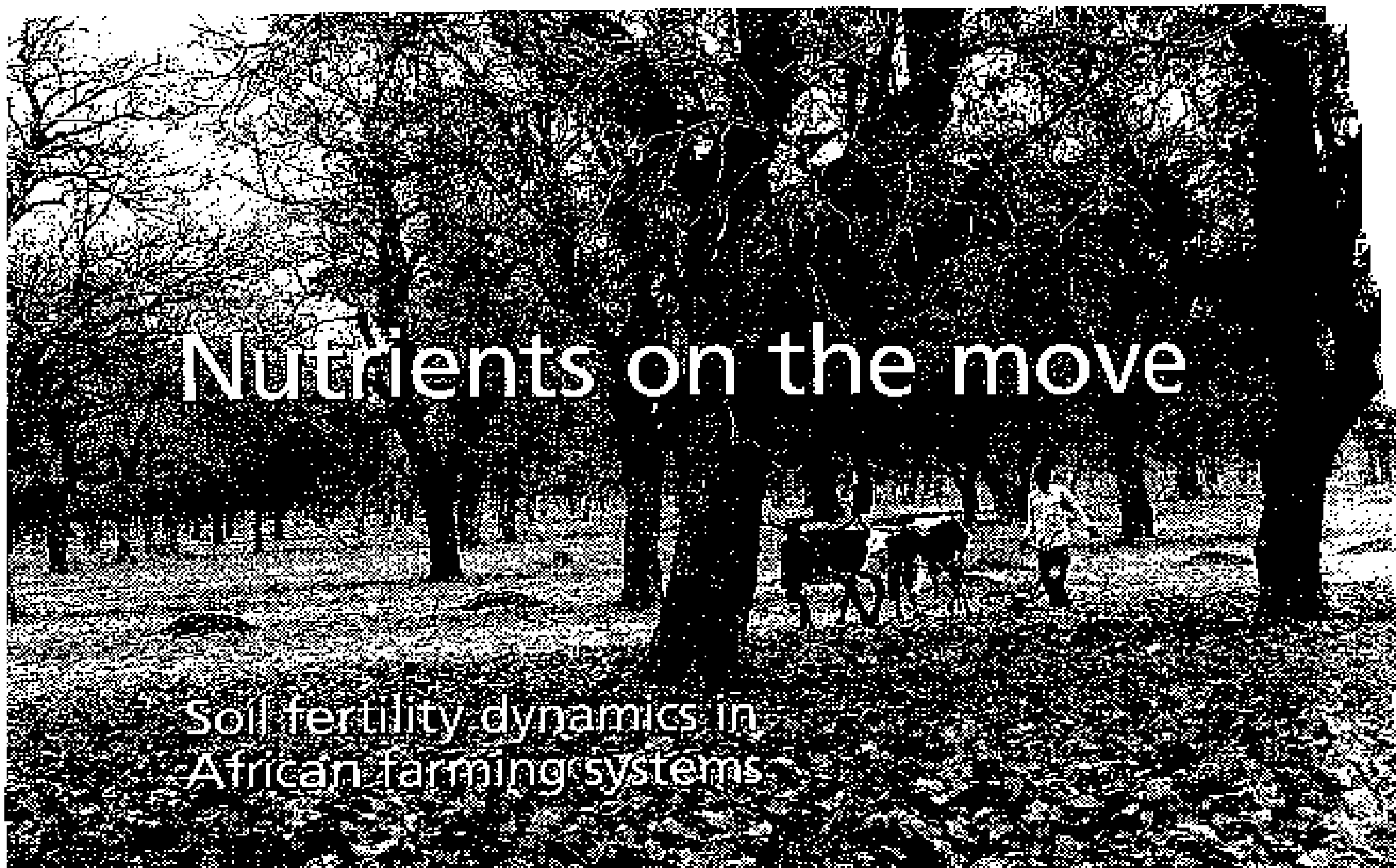

Nutrients on the move

Soil fertility dynamics in African farming systems

Edited by
Thea Hilhorst
and Fred Muchena

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Preface

With so many other issues grabbing the headlines, it is not easy to focus public interest on the state of agricultural productivity in Africa, which is stagnating per capita and per unit of land. There is a growing body of evidence to suggest that this economic situation has been provoked by a gradual decline in the fertility of soils on the continent, which for many years was counteracted by the availability of relatively large reserves of uncultivated land. Although in climatically normal years it was possible to feed the rapidly growing population by putting more land under cultivation, this has had a negative impact on natural ecosystems and is also no longer an option in many areas.

Fallow land is now becoming increasingly rare, forcing farmers to continue to cultivate fields whose soils are often drained of nutrients and organic matter. Unless some kind of action is taken to prevent further decline, biodiversity will deteriorate and the land may eventually become unfit for farming, subject to desertification processes. In such situations, farmers are generally forced to change their traditional practices and intensify their farming methods. In Asia and Latin America, it is often possible to use 'green revolution' technologies to increase yields of certain irrigated crops such as rice, maize and wheat, but these methods have had very limited success in sub-Saharan Africa where farmers have to depend on unreliable rains to water their crops.

However, there is increasing evidence that many farmers are experimenting with their own methods of maintaining and improving soil fertility. In several areas, NGOs and researchers from various institutions have assisted them, tapping into a rich source of indigenous knowledge and assimilating it into the main body of more scholarly wisdom. If they are to have any significant impact, it is essential that the lessons learned from this type of collaboration are disseminated among networks of farmers, researchers and policy-makers, and used to develop affordable integrated technologies that make the best use of resources available both on and off the farm. Their success will also largely depend on the existence of socio-economic conditions that make farming a potentially profitable enterprise and thereby encourage investment in the maintenance and improvement of its most basic asset, the soil.

