there have been a range of studies which have provoked some interesting debates concerning the sustainability of agro-pastoralism in the Sahel. Researchers working on the "primary production in the Sahel" (Penning de Vries and Djiteye, 1982) carried out a detailed investigation of processes of plant growth, soil nutrient and water availability in Mali over a rainfall transect. These researchers concluded that water is limiting to plant production when rainfall is below about 300mm, but at higher rainfall, soil nutrients are the limiting factor in biomass growth (Breman and de Wit, 1983). While primarily concerned with rangeland productivity and pastoralism, these results are also relevant to agriculture in the driest parts of the Sahel.

Sustainable agriculture requires the replacement of nutrients removed in harvested crops by nutrient inputs. In the Sahel the most common form of nutrient inputs is manure from livestock. If primary production is limited, then the number of livestock is also limited. This in turn affects the availability of manure for fertilising fields. Thus calculations can be made, based on the rangeland required to feed enough livestock to provide manure to compensate for nutrient losses from harvested crops. The results of these calculations vary, but suggest that the rangeland to cropland ratio cannot exceed 2-4% if agriculture is to be sustainable (Turner, 1994). In reality, it is clear that many regions of the Sahel are cultivated more intensively than these calculations suggest are permissible. Is land degradation occurring, or is there a fundamental flaw in the calculation?

Many researchers who carry out nutrient balance studies would argue that land degradation is occurring. Stoorvogel and Smaling's study of national nutrient balances in Sub-Saharan Africa (SSA) highlighted concerns over soil nutrient depletion in African soils (Stoorvogel and Smaling, 1990). This concern was reinforced by Van Der Pol's study, centred on a region of Mali, which concluded that soil mining was the basis of Sahelian agriculture (Van Der Pol, 1992). In view of these debates, there is a general consensus that soil fertility is declining due to inadequate use of inputs in agriculture, due to poor soil management among Sahelian farmers.

Northern Nigeria is a part of the Sahel (defined in ecological, rather than political terms), and thus research from northern Nigeria can contribute to the debates concerning the sustainability of smallholder farming in this region. Nigeria is more densely populated than its francophone counterparts, and therefore presents a scenario where agriculture has already exceeded the thresholds of intensity which have been suggested by some of the research cited above. Are smallholder farmers in northern Nigeria mining their soils and causing irreversible land degradation, or have they in some way overcome the perceived limitations of Sahelian agriculture, enabling them to intensify agricultural production beyond the theoretically possible?

In the late 1980s the World Bank commissioned a report entitled "The causes, nature and rate of soil degradation in the northernmost states of Nigeria and an assessment of the role of fertiliser in counteracting the problems of degradation". This study was carried out by Mortimore (1989) who reviewed all available material concerning indicators of land degradation to determine whether land degradation was taking place, and if so, how if might be remedied. The purpose of this report is to consider research since Mortimore's study of 1989 relating to smallholder's soil fertility management in northern Nigeria, and in Maradi Department, Niger). Similar soils and cropping systems are the basis of the farming system on both sides of the international boundary. However, within this region there are variations in population density, rainfall, land tenure and economy (due largely to differing colonial agendas in Nigeria and Niger. This review aims to contribute to the debate concerning the effect of changes in agricultural production on soil fertility and land use management.

2 FARMING IN NORTH-EAST NIGERIA AND MARADI DEPARTMENT

2.1 Climate and vegetation

The Kano region and Maradi Department is a semi-arid area which receives rainfall in a single season lasting from two to five months starting in May-July, and finishing in September. Koechlin (1997) divides this area into a Sahelian region (250-550 mm, 8-10 month dry season) and a sub-Sahelian region (550-750 mm rain and a 7-8 month dry season). Rainfall varies in terms of the total rainfall during the rainy season, and its distribution throughout the season. Low and erratic rainfall makes cropping a risky endeavour. In the sub-Sahelian region farmers focus on millet sorghum, groundnut, sesame and cowpea. In the Sahelian region they resort to the most drought-tolerant crops: millet and cowpea (300-550mm). The natural vegetation also changes with declining rainfall, from open forest-savannah to more open savannah grassland interspersed with trees, predominantly *Balanites Aegyptiaca, Faidherbia albida* and *Adansonia digitata.*

2.2 Soil fertility

The soils of this region (defined as the area north of 11^{o} latitude) have been described in general terms as ferruginous tropical soils (D'Hoore, 1964). The majority are developed from aeolian parent materials (Ahn, 1970, McTainsh, 1982) overlying quartz-rich parent materials such as crystalline rocks of basement complex, granite, aeolian or sedimentary deposits (Jones and Wild, 1975). They are predominantly sandy with low water holding capacity, low organic matter, nitrogen and phosphorus content, neutral or moderately acid in pH, and of low cation exchange capacity (Jones and Wild, 1975) (Table 1). The low clay content is made up of kaolinite. They are prone to surface crusting and sealing. The sandy surface soil lies over more compact subsoil due to downward movement of clay through the soil profile. Free iron oxides produce mottles and concretions, and ferruginous hardpan over basement complex. These soils are usually less than 150 cm deep, and therefore the parent material can influence the chemistry of the soils.

[Insert Table 1: landscape]

2.3 Population and agricultural intensity

As already stated, Nigeria is more densely populated than its francophone counterparts, even in its driest areas. Mortimore's study of 1989 presented a map of land use intensity in northern Nigeria which defined three broad categories of farming:

- *Intensive systems*, where permanent, annual or biannual cultivation occurs (Cropping intensity >60%)
- *Less intensive systems*, where shrub or short-bush fallowing is common (Cropping intensity 30-60%)
- *Extensive systems*, where long bush-fallowing systems operate among uncultivated areas (Cropping intensity < 30%)

Within this region lie some of the most densely populated areas of semi-arid West Africa: the close settled zones surrounding major cities such as Sokoto, Katsina, and Kano (Grove, 1962, Mortimore and Wilson, 1965). The Kano Close-settled Zone (CSZ) has been cited as an exceptional region of agricultural intensity, well ahead of other regions, by many observers (Snrech, *et al.*, 1995, Hill, 1977, Mortimore, 1993), and serves as an example of farming practices which areas of increasing agricultural intensity can seek to emulate or adapt to meet their own particular needs (Harris, 1996).

Thus, within the study area lie examples of low intensity and high intensity farming systems. Comparison of these farming systems can provide information on processes of intensification. What happens to soils as farming intensity increases? More interestingly, how do farmers adapt soil fertility management practices to enable farming intensification to occur?

3 MEASURING SOIL FERTILITY CHANGE

3.1 Defining soil fertility

Soil fertility depends on a range of factors, including water, nutrients, aeration, soil structure and beneficial organisms (micro-organisms and meso and macro-fauna). Soil physical properties regulate the amount of water held within soils, through ensuring good drainage while maintaining a structure of micro-pores which can hold water for uptake through the plant root system. Adequate aeration is as important as adequate water supply. Soil texture also affects the likelihood of soil capping and surface crusting, which can facilitate runoff of rainfall and erosion, and prevent seedling emergence. Biological properties of soils determine whether the soil has sufficient beneficial micro-fauna and micro-organisms, and is free from soil-borne plant diseases and pests which can make soil infertile through impeding crop growth. Soil chemistry affects the availability of plant nutrients within the soil. pH and aeration affect the form in which nutrients are found in the soil. CEC (Cation exchange capacity - a function of the amount and type of clay in soils, as well as organic matter content) affects the ability of soils to hold nutrients in a form readily available for uptake by plant roots. Organic matter plays a very large role in determining soil fertility, through its effect on soil structure, cation exchange capacity, water holding capacity, and through the nutrients released as the organic matter break down.