This book is the fruit of NUTNET, the soil nutrients network made up of NGOs, universities and national agricultural research centres in six African countries and their counterparts in the UK and the Netherlands. I hope that NUTNET's achievements in facilitating and disseminating learning about soil fertility will contribute to the drive to stabilise soils in Africa and create the conditions necessary for the sustainable and profitable production of food and other agricultural goods.

Drs. Leo van Maare
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AB-DLO, ETC-East Africa and IIED were responsible for co-ordinating the project known as NUTNET – *Improving Soil Fertility in Africa: Nutrient Networks & Stakeholder Perceptions*, which has produced this book. Financed by the Government of The Netherlands, NUTNET is an umbrella project to create better links between research teams working on soil fertility management in sub-Saharan Africa, and which brings together three research programmes that have been financed by the European Union. They are: *The dynamics of soil fertility management in savannah Africa*, co-ordinated by IIED and IDS/UK; *Spatial and temporal variation of soil nutrient stocks and management in sub-Saharan African systems* (VARINUTS), co-ordinated by SC/DLO (The Netherlands); and *Potentials of low-external input and sustainable agriculture to attain productive and sustainable land use in Kenya and Uganda* (LEINUTS), co-ordinated by LEI/DLO (The Netherlands). The NUTNET network aims to provide a framework for more realistic policies to support soil fertility management, by improving the understanding of strategies currently adopted by farmers, and by analysing the perceptions of different stakeholders involved in developing policies on soil fertility management.

The case studies presented in this book took as their starting point the results of the three research programmes mentioned above, which were subsequently developed through additional fieldwork, and discussions and exchanges at NUTNET workshops. We are most grateful for the support and feedback provided during the process of reflection and writing by André de Jager (LEI-DLO), Camilla Toulmin (IIED), Eric Smaling (WAU), Ian Scoones (IDS) and Toon Defoer (KIT). We would like to thank James Keeley (IDS) and Jean-Marie Diop (ETC) for their contribution to the workshops. Editorial assistance was provided by Lou Leask and John Leonard, and design and production were in the reliable hands of Eileen Higgins and Bridget Tisdall from IIED. We would also like to acknowledge the support of many others, which has been essential for the success of this work.

Finally, we wish to thank all the farmers whose experience and creativity has provided the basis of this book. We sincerely hope that it will feed into ongoing discussions on more effective support for farmers in their quest to sustain their soils and achieve a more secure and productive future.

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Managing soil fertility in Africa: diverse settings and changing practice

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Introduction

The last few decades have been marked by growing concern about the long-term future of the natural resources on which our lives depend. Although we can be fairly sure that the sun will keep shining for some time to come, greenhouse gas emissions, air pollution, the availability and quality of water, deforestation, desertification and the near-extinction of species have increasingly hit the headlines. They catch the public eye, mobilise research and development funds and, in some cases, lead to major global initiatives.

A less conspicuous but equally vital issue is the availability of good quality soils, which provide the nutrients, water and foothold for plants in both natural and managed ecosystems. Nutrients are transported all over the world through trade in agricultural products and fertilisers but also, mainly more locally, by forces such as erosion, deposition, volatilisation and leaching. Although still in balance at global level, nutrient flows have become unbalanced at lower spatial scales. High loss of nutrients through leaching and volatilisation are a common feature of some intensive farming systems in western Europe. This is threatening the quality of drinking water and air, which has led in turn to regulation forcing farmers to change their practices (de Jager et al., 1999b).

This situation is different in most parts of Africa where the main problem is an inadequate return of nutrients to compensate for losses when crops are harvested and residues taken elsewhere, or due to leaching and erosion. If insufficient inputs are applied to compensate for these losses soil fertility will decline. The information now available on soil degradation in Africa indicates the gravity of the overall situation, as shown by one study of the continent, which estimated average annual losses of nitrogen at 22 kg, phosphorus at 2.5 kg and potassium at 15 kg for each hectare of arable land (Stoorvogel and Smaling, 1990). Research in southern Mali concluded that a major part of farmers' income can be attributed to the run-down of soil nutrient stock or 'soil mining' (Pol, 1992).

Studies at field, farm and village level provide a less negative picture. They demonstrate the widely different management strategies used among farming households to cope with low levels of soil fertility. They highlight the importance of niche management, by which farmers consciously nurture certain fields at the expense of others. Yields are still good and stable on these man-made 'islands of fertility', and many examples have been documented recently across Africa (Smaling, 1998; Scoones and Toulmin, 1999) and other parts of the world (Smaling et al., 1999). However, such concentration in certain areas brings an inevitable impoverishment elsewhere.

We therefore need to ask: what is actually happening at farm and field level, how does soil fertility management vary between different fields, farmers and locations, and what are the implications for interventions aimed at improving soil fertility management? This book presents a series of case studies on soil fertility management in six African countries. They were compiled by the NUTrient NETwork, or NUTNET, which is made up of African NGOs, universities, national agricultural research centres and their counterparts in the UK and the Netherlands. This introductory chapter summarises the main findings of the case studies and attempts to highlight key biophysical and socio-economic constraints on production by smallholder farmers, and the possibilities for improving agricultural productivity in Africa.