Although soil fertility is the result of a convergence of many soil properties, the concept is often simplified to a consideration of soil nutrient status, and where required, a consideration of erosion hazard and moisture availability (in relation to crop needs). In view of the research indicating that nutrients, not water, are limiting agricultural production (Penning de Vries and Djiteye, 1982), recent research on soil fertility has concentrated on nutrient balances and the chemical fertility of soil, often ignoring the other aspects of soil fertility. In the Kano region and Maradi Department soil fertility is low, whereas soil physical properties are not limiting to production, and soil biological properties (including nitrogen fixation and diseases) are not seen as limiting factors in agricultural production. Hence the research reviewed concentrates on the chemical fertility of soils, and further reference to soil fertility refers to soil nutrient status.

3.2 Measuring soil fertility change

Measurement of changes in soil chemical fertility is often done indirectly, by monitoring crop yields, or economic returns to farming. However these indicators can be affected by other factors, such as variability of rainfall or pests and diseases, which can have a stronger effect on yields than a gradual decline in soil fertility. Indicators of farm yields which are not directly related to soil fertility are inappropriate determinants of soil fertility change. Changes in practices such as use of manure or inorganic fertiliser indicate changes in technologies and management, but may reflect availability and perceived need rather than actually changes in soil properties. The best measurement of trends in soil fertility comes from direct measurement of soil properties. This study will focus on some key indicators of soil physical and chemical properties.

Temporal change in soil properties

The simplest empirical way of studying changes in soil fertility is to monitor a soil fertility parameter (such as percentage organic carbon or amount of available nutrient) at one site over time. Ideally, change is measured against a reliable baseline study of soil fertility parameters. Identical sampling methods and analytical techniques are used to replicate exactly the analysis carried out previously, so that direct comparisons of the results can be made. In practice, well documented baseline studies which can be replicated are not always easy to find, and a more imaginative sampling frame is required. Increasingly, researchers are relying on the assumption that land which has not been cultivated is similar in soil properties to a “baseline” soil situation. Thus a comparison between soil under cultivation, and adjacent soil which has not been brought under cultivation, is considered as valid as returning to a baseline sampling are to repeat soil analyses. This spatial analogue method has been employed by several researchers in semi-arid areas of Africa (Mortimore *et al.*, 1990, Essiet n.d., Yusuf, 1999, Murton, 1999).

Both soil sampling methods rely on representative sampling and reliable soil analyses. However this research approach does not show how (in relation to farmers’ management practices) and when (in relation to time under cultivation) changes in soil fertility occurred, nor does it provide information on the importance of different sources of nutrients. A series of soil analysis over time is required to determine the gradual pattern of soil fertility change in the years since cultivation began as management practices have changed.

Nutrient balance studies

In contrast, nutrient balance studies provide a method of measuring net gain or loss of soil nutrients over a very short period of time (one season) which can be linked to soil fertility management. In these studies nutrient gains and losses are determined by recording the magnitude of inputs and outputs to the soil, and the nutrient content of each substance added or removed. They show whether a particular management regime results in a gain or loss of nutrients to the soil. The results of nutrient balance studies are strongly affected by rainfall: high rainfall increases biomass growth, and therefore nutrient offtake in the harvest, so lowering the nutrient balance. Conversely, in a drought year, farmers will harvest nothing, and the soil will have a high nutrient balance.

Nutrient balances provide a snapshot view of the farming system over the period of measurement (usually one farming season or one calendar year). Sequential balances are required to determine the general trend in soil fertility over several years. Nutrient balances do not take into consideration the complex chemistry of soils which affects the availability of nutrients for uptake by plants. Neither do they consider the temporal variation in soil fertility as nutrient-containing materials applied to the soil such as fertiliser, manure or mulches breakdown and release nutrients into the soil.

Nutrient dynamics

Changes in soil properties need to be related to soil fertility management, and this is extremely difficult under smallholder farming conditions of irregular fertilisation according to availability, cost and quality of purchased inorganic fertiliser inputs or manure. During the course of a nutrient balance study, nutrient flows are identified and quantified. It is useful to compare the direction and magnitude of nutrient flows on farmers' landholdings under differing soil management regimes and the factors regulating those flows. Such studies of nutrient dynamics provide a framework for understanding how farmers manage nutrient inputs, flows within the farmholding, and losses of nutrients from the system. Models of nutrient dynamics can be based on a plot, fields, farmholding, village area or larger unit. Studies of nutrient flows at the farm or village level can provide an understanding of the interaction of factors from which the nutrient deficit arises. Nutrient cycling studies at the farm level offer direct measurement of nutrient inputs and outputs at the level where management decisions are actually made. When working at this scale the constraints affecting management decisions (e.g. knowledge, labour and capital) can be investigated.

[Table 2 insert here: Landscape]

4 FARMING SYSTEMS IN NORTH EAST NIGERIA

4.1 Contrasting farming systems

Soil fertility research has been carried out at four sites within the region which fall on a transect of rainfall and population density (Table 2) and represents the three categories of farming defined by Mortimore in 1989 (Section 2.3). Kaska, in Yobe State, and Futchimiram, in Borno State of north-east Nigeria, represent two low intensity farming systems at the ecological limits of rainfed farming. These had rainfall 349 and 326 mm over the period 1993-1995 respectively (Mortimore and Adams, 1997). Kaska is located in the diverse landscape of the Manga grasslands, where moving dunes, upland *tudu* soils (predominantly rangeland), sloping *faya* soils and *kwari* soils (found in seasonally flooded depressions (*tafki*) provide farmers with a range of soils and environments for agriculture. Futchimiram is found in a more homogenous landscape.

Dagaceri, in Jigawa state of Nigeria is an example of a short fallow farming system undergoing rapid intensification as population densities rise and agricultural expansion approaches its limits. Dagaceri is an agro-pastoral system remote from markets.

Tumbau, in the Kano CSZ, is a highly intensive farming system in a very densely populated area where all land is under cultivation and crop and livestock production systems are fully integrated. This farming system represents a degree of intensification rarely seen in semi-arid areas of West Africa.

4.2 A transect of agricultural intensification

Table 2 summarises the four farming systems studied. Although there are differences in the environment, particularly the unusual *tafki* surrounding Kaska, these farming systems are based on similar soils and rely on the same major crops. All except Tumbau are agro-pastoralist systems. Kaska, Futchimiram, Maradi and Dagaceri have receive fairly similar amounts of rainfall. Tumbau is considerably different in terms of rainfall and population density, which alters the range of crops, grasses and trees which grow in the area, and the productivity of these species. Furthermore, in Tumbau, agriculture and pastoralism have been fully integrated. There is a gradient in population density from the lowest-intensity farming systems in Futchimiram and Kaska, through the short-fallow farming system of Dagaceri, to the intensive system of annual cultivation in the Kano CSZ. These farming systems represent the three broad categories of land management described by Mortimore. The rise in population density from Futchimiram through Kaska, Dagaceri and Maradi to Tumbau can be seen as steps along an intensification pathway : a spatial analogue of temporal change (Mortimore and Adams, 1997).

4.3 Land use change since 1950

The landscape of northern Nigeria is a mosaic of rangeland and farmland. Within farmland, a division can be made between compound or in-fields and bush fields, which results in a ring system of concentric circles of decreasing cultivation intensity moving outward from a village (Prudencio, 1993). As food requirements increase with increasing population, farmers expand the cultivated area, and opportunities for itinerant agriculture with long fallow period of recuperative fallow disappear. Over the last forty years, the cultivated area in northern Nigeria has increased from 11% of the total area to 34% (Silviconsult, 1991).

Table 3 indicates changes in land use, determined by air photo interpretation, in the four villages located in Nigeria (Turner, 1997). In Futchimiram the percentage of land under cultivation has remained constant over this time period, however the amount of grassland has increased from 46% to 62% of the land area, as open woodland has been reduced by 23%, and the amount of degraded or sparsely vegetated land has increased to 7.5%. In this area farmers practice a form of shifting cultivation, where areas are cultivated for a few years, and then allowed to return to rangeland. The land use data suggest that woodland is being cleared to create more rangeland. It may be that cleared land is being used temporarily for cropping before becoming rangeland.

Land use change in Kaska appears more complex. Arable upland has increased by 10 %, presumably at the expense of grass upland which has reduced by the same amount between 1950 and 1990. However this situation may be more complex, as the area covered by active dunes have increased by almost 20%, and open woodland first increased and then decreased. Arable lowland has reduced by almost 15%. The dry period of the early 1970's and the later drought in 1984, may have contributed to the increase in moving dunes.

There has been a large increase in the arable area in Dagaceri, which changed from 35% to 56% between 1950 and 1969, and since then has remained more or less constant, at 55%. This has been mostly at the expense of grass upland, which has reduced by 15%, and partly at the expense of woodland. It is intriguing to note that between 1969 and 1981 there was no further increase in cultivated area. This raises the questions as to what farmers have done to increase their agricultural output. Has agricultural expansion been stopped by pastoralists insisting on the need to preserve remaining rangeland for livestock production, or is there a point at which farmers feel that the increased distance from household to fields is more troublesome than the increased effort required to maintain soil fertility on existing agricultural land? Degraded land has increased from 2% to 11% over the 30 year period.

In Tumbau more than 75% of the land was under cultivation in 1950, and this has increased to almost 90%. Effectively, all available land is under annual cultivation now. Unlike Dagaceri, the amount of degraded land is under 10%. However, in contrast to the other three villages, settlement takes up much more land area.

This information on land use change needs to be considered in relation to measurements of soil fertility to assess whether each farming system is maintaining or degrading the fertility of the soils, and its long-term sustainability.

[Tables 3 and 4 inserted here : Landscape.]

5 STUDIES OF SOIL FERTILITY IN NORTHERN NIGERIA

5.1 Low intensity farming systems

In Futchimiram, results of analysis of soil under cultivation (Yusuf, 1999) (Table 4) compared with control sites (spatial analogue method to identify temporal change in soil fertility) shows that long cultivation resulted in an increase in sand, and reduction in clay and silt fraction. Cultivation was also associated with a reduction in pH, from 6.4 to 5.9. There was no change in organic carbon or nitrogen status of the soil. Cultivation also reduced the water holding capacity of soils by 2-3%. Fallowing did not restore soils to their original status.

In Kaska, upland *tudu* and lowland *faya* soils are broadly similar (Yusuf, 1999) (Table 5): lowland soils would appear to have a lower pH and higher available phosphorus and water holding capacity, which is surprising considering the similarity in organic carbon and soil texture. Wetland *kwari* soils have significantly different soil texture (64% sand, 35.9 % silt + clay). Cultivation of *tudu* soils reduced the organic carbon levels from 0.19% to 0.08%. Cultivation led to an increase in sand fraction at the expense of the silt and clay fractions in all the soils. In these low intensity farming systems it would appear that agriculture has the biggest effect on soil texture, rather than soil nutrient status. This may be due to the effect of cultivation in encouraging erosion (Folorunsho, 1999).

5.2 Medium intensity short-fallow farming systems

The very high intensity and very low intensity farming systems present the two extremes of a gradient of farming practices. The majority of farming in semi-arid areas is carried out as a semi-permanent, short-fallow farming system (Ruthenberg, 1974). As populations increase, this is the farming system that will either degrade, or evolve through intensification. Dagaceri village is an example of such a farming system.

Farmers in Dagaceri distinguish three local soil types, on the basis of colour and texture. White soils (Hausa: *Keza-keza*) are located on the higher slopes and crests of dunes, red soils (Hausa: *Katikime*) are located on lower dune slopes, and black soils (Hausa: *Tulo-tulo*) are located in depressions where finer material and water accumulate during the rainy season. White soils have higher sand content, and lower silt and clay content than red and black soils. Black soils have the lowest sand content, and highest silt and clay content. All three soil types contain negligible amounts of nitrogen, are low in organic C status, but contain surprisingly high amounts of available phosphorus.

[Table 5: landscape]

[Table 6 : landscape]

[Table 7: landscape]

Soil analysis using the spatial analogue method (Essiet, n.d., Table 6) showed that:

- cultivation appears to reduce sand content and increase clay content of white soils, the effect of which is only slightly reduced by long fallow;
- acidification occurs in red soils under long cultivation, which is not remedied by long fallow;
- organic carbon declines in soils under long cultivation, which is reversed under long fallow;
- high available phosphorus is present in white soils, but declines under cultivation;
- phosphorus levels were extremely low in red soils, but increased dramatically (1-66 ppm) in soils under long cultivation.

Essiet concluded that:

- cultivation resulted in loss of clay in all soil categories except the white soils;
- an increase in organic carbon levels is required to make best use of any applied fertiliser;
- local farmers believed that white soils were best, followed by red soils and then black soils - the chemical analysis supports these local perceptions.

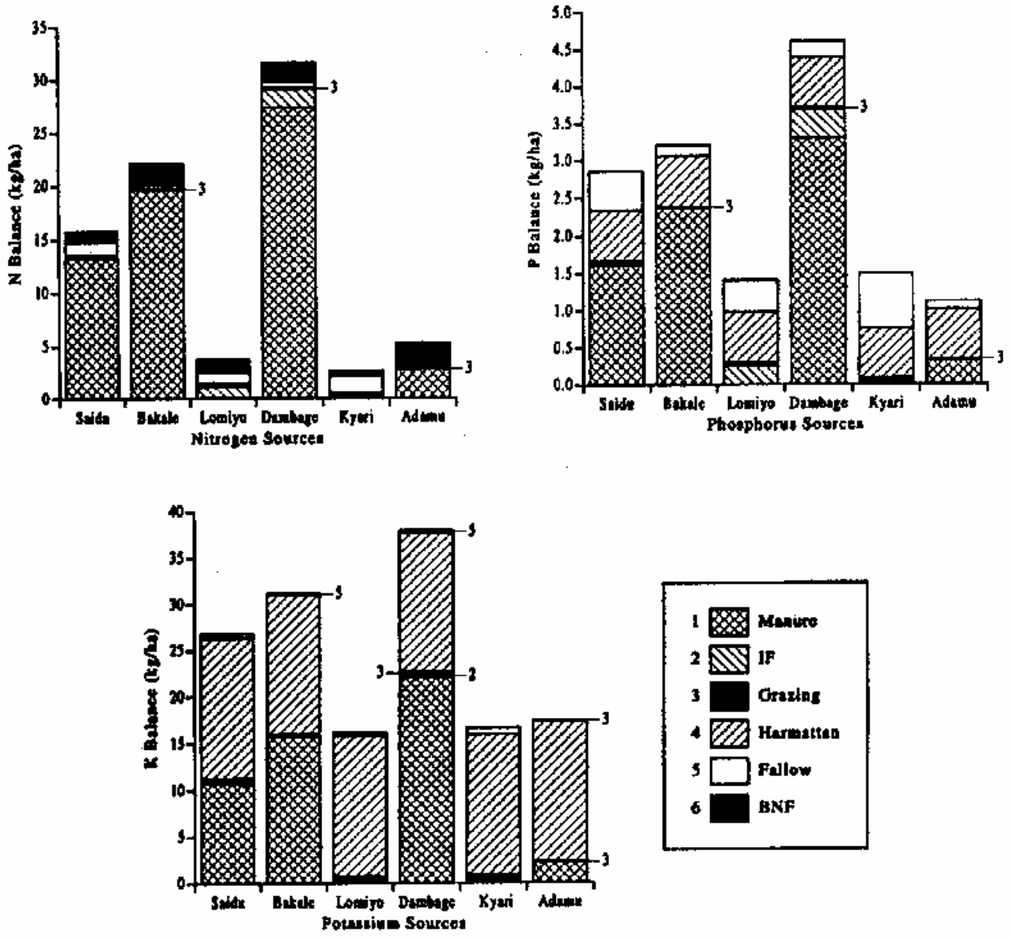
A more detailed study of the effect of soil management on soil properties was carried out in Dagaceri, by Yusuf (1999) (Table 7). Yusuf considered the same white, red and black soils, under management regimes of long fallow, rotational manuring (white soils only), and long cultivation, and compared these to uncultivated soils. Conclusions to be drawn from his study are as follows.