The sites

The case studies presented in this book cover thirteen sites across Uganda (chapter 2), Zimbabwe (chapter 3), Ethiopia (chapter 4), Mali (chapter 5), Burkina Faso (chapter 6) and Kenya (chapter 7). Each site has been categorised as belonging to one of three zones, mainly on the basis of its altitude and the distribution and average amount of rainfall: those with low agricultural potential (LP), medium potential (MP) and high potential (HP). Table 1 lists the sites and their basic characteristics. The two chapters on Mali and Burkina Faso are village level studies, while the other four chapters analyse change and diversity in soil fertility management at the level of a district or province.

The sites considered to be of low agricultural potential are those in Mali and Burkina Faso, and Chivi, in Zimbabwe. They are located at low altitudes, where the climate is often hot and semi-arid, the rainfall pattern is unimodal, and soils are mostly sandy, with inherently low fertility. As can be seen from Table 1, population densities in the LP zone range from 10 to 60 people/km^2. Farmers n Mali have the largest herds and cultivate the biggest fields, while Zimbabwean farmers in the communal areas have the smallest fields, largely as a result of the land tenure system. Millet and sorghum are the main crops grown in Mali and Burkina Faso and any surplus is usually sold in the market. Farmers in Chivi also produce maize and some are engaged in cash crop farming. Off-farm employment is important and many men migrate to cities and neighbouring countries in search of work.

The lowlands of southern Ethiopia, Machakos in Kenya, Mangwende in Zimbabwe, and Pallisa in Uganda are sites of medium agricultural potential (MP). They are located at higher altitudes, and have more varied agro-ecological conditions and soil types than the study areas in the LP zone. Slopes are generally not very steep, except in Machakos. The rainfall pattern is bimodal in most sites, and average precipitation is higher and better distributed in these areas, although it can also be quite variable. Population density ranges from 100 to 229 people/km^2, and is highest in Pallisa. Average farm size for the MP area lies between 2.9 and 4 hectares, with 2 to 6 cattle, which spend most of the time grazing in the common woodlands and pastures. Maize and other cereals are grown as subsistence crops and are also produced as cash crops. Farmers in Mangwende and Machakos as well cultivate vegetables on a commercial basis. Off-farm income and remittances are important in all MP sites.

The sites with high agricultural potential (HP) include the highlands of southern Ethiopia, Embu and Nyeri in Kenya, and Kabarole in Uganda. They are all located at higher altitudes, and benefit from inherently fertile soils and a relatively cool, humid climate with bimodal rainfall patterns. Slopes in this zone are generally steep, and population densities high, ranging from 132 to 400 people/km^2. The average number of cattle per farm varies from 1 to 3, with many of them kept in zero-grazing units where they are fed crop residues and fodder from privately owned grass plots. Farms in these sites are generally very small. In Nyeri and the highlands of Ethiopia, the average farmer cultivates one hectare or less, while those in Embu and Kabarole cultivate about two hectares. The principal food crops grown are maize in Kenya, bananas in Uganda, and rootcrops and enset (*Enset ventricosum*) in Ethiopia. Tea, coffee and vegetable production is undertaken on a commercial basis, as is the raising of dairy cattle by farmers in Kenya and Uganda. A significant amount of family income in most of the research sites is derived from off-farm activities, with contributions ranging from 10-60% of total earnings.

Monitoring changes in soil fertility

Calculating nutrient balances

The case studies show that farmers rely on a diverse range of soils (listed in Table 1) and that there is considerable variation in soil fertility between sites. It is possible to determine how soil nutrient levels are changing by analysing the inflow and outflow of nutrients in the system, using a farm or a field as the unit of analysis.

It has already been noted that over the last few years many studies have become available on nutrient balances at regional, farm and plot level (e.g. Smaling et. al., 1993; Pol, 1998; Smaling, 1998; Scoones and Toulmin, 1999; Ramisch, 1999; Defoer and Budelman, 2000; Scoones, 2000). Studies of nutrient balances focus primarily on nitrogen (N) and phosphorus (P), while potassium (K) only features to a lesser extent and micronutrients or the carbon (C) cycle are seldom taken into account at all. Some of the balances calculated are partial, only including 'visible' flows of inputs and outputs that are easier to measure and are also considered to be more meaningful to farmers (e.g. In1, In2, Out1, Out2 - see Box 1).

Table 1 Comparison of various characteristics across case study sites

Country	Sites	Zone*	Rainfall (mm)**	Altitude (masl)	Main soil type	Population density (p/km²)	Average cattle holding	Average farm size (ha)	Off-farm income
Mali	Siguiné	LP	350-550/U	300	Arenosols	15	20	44	+
Mali	Dilaba	LP	550-750/U	300	Lixisols	40	16	17	+
Zimbabwe	Chivi	LP	450-800/U	400	Luvisols	45	2	2	++
Burkina Faso	Kirsi	LP	500-700/U	300	Lithosols	60	1	5.5	+++
Burkina Faso	Thiougou	LP	800-1000/U	300	Luvisols	47	2	7.3	++
Kenya	Machakos	MP	500-900/B	1340-1710	Acrisols	100	5	2.5	++
Zimbabwe	Mangwende	MP	750-1200/U	1000	Lixisols	104	6	3	++
Ethiopia	Lowlands	MP	542-1636/B	1170	Nitisols	110	3	4	++
Uganda	Pallisa	MP	800-1200/B	1070-1160	Ferralsols	229	2	2.9	+
Ethiopia	Highlands	HP	771-1743/B	2100	Nitisols	375	3	1.0	++
Kenya	Embu	HP	700-2000/B	830-2070	Andosols	132	2	2.3	+
Kenya	Nyeri	HP	700-2200/B	1220-2400	Andosols	250	2	0.9	++
Uganda	Kabarole	HP	1300-1500/B	1500-1800	Andosols	400	1	2.3	+

*LP=Low agricultural potential; MP= Medium agricultural potential; HP= High agricultural potential. **U=Unimodal; B=Bimodal.

Source: Case studies.

The results of many studies of nutrient balances indicate that, in general, at farm level the sum of nitrogen balances for all fields is negative, while a more mixed pattern is observed for phosphorus. However, balances may be positive for specific crops, especially certain cash crops, or for particular types of field such as plots near the homestead (Scoones and Toulmin, 1999). A negative balance implies that soil stocks of a certain element are decreasing. If soil reserves are high, this does not necessarily constitute a constraint on production, although such a situation will not be sustainable in the long run. Nutrient balances should, therefore, be assessed in relation to the stocks of available, or active, soil nutrients (Defoer et al., 2000).

Role of soil organic matter and nutrient stocks

The production capacity of a soil is not determined by soil nutrients alone. Organic matter plays a crucial role in maintaining the quality of a soil, as it improves the structure, facilitates aeration and determines the capacity of the soil to hold water and exchange nutrients. Any deterioration in organic matter will adversely affect these characteristics, and ultimately trigger further losses of nutrients through leaching and erosion.

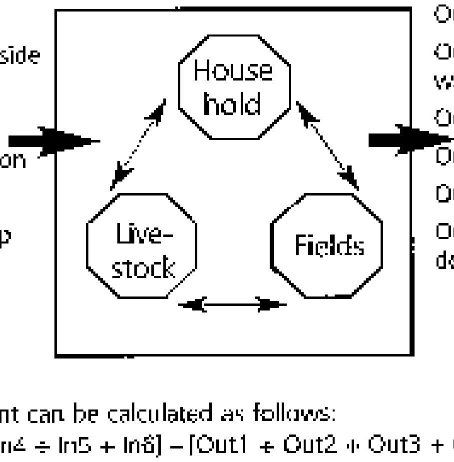
The level of organic matter influences the availability of nutrients to plants. Nutrients, which are present in the soil solution, are immediately available for uptake. They are in equilibrium with ions absorbed by the complex of clay particles and well-decomposed soil organic matter. The capability of a particular soil to absorb nutrients is referred to as the cation exchange capacity (CEC) and when soils contain little clay, organic matter becomes a more important means for storing nutrients. Hence, in soils with low clay and organic matter content, applied

Box 1 Analysis of nutrient flows on farm

Inflows

In1: Mineral fertilisers
In2: Organic inputs from outside the farm
In3: Atmospheric deposition
In4: Biological nitrogen fixation
In5: Sedimentation
In6: Perennial crops taking up nutrients from the subsoil

Farm
(Internal flows)



Outflows

Out1: Products leaving the farm
Out2: Crop residues and animal wastes leaving the farm
Out3: Leaching below the root zone
Out4: Gaseous losses
Out5: Erosion and runoff
Out6: Human excreta disposed of in deep pit latrines

The balance of a given nutrient can be calculated as follows:
Balance = [In1 + In2 + In3 + In4 + In5 + In6] – [Out1 + Out2 + Out3 + Out4 + Out5 + Out6]

nutrients are easily lost from the root zone. Another source of nutrients exists in the pool of active soil organic matter: these become available through mineralisation within one or a few years. The size of the active pool, and its C:N and C:P ratios, determine how much N and P are mineralised as the soil organic matter decomposes. Adding poor quality organic fertilisers with high C:N and C:P ratios will contribute few available nutrients to the soil, and may even immobilise existing nutrients. A soil contains, in addition, stable organic matter pools which are not easily decomposed, only releasing nutrients over a period of a few decades. Soils also have mineral reserves of P and K from which nutrients are not available in the short term.

Results of nutrient balance studies

Most of the case studies in this book include detailed analysis of nutrient balances. Methods and focus vary across the studies, with nutrient balances usually calculated on the basis of a limited number of farmers, using data for only one to three seasons. Some balances are only partial (Mali, Burkina Faso), while others cover the range of inflows and outflows listed in Box 1 (Uganda, Ethiopia, Kenya). There are farm balances, representing the sum of the balances for the different fields (Uganda), and balances for specific types of field (Ethiopia, Mali, Burkina Faso) or for certain crops (Kenya). Ethiopia, Mali and Kenya also present balances for different categories of households. Table 2 summarises some of the nutrient balances presented in the case studies for N, P and K, nitrogen stocks, and yearly changes in the percentage of N. Where possible, we have chosen to present farm balances as well as some of the balances for outfields or, if these are not available, balances for cereal crops.

In the farming systems in Uganda, Ethiopia, Mali and Burkina Faso, there is a distinction between home fields and bush fields or outfields. The nutrient balances from Ethiopia and Burkina Faso show that soil fertility levels are being maintained or even increased in the fields around the homestead, which are used for growing important food crops and other high value crops with substantial nutrient requirements. These are the most intensively managed fields, where farmers apply a large proportion of their available inputs. The bush fields or outfields are often a considerable distance from the homestead, making it costly to transport organic fertilisers to them. Farmers apply few inputs to these fields, remove most of their crop residues to enrich the soil elsewhere and may leave them fallow for a time. Moving sources of nutrients around in this way creates 'hotspots' of good quality, fertile soil, even where the sum of the nutrient balances in all the fields may be negative at farm level.