- Cultivation results in a decline in the sand fraction in red and black soils when cultivated, but not in white soils.
- Acidification of white soils occurs under cultivation, but this effect is less pronounced on red and black soils.
- Cultivation on white and black soils reduces available phosphorus, but the opposite effect is seen on red soils.
- Organic carbon is reduced when soils come under cultivation, but rotational manuring of white soils managed to restore the organic carbon levels to their initial status.

Yusuf concluded that intensive cultivation results in a reduction in clay content and increase in sand. However Folorunsho (1999) argued that this change in soil texture is due to erosion under continuous cultivation.

A nutrient balance study in Dagaceri focussed on six farmers who practised contrasting soil fertility management strategies (Table 8, Harris 1999). Figure 1 shows the inputs of nitrogen, phosphorus and potassium into the farming system under the six contrasting management strategies, and illustrates the potential importance of manure as a source of nitrogen, which is only appreciated by those who are able to manure their land (see below for a discussion of constraints to using manure). Chemical fertilisers, which are more expensive and not reliably available, are less significant contributors of nutrients. The gain from nitrogen fixation is limited by the amount of legumes included in the crop rotations. Dagaceri is a marginal groundnut area, and most farmers grow cowpeas

Figure 1: Inputs of nitrogen, phosphorus and potassium in the short-fallow farming system of Dagaceri



intercropped with cereals. The density of cowpea in the crop mixture is low. Harmattan dust makes a significant contribution to phosphorus and potassium inputs. Figure 2 shows the nutrient balances achieved by the six farmers. The best nutrient balances are on those farmers which are under an intensive manuring programme. Farmers who rely on fallowing or very low inputs have the most negative balances.

Table 8: Soil fertility management strategies of six farmers in Dagaceri

Farmer	Description	Soil fertility management strategy
Salisu	A Fulani herder and farmer	Corralling of cattle herd on farmland
Baburi	A large landowner who was also owned a plough and cart	Intensive manuring
Lawani	A small landowner who recently lost his cart (broken)	Inorganic fertiliser
Dogari	A small landowner who practised intensive manuring on all his fields	Intensive manuring and inorganic fertiliser
Kalari	A large landowner who practises fallow rotation	Fallowing
Audu	A large landowner practising short-fallow rotation and intensive manuring	Fallowing

Figure 3 describes the nutrient flows within this transitional short-fallow farming system. The nutrient cycle shows two systems which are operating in parallel: that of rangeland which is grazed by livestock and receives their manure in return, and that of farmland which is manured by livestock from the village and farmers' compounds, and produces crop residues to feed the livestock. The two systems are linked by nutrient transfers between them, and common management.

Within this framework each farmer employs a nutrient management strategy to influence flows over which he has control. These strategies to gain the main three nutrients important to maintain soil fertility are clearly seen in Table 8. Salisu relies on corralling cattle, and the manure they supply for his farmland. Dogari and Baburi manure their land intensively. Audu does manure some of his land, but tends to rely on fallowing land, as does Kalari. Both Lawani and Dogari used inorganic fertiliser. Lawani has insufficient land for fallowing to be an important strategy in his system. Kalari relied on fallow to provide 70% of the nitrogen inputs, about 50% of the phosphorus inputs, and 80-90% of the potassium inputs into his land.

5.3 High intensity farming systems

The Land Resources Division carried out a survey of the Kano plains area (Wall, 1979) which included soil sampling and analysis, and this has provided a baseline for later work concerning soil fertility change. A study investigating the limits to intensification of farming in the Kano CSZ (Mortimore, Essiet and Patrick 1990) returned to the exact sampling sites visited in 1977 and took fresh soil samples, to study changes in soil

Figure 2: Nutrient balances of six farmers in the short-fallow system of Dagaceri

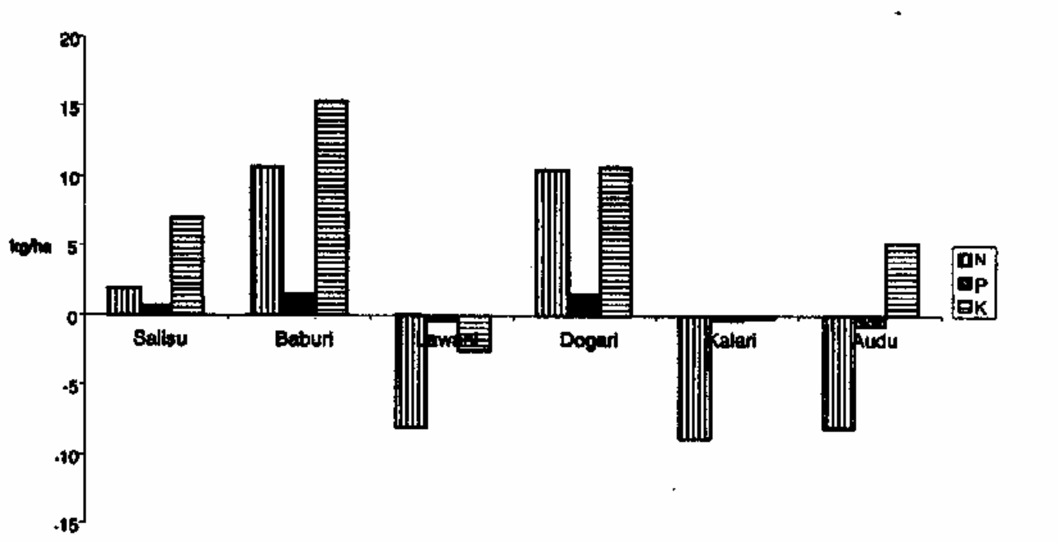
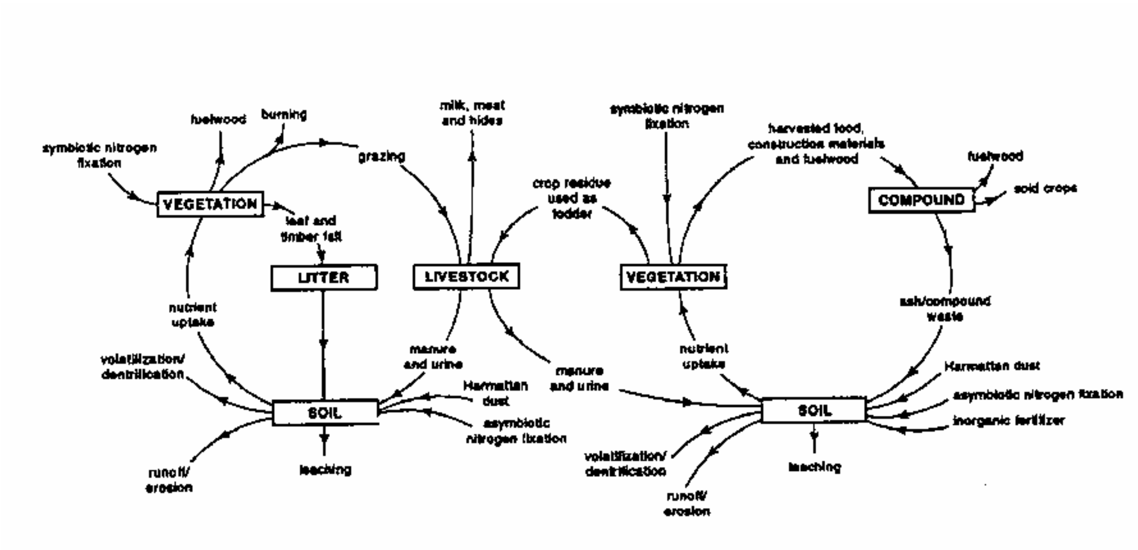


Figure 3: Model of nutrient cycling in a short-fallow farming system (Harris, 1999)



fertility parameters over the intervening thirteen years (Table 9). Over a period of 13 years bulk density, particle size distribution, percent organic carbon, total nitrogen, pH, cation exchange capacity, and exchangeable calcium, magnesium and sodium were stable. Neither was there any evidence of yield decline. Although the soils have low fertility levels, they are not degraded. The study concluded that "the farming system of the CSZ is sustainable in an ecological sense in the short and medium term" (say 30 years) (Mortimore *et al*., 1990: 83). It also found that "the maintenance of soil fertility is the prime objective of small-holder management" (Mortimore *et al*., 1990).