Table 2 shows that most N balances are negative, with higher losses in the more productive farming systems, where rainfall is high. More detailed analysis shows that the negative N balances are mainly due to leaching (Out3, see Box 1), which caused estimated losses of 150 kg/ha in Nyeri (Kenya), 103 kg/ha in Kabarole (Uganda), 52 kg/ha in Embu (Kenya), and 22 kg/ha in the highlands of Ethiopia (Eyasu, 1998).

All these areas have steep slopes and erosion (Out5) also provokes losses of N, as well as of P and K. Erosion control seems most effective in the highlands of Ethiopia, where farmers carefully manage their plots and apply large amounts of organic material. However, the soil stock has become more depleted over time, despite their efforts.

Table 2 Nutrient balances, stocks of N, and annual changes in N content of the soil

Zone	Country	Site	Type of balance Field	Type	N balance	P balance	K balance	N stock	Annual change in % of N
LP	Mali	Siguiné	Bush field	Partial	-24/-40*	--3/-5*	-30/-50*	-	-
LP	Mali	Dilaba	Millet	Partial	-23/-29*	-3/-4*	-36/-43*	-	-
LP	Burkina Faso	Thiougou	Bush field	Full**	-24	-6	-32	1200	-2.0
MP	Kenya	Machakos	Maize	Full	-34	-2	-13	-	-
			Farm	Full**	-30	3	0	5200	-0.6
MP	Ethiopia	Lowland	Out field	Full	-54/-95*	3/7*	-	-	-
			Farm	Full****	-36	1	-	3600	-1.0
MP	Uganda	Pallisa	Maize	Full***	-10	-	-	-	-
			Farm	Full	2	-1.5	15	4500	0
HP	Ethiopia	Highlands	Out field	Full	-20/-41*	-1/6*	-	-	-
			Farm	Full****	-38	4	-	7200	-0.5
HP	*Kenya*	*Embu*	*Maize*	*Full*	-44	6	-15	-	-
			Farm	Full**	-55	9	-15	9000	-0.06
HP	Kenya	Nyeri	Maize	Full***	-75	-	-	-	-
			Farm	Full**	-185	-49	-63	12300	-1.5
HP	Uganda	Kabarole	Farm	Full	-174	-61	-41	11800	-1.5

Key: - = no data. * Variation between socio-economic categories. ** Unpublished VARINUTS documents. Calculation for the average farm balance in Embu is based on data for land use zone 1; N stock for Thiougou is estimated from organic matter content, assuming a C:N ratio of 10. *** Unpublished LEINUTS documents. **** Average farm balances are calculated by weighing the relative contribution of all field types for poor and rich farmers. Other data are from the case studies.

Balances for P are mainly positive, except for Kabarole (Uganda) and Nyeri (Kenya), which are badly affected by erosion. Losses for K are high, except for Pallisa, mainly because not enough organic fertiliser is applied to compensate for the removal of crop residues, while mineral fertilisers do not always contain K.

Stocks of N in the soil are becoming most seriously depleted in Kabarole (Uganda), Nyeri (Kenya), the lowlands of Ethiopia, and Thiougou (Burkina Faso), where annual losses amount to approximately 1-2% of current reserves (Table 2). As around 80 to 90% of the soil N stock is part of the stable soil organic matter pool and unavailable for plants in the short term, the capacity of the soil to supply nutrients will diminish considerably within a few years if annual losses of more than 1% from the active pool of nutrients are sustained (Hassink, 1995). In Thiougou (Burkina Faso) and the lowlands of Ethiopia, N stocks and soil organic matter content are low, and the N balances negative. In Thiougou, the yearly inputs of mineral and organic fertiliser and the output of useful products are both very low (5 kg/ha) and more or less in balance. The negative N balance is largely due to leaching and erosion, which accounted for recorded outflows of 25 kg/ha and 11 kg/ha respectively. Most of the nitrogen losses from the outfields in Ethiopia are caused by the wholesale removal of crop residues (Out2), and leaching (Out3) and gaseous losses (Out4) are higher there than in the highlands (Eyasu, 1998). This affects not only the ability of the soil to supply nutrients, but also its structure and water holding capacity, and will eventually result in further losses through leaching and erosion.

Nutrient management practices

The six case studies presented in the chapters analyse how different farmers manage their soils and how practices have changed over the last few decades in a variety of sites. This section discusses the role of various practices observed during the case studies, the main reasons why farmers use an array of methods and their relative importance for different kinds of households. A list of the main practices discussed in the chapters is presented in Table 3 below. The various soil fertility enhancing methods recorded by each study have been grouped according to the role they play in the flow of nutrients into, out of, or within the farm (see Box 1). These are practices which aim to:

- Add nutrients to the farm,
- Reduce losses of nutrients from the farm,
- Maximise the recycling of nutrients already within the farm,
- Increase the efficiency of nutrient uptake.

Adding nutrients

This is the most frequently used method of maintaining and improving the availability of nutrients in the soil. Farmers use a wide variety of techniques, some of which have been practised for generations, and some of which are relatively new.

Table 3 Practices currently used in the case study sites

Practices and associated nutrient flows — *Country / Zone / Site*	Ma LP Sig	Ma LP Dil	Zi LP Chi	Bu LP Kir	Bu LP Thi	Ke MP Mc	Zi MP Mn	Et MP Ll	Ug MP Pal	Et HP Hl	Ke HP Em	Ke HP Ny	Ug HP Kab
Adding nutrients													
Fallowing (In4,6; Out2-5)	*	*	*	–	*	–	*	*	*	–	–	–	–
Using mineral fertilisers (In1)	–	–	*	*	*	–	*	*	–	*	*	*	–
Using rock phosphate (In1)	–	–	–	–	*	–	–	–	–	–	–	–	–
Inflow of nutrients from grazing (In2)	*	*	*	*	*	*	*	*	*	–	–	–	–
Cultivating N-fixing plants (In4)	*	*	*	*	*	*	–	–	*	*	–	*	*
Minimising nutrient losses													
Controlling erosion, run-off and leaching (Out3,5)	–	–	*	*	–	*	–	–	–	*	*	*	*
Trees in fields (In6)	*	*	–	*	*	–	*	*	*	*	*	*	*
Double digging (Out3)	–	–	–	–	–	*	–	–	–	–	*	*	–
Managing internal flows													
Applying manure, urine, slurry (Internal Flows; Out3,4)	*	*	*	*	*	*	*	*	*	*	*	*	*
Recycling -composted- organic materials (Internal Flows)	*	*	*	*	*	*	*	*	*	*	*	*	*
Incorporating crop residues (Internal Flows)	–	–	*	–	–	–	*	*	–	*	–	–	–
Increasing the efficiency of nutrient uptake													
Selecting crops to match soil fertility levels	*	*	*	–	–	–	*	*	*	*	–	–	–
Concentrating nutrients in particular fields (Internal Flows)	*	*	*	*	*	*	*	*	*	*	*	*	*
Managing nutrient application on crops (Out3,5)	–	–	*	*	*	*	*	–	–	*	–	–	–

* = Used in the case study sites and discussed in the chapter; – =Not important, or not observed in the case study sites.

Internal Flows are between components in the farm (fields, livestock, household).

Source: Case studies.

Fallowing

At the beginning of the twentieth century fallowing was the most commonly used method of restoring soil fertility in all the case study sites. Where sufficient land was available, fields were left fallow for many years. Trees and bushes were cut and burned to release nutrients, when the field was cleared for farming again. This practice has declined over the past decades, in terms both of the percentage of farmers leaving their fields fallow and the length of the fallow period, obliging farmers to use other means of replenishing nutrient in the soil.

The main cause is that less land is now available for fallowing. An increasing amount of land is being used for cultivation, partly because of the expanding population, but also as a result of the introduction of the plough, and the need to earn more from cash crops. Furthermore, as rainfall declines and the yield per hectare falls, farmers may try to compensate by cultivating larger fields (Burkina Faso, Mali). The lack of land has also forced them to use more fragile and less productive soils, and in Burkina Faso this has led to the appearance of a crusted, hardpan surface. The expanding fields encroach on pastures and woodlands that are used for grazing cattle and for gathering wood and a range of other bush products. This has a knock-on effect on the ability of farmers to restore the fertility of their soils, for as the available grazing land diminishes so does the possibility to keep livestock and thus the supply of manure.

There are marked differences in current practices across the study sites. In Siguiné (Mali) and Thiougou (Burkina Faso), fallowing is still the only method of replenishing nutrients in the far-flung bush fields. Farmers in Kirsi (Burkina Faso) and Dilaba (Mali) are constrained by serious shortages of land, and consequently rely on fallow much less now than they did thirty years ago. The small areas of fallow still present in Dilaba are maintained to provide grazing areas for plough oxen. Although there is some land under fallow in Zimbabwe, Uganda and Ethiopia, this tends to be a sign of distress, rather than a positive management decision, and is largely due to the household lacking sufficient labour, money or animal traction to cultivate their fields. Fallowing is no longer of significance in any of the HP sites.

Various research programmes, such as those of ICRAF, are exploring the possibilities of 'improved' and seasonal fallow, which involve promoting the growth of selected species of leguminous trees, shrubs and herbs that perform better than indigenous fallow species. However, in none of the case studies was the introduction of new legumes as improved fallow of significance.

The use of mineral fertilisers

Since the 1960s the most important soil fertility technology promoted by the extension services has been the use of mineral fertilisers. Costs were often subsidised, and supplies distributed by government or rural development projects with assistance from international donors.

Table 4 gives an overview of the percentage of farmers using mineral fertilisers in the study sites since the 1960s. Initially, they were hardly used, except in Kenya, but by 1980 most of the farmers in Zimbabwe, Ethiopia and Kenya were applying them to their fields. The figures are more or less the same in 1998, although they are slightly lower in Chivi (Zimbabwe) and higher in Nyeri (Kenya). In Burkina Faso, a small, but gradually increasing number of farmers are using mineral fertiliser. The data for Mali mask short periods when fertiliser was used on groundnuts. At that point they were grown as a cash crop, and there was an organised supply of inputs, as well as credit and marketing systems. The farmers in the Ugandan sites have never used much mineral fertiliser.

Overall, data on fertiliser consumption in Sub-Saharan Africa show a steady increase from the 1960s to 1990, followed by a period of stagnation (IFDC, 1999; Naseem and Kelly, 1999). National rates of fertiliser consumption have fallen in Mali and Zimbabwe, increased slightly in Kenya and more considerably in Burkina Faso and Ethiopia. Very little fertiliser is used in Uganda (see Table 4).