Table 9: Changes in soil fertility in the Kano Close-settled Zone over 13 years

Land System	Year	Sand (%)	Silt (%)	Clay (%)	Bulk density	pH	Org C (%)	Total N	CEC Me%
307/329	1977	91	6	4	1.37		.296	.030	2.4
	1990	90	5	4	1.38		.221	.037	3.0
333	1977	92	5	4	1.39		.234	.029	2.1
	1990	89	8	4	1.40		.211	.033	2.1
335	1977	89	7	4	1.40		.149	.026	3.2
	1990	92	4	5	1.44		.165	.027	1.0
All	1977	90	6	4	1.38		.237	.029	2.4
	1990	91	6	4	1.40		.205	.033	2.2
Cultivated upland	1977	83	8	9	1.29	6.3	.226	.034	2.7
	1990	90	6	4	1.37	6.7	.202	.027	6.2
Forest reserve	1977	84	13	3	1.23	5.5	.264	.036	5.2
	1990	89	6	6	1.34	6.8	.176	.025	5.4

Wall *et al*., 1979, Mortimore, 1989.

This research was followed by a further study of soil fertility change, using the spatial analogue method (Yusuf, 1999) (Table 10). Yusuf identified seven management classes, and analysed samples from each class. Yusuf's data suggest a decline in clay and silt fractions due to cultivation, and a rise in soil pH.

The same area was the focus of a nutrient balance study (Harris 1996, 1999). This case study focused on three farmers with contrasting resources. The research was carried out over two full calendar years (1993 and 1994). The results, presented in Figure 4, show how variable nutrient balances can be, from year to year and farmer to farmer. Individual fields varied dramatically. Overall, Figure 4 indicates that the cations K, Mg and Ca are well supplied, whereas N and P are more critical to the system. The role of rainfall in determining the size of the harvest, and therefore nutrient offtake, was seen to be important in affecting each year's balance. The long-term average is a better indicator of the sustainability of the system over the longer term.

Table 10: Effect of management on soil properties in Tumbau, the Kano close-settled zone (Yusuf, 1999)

Management	Sand (%)	Silt (%)	Clay (%)	pH	Org C (%)	Total N (%)	Avail P (ppm)	WHC
Uncultivated	81	15.5	3.6	5.7	0.56	0.02	16	16
Short fallow	83	15	2	5.4	0.27	0.02	16	16
Rotational manuring	83	15.2	1.7	4.7	0.69	0.03	19	19
Annual manuring	83	14.7	2	6.3	0.42	0.03	18	18
Inorganic fertiliser	88	11.3	1.2	6.0	0.26	0.04	15	15
Long cultivation with inorganic fertiliser and manure	83	14.5	2.3	6.0	0.47	0.02	19	19
Continuous cultivation	85	14	1.4	6.0	0.65	0.02.	17	17

Figure 4: Nutrient balances of three farmers in the intensive farming system of the Kano close-settled zone (Harris, 1996)

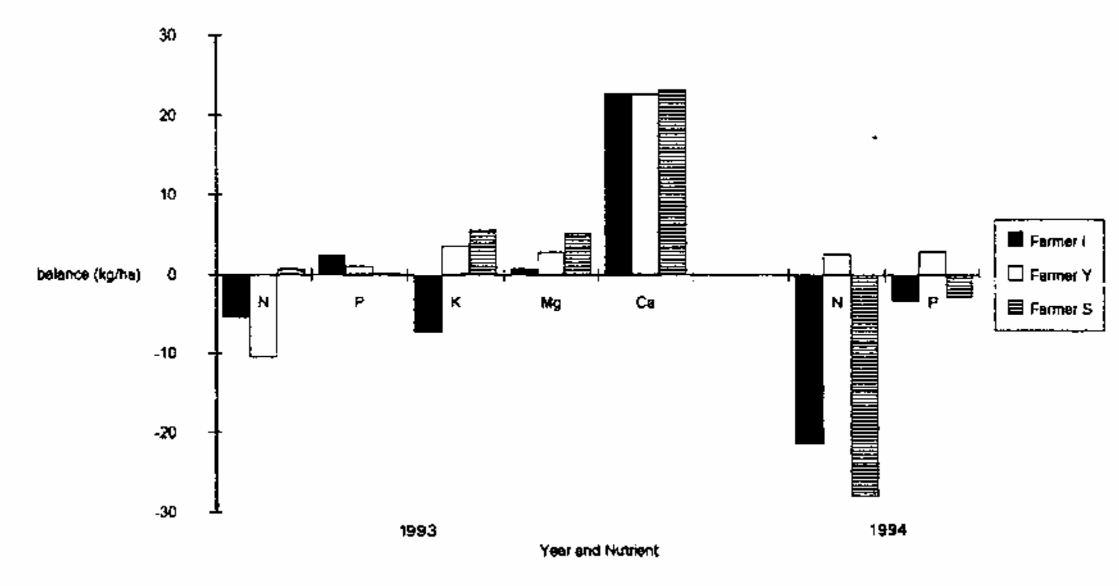
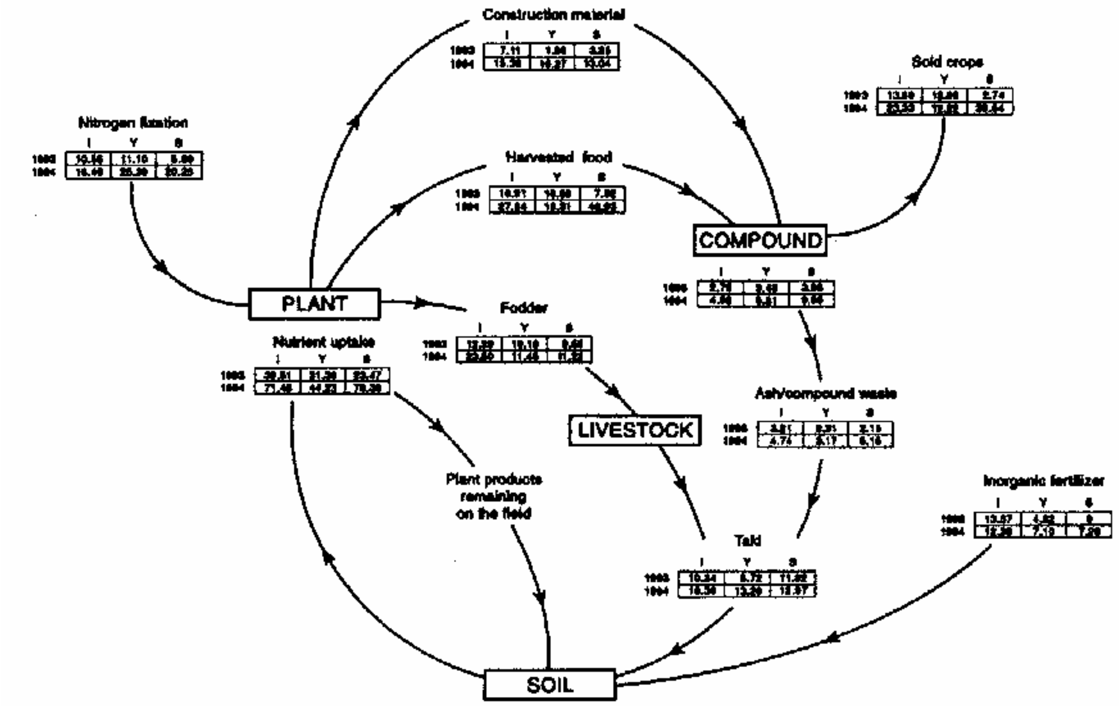


Figure 5: Model of nitrogen cycling in the Kano close-settled zone (Harris, 1998a)



Of far more interest than the nutrient balance alone is the information which the research provided concerning nutrient dynamics in the farming system: the magnitude and direction of nutrient flows and transfers onto and off the farmholding, and within the farmholding between fields, the compound, and livestock. The balance varied from farmholding to farmholding, according to the ability of the farmer to manage the dynamics of nutrient flows between fields and the compound, and between crops and livestock (Figure 5).