The use of mineral fertilisers has not followed an evolutionary path in the case study sites. For example, in the 1970s, farmers in the lowlands of Ethiopia switched from fallowing to using mineral fertilisers, but went back to organic fertilisers again in the 1980s, when the main project promoting their use was shut down: prices increased and the input supply

Table 4 Trends in the use of mineral fertilisers across the case study sites

Site	Country	Zone	Households using mineral fertiliser (%)			Average fertiliser consumption at national level		
			1960	1980	1998	1970-79 kg/ha	1980-89 kg/ha	1990-97 kg/ha
Dilaba	Mali	LP	0	0	0	4.9	8.7	7.5
Siguiné		LP	-	-	0			
Kirsi	Burkina Faso	LP	-	0	+	1.4	4.3	6.4
Thiougou		LP	-	+	+			
Chivi	Zimbabwe	LP	-	++	+	23.8	24.9	20.6
Mangwende		MP	0	+++	+++			
Lowlands	Ethiopia	MP	-	+++	+++	1.5	4.1	10.0
Highlands		HP	-	+++	+++			
Pallisa	Uganda	MP	0	-	-	0.7	0.1	0.1
Kabarole		HP	-	-	-			
Nyeri	Kenya	HP	+	++	+++	12.0	21.2	22.4
Embu		HP	++	+++	+++			

- = not used; 0= used by very few farmers; + = less than one third of farmers ; ++less than two thirds of farmers; +++ = more than two-thirds of all farmers use mineral fertilisers.

Sources: case studies and FAO (1999).

systems collapsed. Since 1995, the central extension message in Ethiopia has been the promotion of mineral fertilisers in combination with high yielding varieties, and their use is on the increase again. In both sites in Zimbabwe, the application rates of mineral fertiliser have declined considerably since the 1980s. In Kenya, application rates have remained high for tea, but were reduced for coffee when prices and profit levels. In Burkina Faso, some farmers are using mineral fertiliser at a low rate. Farmers in Mali may occasionally use tiny amounts of mineral fertilisers while it is not used at all in the case study sites in Uganda.

In the 1990s many farmers thus cut down on expensive mineral inputs and started applying more organic fertilisers from a variety of sources. While they have continued to use some mineral fertilisers, this is often only at a fraction of the recommended rate. They mainly put this down to increased costs, the disruption of services supplying inputs, and the disappearance of agricultural credit systems. Most of these changes are the result of structural adjustment policies that have been introduced since the end of the 1980s, heralding the end of subsidised fertilisers and of government involvement in input delivery and agricultural credit, and the devaluation of local currencies.

When they talked about their experience with mineral fertilisers, many farmers said that they are much easier to transport and apply than organic fertilisers, which are not only bulky and hard to handle, but are also of very variable quality. However, they also observed that relying solely on mineral fertilisers seemed to affect negatively the quality of the soil. Many of the problems farmers encountered with mineral fertilisers seem to stem from not knowing how and when to apply them, and because they are often only able to obtain a single type of mineral fertiliser. If the available fertiliser is inappropriate for the prevailing soils, as was the case in Kenya, it is more likely to cause problems than solve them.

Another constraint for many small-scale farmers is that they have to purchase mineral fertilisers for cash. Before deciding to use this type of input they must therefore consider the potential profitability of the crop, the likelihood of recouping their investment, and the potential risks involved. Farmers working in more unpredictable, semi-arid climates face more risks and have to apply mineral fertilisers very carefully, as they may damage plants, if there is insufficient moisture in the soil. Many farming households are chronically short of money, and lack access to credit, and the fact that mineral fertilisers are not always available in small quantities can impose yet another financial burden on them. The lion's share of all nutrient inputs tends to go on cash crops, which have the potential to produce an economic return. Farmers understand the need to apply more mineral fertilisers, but they are unlikely to be able to do so in the current economic climate. The authors of the case studies on Zimbabwe, Kenya, Uganda and Mali therefore suggest that it would be valuable to conduct research on the most efficient use of small quantities of mineral fertiliser.

Rock phosphates

The Soil Fertility Initiative[1] has been particularly concerned with the 'recapitalisation' of African soils through the use of rock phosphate. There are substantial deposits in various countries across Africa, and some of them, such as Togo, Senegal, Morocco, and Tunisia, even export to the world market. Other countries like Mali and Burkina Faso have deposits that they want to develop for the local market, with a view to increasing the use of rock phosphate and replacing imported fertilisers. Both Mali and Burkina Faso currently have only limited capacity to mine rock phosphate, and also face considerable problems distributing it to farmers. In Burkina Faso, for example, rock phosphate is rarely available on the open market, and is mainly distributed through projects and extension services. However, both countries are developing initiatives to increase their capacity to produce and distribute this mineral more effectively.

In the early 1990s Mali and Burkina Faso launched campaigns to promote rock phosphate, and it became an issue of national pride to make the best use of this asset. However, the campaigns had only modest results. This may have been because initially its exponents were promoting rock phosphate as a direct source of nutrients, while now the emphasis has shifted to its capacity to improve the quality of soil, thus increasing the uptake efficiency of nutrients supplied through fertilisers (Bumb and Teboh, 1996). Among our case studies, rock phosphate is only used at present in Thiougou. Extension services and a local project facilitate deliveries to the farmers, who mainly apply it to their compost pits. In the past it was used in Kirsi but farmers have replaced it with ash, which they do not have to buy.