6 FARMING SYSTEMS IN MARADI DEPARTMENT, NIGER

The *département* of Maradi is a region in Niger with comparable rainfall (400-600 mm) and soils to that of the villages discussed in north east Nigeria (Issaka, 2000). Agriculture is based on sandy soils composed of aeolian material overlying basement complex (Feau, 1977). The farming system is based on the same crops: millet, cowpea, sorghum, and some groundnut (Grégoire, 1980). Within Maradi Department are four villages which have been the sites of research on soil fertility management and agricultural change. Like the villages of Nigeria, the villages of Dan Kullu, Sharken Hausa, Magami and Jiratawa also represent a gradient of rainfall and population density (Table 11), with Dan Kullu suffering from the most severe climatic constraints with a rainfall of 350mm, Sharken Hausa 400, and Jiratawa and Magami receiving an average of 450 mm from 1968-87.

In a study of soil and vegetation (Feau, 1980) it was clear that all of the region was affected by human presence, seen as bush clearing, agriculture or rangeland. Grégoire's detailed study in the village of Gourjae (1980) described a ring system of cultivation surrounding the villages, where manured infields could be clearly distinguished from non-manured outfields by air photo interpretation. Manuring resulted in greater organic matter on fields, and a darker coloured soil. The same effect was seen in the area surrounding the corral sight at Peul encampments. Comparison of air photos from 1957 and 1976 shows that there had been a reduction in fallow land (Grégoire, 1980).

7 STUDIES OF SOIL FERTILITY IN MARADI DEPARTMENT

In 1990, Issaka returned to Maradi Department to measure changes in soil fertility in these four villages, using the spatial analogue method (Issaka, 2000) (Table 11). Soil samples were taken from areas which had not been cultivated for 50 years, land under fallow for 20 years and currently used as pasture, land under continuous cultivation for 30 years without any addition of inorganic fertiliser, and land under continuous cultivation for 30 years receiving occasional inputs of manure and inorganic fertiliser.

It should be noted that Issaka assumed that long-term fallow (50 years) regenerates soil fertility. However Issaka's results indicate the fallow land and pasture land were not always of higher fertility than land under cultivation. In Dan Kullu, an absence of land under fallow for 50 years resulted in the "baseline" being land fallowed for 10 years.

Table 11: Effect of management on soil properties in four villages in Maradi Department

Management	pH	Org C (%)	Total N (%)	Assimilable P (ppm)
Jiratawa				
Without fertiliser	5.6	0.16	0.006	3.6
With fertiliser	5.8	0.25	0.023	11.0
Rangeland	6.4	0.13	0.004	11.0
Fallow 50 years	6.5	0.40	0.003	15.6
Magami				
Without fertiliser	5.3	0.15	0.003	1.0
With fertiliser	5.3	0.21	0.004	1.9
Rangeland	5.5	0.17	0.004	3.3
Fallow 50 years	5.1	0.20	0.005	3.4
Sharken Hausa				
Without fertiliser	5.4	0.11	.003	2.3
With fertiliser	5.8	0.17	.005	3.6
Rangeland	5.7	0.20	.007	5.8
Fallow 50 years	5.6	0.15	.006	4.2
Dan Kullu				
Without fertiliser	5.7	0.08	.002	0.6
With fertiliser	5.7	0.11	.003	1.8
Rangeland	5.5	0.10	.002	1.7
Fallow 10 years	5.4	0.13	.003	1.4

Source: Survey, Issaka, 2000.

In Dan Kullu, the driest village of the transect, soils cultivated without inputs had the poorest soil chemical properties (but not the lowest pH, which occurred on land fallowed for 10 years). In Magami, organic matter and carbon levels were highest on fallow and fertilised fields. Phosphorus and nitrogen were highest on rangeland and in fallow fields. In Jiratawa, phosphorus, organic mater, carbon and pH were highest on land which had been fallowed for 50 years. In general, the results show that land under continuous cultivation without inputs, and rangeland, both suffer soil fertility decline. However, the use of low levels of inputs has a marked effect on soil fertility in the cultivated soils.

Feau's study (1977) provided a baseline of soil sampling in Sharken Hausa to which Issaka returned in the late 1990's. He returned to an area in Sharken Hausa where the results of analysis of three profiles in 1977 were available. Each site is under continuous cultivation without inorganic fertiliser. Over the 12 year period, soil pH had diminished by one unit, calcium had increased by 40%, magnesium and potassium had decreased slightly, sodium had increased slightly, and organic carbon had diminished by 50% (Issaka, 2000).

8 SOIL FERTILITY MANAGEMENT STRATEGIES

The results from Nigeria show that the range of soil fertility management technologies practised in each village increases with the intensity of the farming system. Comparable information is not available in Issaka's study in Niger, though previous research by Feau (1977), Grégoire (1980) and others suggest that the same is true for the farming systems in Maradi. Combined with the increasing differentiation in soil types, the systems become more complex as they become more intensive. Fallowing, crop rotation, nitrogen fixation, night parking of livestock, cut-and-carry feeding with manuring of fields, and inorganic fertiliser are the options accessible to farmers. These can broadly be defined as strategies relying on external inputs (such as inorganic fertiliser or manure from off-farm sources), and strategies relying on recycling of nutrients within the farming system.

8.1 Fallowing

Farmers vary the activities on a single plot of land, in the belief that some practices will lead to nutrient accrual which can benefit crops in subsequent years. A fallow-crop sequence is believed to benefit the crop, which can make use of nutrients accumulated in the soil during the fallow period. However under semi-arid conditions, nutrient accrual under fallow is extremely low. Low rainfall conditions mean that vegetation growth is slow (in comparison to sub-humid and humid regions), and therefore the gain in soil organic matter is slow. More significantly, fallow land in these regions is not abandoned completely: it is still seen as a source of fodder for grazing livestock, and shrubs and trees are sources of fuelwood and browse. Grasses may also be cut for thatch, and useful products of trees and shrubs may be collected for food, medicinal purposes, or if they have economic value. The result is that land under fallow is in reality still harvested for a variety of products, which results in nutrient removal. Nutrient inputs in fallow land have been estimated to be 2 kg N/ha, 1.57 kg P/ha on fallow land protected from nutrient offtake, but -3.56 kg N/ha. 0.22 kg P/ha on fallow land which is grazed and from which fuelwood is harvested (Harris, 1998b).

8.2 Manure from grazing livestock: night parking

In many regions of semi-arid West Africa farming is practised alongside pastoralism. As agricultural expansion encroaches on rangeland, and farmers face a need for soil fertility improvement, arrangements are made to exchange access to crop residues on fields for livestock manure. The simplest manner is for farmers to leave residues lying in the field, and allow pastoralists' livestock to graze the residues. Livestock leave manure and urine on the field, returning nutrients to the cycle. However the amount of manure left on the fields by grazing animals is very small (Powell and Mohamed-Saleem, 1987), because animals usually void at night or early in the morning, a time when they are usually in kraals, or being watered. Monitoring dry season grazing practices Powell (1986) determined that over six months, an average of 111 kg/ha dm of manure was left on the fields. Given the small quantity, wide dispersion and the amount of time it remained on the soil surface before incorporation into the soil, he concluded that this would have a limited effect on soil fertility.

Therefore, to enhance fertilisation of their fields, some farmers enter into "contracts" with herders, in which an arrangement is made for herders to "park" their animals on a specific field for several nights. Powell (1986) found that the major contribution of cattle to soil fertility was through overnight grazing on fields during the dry or early wet seasons. One half of his sample of 22 farmers arranged with Fulani herders to camp their animals on their fields. In this arrangement, approximately 50 cattle are kraaled on an area of approximately 0.04 ha, for five nights. The average herd produced 275 kg dm in this time, equivalent to 6875 kg manure/ha, which contained 41 kg N/ha, and 10 kg P/ha. Such "night parking" has been recorded in Kaduna state (Powell and Mohamed-Saleem, 1987), Niger (Williams *et al*., 1995) and Mali (Schlecht *et al*., 1995). As the rains approach, the nutrient quality of manure improves. Ideally parking arrangements take place just before or at the onset of the rains. To avoid compaction of the soil, animals are parked on the fields for only two or three nights. During the wet season, parking can supply 5,500 kg manure/ha, containing 104 kg N/ha, and 15 kg P/ha. In general, such fertilisation occurs every two years.

This arrangement transfers nutrients from rangeland, where livestock graze and take in nutrients, to farmland, where livestock deposit nutrients as manure. From the farmer's point of view, it is an external source of inputs: the farmer gains nitrogen from outside his landholding. However, it is a not a new source of nutrients to the region, and ultimately rangeland is degraded at the expense of farmland. Livestock-mediated transfers of nutrients from rangeland to crop land are beneficial to the individual farmer as a source of nutrients for his fields (which doesn't require much payment), but are only an internal transfer within the farming system, rather than a sustainable source of nutrients from external resources.

8.3 Atmospheric inputs: Nitrogen fixation and Harmattan dust

Semi-arid West Africa is subjected to seasonal dust deposition resulting from the Harmattan wind. This dust contains a range of micro-nutrients, and also large amounts of magnesium, calcium and potassium (McTainsh 1982). Small amounts of phosphorus are also carried in the dust. Each Harmattan season leaves a small layer of sediment on farmland. Although farmers cannot control the amount of Harmattan dust which arrives each year, this is an important input into the system (Harris, 1998a).

Symbiotic nitrogen fixation is a potential source of nitrogen inputs into the farming system for those farmers who cultivate legumes, and is the most obvious way to increase nitrogen inputs at low cost. In low and medium-intensity farming systems, the nutrient gain through nitrogen fixation is extremely low, mostly because farmers plant very few legumes. Farmers could increase nitrogen fixation by planting cowpea more densely in the fields. Giller and Wilson (1991) quote examples of nitrogen fixation by *Vigna unguiculata* in Nigeria reaching 47-120 kg N/ha. While farmers may not be able to achieve such high rates of fixation, a more likely achievement of an input of 25 kg/ha would still have an important effect on the nutrient balance. In addition to increasing nitrogen fixation, this would provide greater harvest of a valuable and nutritious crop, provide fodder for animals (who would convert it to manure) and it could provide greater cash income to the farming household.

Both groundnut and cowpea cultivation require labour inputs. Groundnuts are separated from the haulms by hand, and this takes many days of manual labour, usually done by women and children. Cowpeas are harvested daily over a lengthy period, which is again a task performed by women. The benefit of legumes haulms and hay for livestock fodder is only realised if farmers collect them from fields at harvest time. This too can increase the labour burden on farm households. This could be reduced if legumes are planted densely in one field, and legume cultivation is done in rotation around all fields.

8.4 Compound waste

Compound waste, which includes manure from livestock tethered in or near the compound, household waste and cooking ash, is a valued source of soil amendment. Its composition is highly variable and it is often of low nutritive value, due to storage methods (Harris, 2000, Lekasi *et al.*, 1998). Therefore large applications of compound waste must be made if it is to have any effect on soil physical or chemical properties. Compound waste is available to the farmer without the need for any cash payment, however it does required considerable labour inputs to transfer manure from the compound to fields. Headloading is only feasible for those fields located closest to the village. Transfer of manure to further fields requires ownership of, or access to, carts and /or draught animals.

When manure from the compound is gained through livestock grazing rangeland during the day, the nutrients come from outside the farmholding, but within the farming system (as in the case of 6.2) (e.g. Harris 1999). However if livestock are fed on crop residues from the farmer's fields, the input is not external, but results from a recycling of existing nutrients under the farmers' management (e.g. Harris, 1996).

8.5 Inorganic fertilisers

Inorganic fertilisers are the simplest way to add specific nutrients to soil in high concentrations. However inorganic fertiliser is not reliably available in Nigeria. In theory a range of types of fertiliser can be purchased during the rainy season, but in practice, these are often not available until a month or two after the rains have come. Even when available, the price can prevent farmers from purchasing it as late supplies or shortages encourage an active black market. However those farmers who are unable to manure their fields (whether due to lack of manure or labour) are aware of the need to provide some fertiliser to their soils, and try to buy some inorganic fertiliser. Many farmers only buy one or two bags of fertiliser, and some buy fertiliser by the bowl full (*mudu*), as they cannot afford to buy a whole bag. The types of fertiliser available vary from year to year, and choice is not wide. Due to their cost, inorganic fertilisers are usually distributed by hand, allowing farmers to target them to specific crops within the intercropped field (usually cereals).

8.6 Nutrient cycling through crop-livestock integration

As the need for manure to fertiliser fields increases, many farmers are keeping their livestock in their compounds, and feeding them on crop residues harvested from their fields. By doing this, farmers ensure that nutrients in their crop residues are consumed by their livestock, and that all the manure their livestock produce can be returned to their fields. In extensive and short-fallow farming systems farmers may supplement the supply of their own crop residues by sending livestock out to graze rangeland during the day. However in the Kano CSZ, where there is virtually no land for grazing, farmers are forced to produce livestock fodder from their fields. Legumes become more important, as they provide a protein-rich source of fodder to consume alongside the crop residues.

This integration of crop and livestock production demands high labour inputs, to harvest fodder and transport manure to the fields. However it enables farmers to manage and control nutrient flows according to their needs, and reduces nutrient losses from the system. Integration of crop and livestock production enhances nutrient recycling and conserves nutrients within the farmholding. If legumes are grown and are fixing nitrogen, it provides an input to the farming system. Sale of legume grain provides income, which can be used to invest in inorganic fertiliser for soil fertility improvement, or in non-farming activities to diversify the livelihood system.

Less densely populated areas are more prone to labour scarcity, which can limit the process of agricultural intensification (Boserup, 1965). Crop-livestock integration requires high labour inputs, as bulky crop residues and heavy manure and compost are transferred from the fields to the compound, and then back to the fields. Distance from the compound to fields also affects farmers' ability to harvest crop residues for use as fodder and manure fields. In the less densely populated countries of francophone West Africa, farm sizes are larger (commonly 3-10 ha), and more fields are further from the household. Livestock populations are also lower, so that there is less manure to fertilise fields, even if sufficient fodder is available (Williams *et al.*, 1995). Legumes play a minor role in such systems, and therefore the potential benefits they provide in terms of nitrogen fixation, high protein livestock fodder, and a saleable cash crop are not fully realised.

9 DISCUSSION

The eight farming systems referred to are small examples of the range of farming systems in northern Nigeria and Maradi. In low-intensity farming systems, the range of soil fertility management techniques practised on soil is low. Farmers rely on fallowing, and possibly some return of nutrients to farmers' field during dry-season grazing by livestock. As fallow periods are shortened and cultivation intensity rises farmers alter their practices to enable them to maintain or improve yields on declining land area per person: planting densities increase and intercroppping patterns become more complex. Manure from grazing animals is more highly valued, and more elaborate strategies for encouraging livestock to graze fields are employed. These inputs come from within the farming region. In the long term, they can result in soil nutrient depletion across the whole farming system. However, farmers may not see the negative effects of rangeland to cropland nutrient transfers for some time. In short-fallow farming systems farmers increasing rely on manure, compost and household waste to improve soil fertility. For example, in Dagaceri, complex nutrient flows are the result of individuals' strategies of crop-livestock integration. Some farmers use grazing livestock to transport nutrients from common-access rangeland to farmland. Others integrate crop and livestock production more fully, approaching the fully integrated nutrient cycling system of the Kano CSZ. As soil fertility becomes a higher priority, farmers purchase fertiliser, or tether animals in compounds and carry manure to the fields. Ultimately, zero-grazing systems which involve cut and carry feeding of cereal and legume residues and high labour inputs to ensure manuring (on rotation or annually) are adopted. Tumbau has the most complex intercropping systems (Harris, unpublished data, Van Ek, unpublished data), and the greatest range of farming technologies. In such a farming system nutrients are recycled internally, and nutrients are gained through nitrogen fixation and moderate use of inorganic fertilisers. Throughout the transect of intensification studied, the option of intensifying production through greater crop-livestock integration allows farmers to remain in their communities and on their land, rather than leaving the village to seek work in urban centres.

Soil fertility research has evolved from land capability classifications in which soil surveys predicted what could be grown successfully in an area, to a greater understanding of human factors which affect soil fertility management. Within each farming system are a range of individuals practising soil fertility management according to the individual resources available to them. Under conditions of low labour to land ratios it is sensible that a farmer should operate an extensive slash and burn system as it provides the best return for low inputs of farm labour (Boserup, 1965, Netting, 1993). At higher labour to land rations, farmers may engage in more labour intensive soil fertility management strategies. Integrated nutrient management involve using all the resources available, including labour (depending on family size and ability to hire labour), livestock manure, draught animal power, crop varieties, fertilisers and knowledge to work on the land which they have access to. The availability of these resources will vary according to the prevailing natural and socio-economic environment: rainfall, availability of purchased inputs, economics of the farming system, and population pressure. Thus individual farmers, and farming communities must be responsive to their environments, resulting in a dynamic process of soil fertility management.

Pieri (1989) reviewed 30 years of research on soil fertility in the West African Sahel and concluded that these farming systems were sustainable at low output levels. However it is clear that populations will continue to increase, and therefore there is a need to intensify production in these systems. The examples of the Kano CSZ and Mossi Plateau show that the limits of low-external input agricultural systems lie beyond what is currently practised in most parts of Sahelian West Africa. Population density is a limiting factor: at low population densities the distance of fields, and the labour required for efficient nutrient recycling, limit production (Harris, 1996). Crop livestock integration overcomes the initial constraints to agricultural intensification by providing organic matter, transportation, income diversification (through production of livestock as well as crops) and animal traction (McIntyre, Bourzat and Pingali, 1992). Successful integration also involves an increase in legume production within the system to provides fodder for livestock (and organic matter to be recycled to the fields as manure), increases inputs of nitrogen through nitrogen fixation, and, through the sale of legume grain, provides cash which may be used to invest in inorganic fertilisers.

Integration of crop and livestock production to enhance nutrient cycling is not simply a technical solution. Efficient nutrient cycling requires significant resources of labour: transportation to collect and store crop residues; provision of water and daily fee to livestock tended in compounds; manure storage and subsequent transfer to fields; and spreading of manure prior to incorporation into the soil. In densely populated areas such as the Kano CSZ it becomes possible for farmers to adopt these more labour-intensive farming practices which conserve soil fertility through improved nutrient cycling (Boserup, 1965). However there are a range of other factors which have contributed to the success of the Kano CSZ, and are prerequisites to successful intensification of agricultural production. These include labour (more readily available in a densely populated area), high livestock density, land tenure, dispersed settlement patterns and the absence of infields, investment in oxen, ploughs and carts, diversity in the farming system, and low dependence on external inputs (Harris, 1996).

The tasks involved in intensive integrated crop-livestock farming systems require efforts from the household labour force, and must be fitted into a demanding schedule which includes farming, household maintenance, child care and food preparation, as well as other activities. There may be trade-offs concerning labour allocation to other income-generating activities (e.g. food preparation and selling or migrant work) (Mortimore and Adams, 1999). Access to resources such as carts for transportation depends on financial ability to afford such equipment, or social networks to provide it (Wolmer, 1997).

Investment in agricultural intensification is also dependent on land access and distribution. Secure land tenure is necessary to justify investment in soil fertility management. The distribution of land in relation to the location of the household is also a significant factor. Grégoire (1980) noted that there seemed to be a point beyond which agricultural expansion was more trouble than intensification of production on existing soils. Dispersed settlement patterns, as seen in the Kano CSZ, have facilitated agricultural intensification by reducing the distance which crop residues and manure need to be transported. In this region, there is little distinction between infields and outfields as manure is rotated around all fields. In less densely populated areas, labour in transportation of inputs and crop residues limits this practice (Harris, 1996).

All of the farming systems studied are low input/low output farming systems. The low yields (of the order of 1 tonne / hectare of grain) are sufficient to meet family food needs in some, but not all, years. However farmers also produce legume grain, which is mostly sold, and tree and livestock products. For many farmers, grain self-sufficiency still results in food shortages, as farmers are forced to sell grain at harvest time to meet financial obligations, and then buy grain later in the season. Farming does not result in financial self-sufficiency, and most farmers rely on other means of income to supplement household needs (Ibrahim, 1999). Ibrahim (1999) has shown that household income comes from a range of diverse sources, and farming generates farm-related employment such as labour, renting of carts and ploughs, post-harvest processing (especially threshing), and supports blacksmiths. Villages are economic centres where dried goods (salt, sugar, tea) or prepared foods are sold, and Koranic teachers, barbers, prayer leaders, butchers and tailors all practice their trades. As populations increase and farming systems intensify, the opportunities for such income diversification expand (Haswell, 1973).

Within this region there are farmers who do not have sufficient resources to allow them to intensify production. Shortage of land (more common in the Kano CSZ, but beginning to occur elsewhere) forces farmers to turn to alternative sources of income. Those with a more entrepreneurial spirit may find niches in the local economy, or get involved in economic opportunities outside of the farming environment. For poorer farmers who are unable to invest in new enterprises and have no other skills, labouring on others' farms may be the only option. Moller (1998) noted that those farmers who invested in non-farming economic activities to diversify income sources and were successful were able to re-invest in soil fertility management. However poorer farmers were often unable to diversify, with the result that their long-term future seemed less sustainable.

Due to economic conditions, low external input strategies are more common than those requiring high investment or cash expenditure. Despite the enthusiasm of researchers who argue that smallholder farming systems cannot be viable without the adoption of external inputs (Van Keulen and Breman, 1990, Stangel, 1995), strategies which are highly dependent on external inputs are not viable at present. Fertiliser is scarce, and its availability at appropriate times in the agricultural calendar unreliable. Low external input farming systems are more suited to the economics and infrastructure under which smallholder farmers in Africa operate. Unless the constraints to increased use of inorganic fertiliser can be resolved, these farming systems can only rely on low-external input strategies to maintain soil fertility. For the low and medium intensity farming systems, there is scope to intensify further, towards the model of the Kano CSZ.

However, what is the future for Tumbau? All land is under cultivation, and farms are so small that they could not be expected to support families if further subdivided. Increasing nitrogen fixation could add new nitrogen to the farming system at low external cost. However it is hard to see how nutrient cycling efficient could be improved further. Diversification to non-farming activities seems likely, because as the close-settles zone becomes more densely populated other sectors of the economy can grow. Farmers are already involved in a wide range of farm-related and non-farming economic activities. Development policies which encourage diversification of livelihood strategies will support those farmers whose landholding are becoming too small to provide a secure means of livelihood, and encourage a more broadly based economy. Soil fertility management is not just a question of nutrient management, but also resource management, where those resources include crop residues, livestock, manure, labour, social networks, and land. Socio-economic conditions can enable, or inhibit, soil fertility management strategies.

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