Inflows of nutrients from grazing

Cattle play an important role in the rural economy and in soil fertility management. They are the most important and widespread source of manure, while the droppings of small ruminants tend to be used as a fallback when other sources of fertiliser are in short supply. Cattle, donkeys and horses also provide draught power and are used to prepare the land and transport materials to and from the field, and to the market.

Ownership of livestock is an important indicator of wealth in most of the case study sites, with the more successful households owning larger herds. However, the droughts in Zimbabwe in the 1990s, and the war in Uganda in 1987, highlighted the fact that these herds are vulnerable and that significant losses can seriously affect the whole farm. If farmers rely on animal traction for ploughing and other operations, their capacity to cultivate will be seriously compromised by a sudden reduction in the size of the herd and, as less dung will be available to produce manure, they may also have to rethink their soil fertility management strategies.

For part of the year, fallow land and woodlands are used for grazing cattle, which then transfer nutrients from the common pastures to the farm when they pass the night on the

[1] The Soil Fertility Initiative (SFI) was set up in 1996 to assist African countries with the development of action plans in response to declining fertility in their soils. The SFI brought together FAO, World Bank, research institutes, and donors amongst others. Since 1999 the focus seems to have shifted towards country-led initiatives with some cross-border sharing of experience where appropriate.

field or in stalls at the homestead. With good management, this practice can provide an important source of nutrients for the farm, although this is often at the expense of the common lands (Defoer et al., 1998; Ramisch, 1999). This source of nutrients is particularly important for cattle-owning households in the LP zone and some of the MP areas, where common grazing areas still exist. The role of crop-livestock integration in soil fertility management will be discussed below.

Cultivation of nitrogen-fixing crops

For generations, farmers have grown cereals in association with legumes, particularly beans. This is still common practice in Mali, Burkina Faso, Chivi in Zimbabwe and Pallisa in Uganda. However, where land is becoming increasingly scarce, priority is given to cereals. Legumes are disappearing from the cropping system, and are now limited to beans grown in gardens (Ethiopia, Kenya, and Mangwende in Zimbabwe). In some of the HP sites, such as Nyeri in Kenya, NGOs have suggested planting borders of legume trees around fields to provide green manure. Various farmers in Kabarole, Uganda, have taken the idea one step further and started using the trees as live poles to support their passion fruit crops.

Minimising nutrient losses

The most important techniques for cutting nutrient losses involve a range of anti-erosion measures, such as the construction of bunds and terraces, or the use of mulch and ground cover. Some of the nutrients lost through leaching may be recaptured by planting trees or using certain tillage practices. Some practices have evolved from traditional methods, but most have been developed recently.

Measures to control erosion, run-off and leaching

The prevention of soil erosion is one of the measures most commonly used to reduce losses of nutrients and it is particularly important where slopes are steep. The dramatic consequences of severe gully erosion may be the reason why, over the years, so many African countries have introduced policies and projects to combat soil erosion. In the 1920s, the British colonial government in Kenya, Uganda and Zimbabwe tackled the problem by imposing regulations and bylaws prohibiting the cultivation of fragile areas such as slopes, river borders, swamps and inland valleys, and by obliging farmers to build soil conservation structures. Governments that came to power after Independence continued in the same spirit, but the bylaws were often dismissed because of their association with colonial rule, and farmers abandoned these practices when they realised that they would not be enforced.

As soil erosion became a key issue again in the 1970s and 1980s for governments and donors, another set of large development programmes were introduced in countries such as in Burkina Faso, Ethiopia, and Kenya, where they were often executed in a rather top-down way. Since mechanisation was too expensive or impractical on slopes, an enormous amount of labour was required to implement the plans to build terraces and bunds. When it became clear that farmers were not prepared to maintain these structures, and that the programmes therefore had very little impact, they were either reoriented or completely phased out.

A watershed approach, using more participatory methods and group action, is now being advocated in Kenya. In Burkina Faso, projects work in consultation with farmers, assisting them with the construction of stone lines, while researchers have developed technologies that are more cost-effective in terms of labour and resources. Having been largely left to their own devices, farmers in southern Ethiopia have reverted to more traditional approaches to constructing terraces, and soil conservation is on the agenda again for farmers in Zimbabwe, with a particular focus on capturing rainwater and increasing its infiltration

Overall, it seems that farmers in the various case study sites are starting to pay more attention to erosion control, and are overcoming their reluctance to implement certain measures. Their main problem is mobilising the labour needed for the initial construction work, particularly for terraces and stone bunds.

Trees in fields

Nutrients that have leached from the subsoil may be recaptured by planting or maintaining trees in fields, as the decomposition of fallen leaves makes the 'lost' nutrients available to plants again. Trees are a common feature in West African fields, mainly because they provide shade and useful products that are generally harvested by women. Although land is now often prepared and weeded with animal traction, farmers still manage to maintain a certain density of trees in their fields. One particularly valuable species which improves soil fertility is an acacia tree (*Faidherbia albida*). This leguminous tree drops its leaves during the rainy season, and provides shade and fodder during the dry season when it also attracts livestock which deposit dung around its base. In Mali, the protection and maintenance of *Faidherbia albida* is recognised as a method of improving soil fertility.

In Zimbabwe, many trees were removed on the instruction of extension workers who advocated a 'clean' surface, although farmers are aware that trees can provide fertile niches in a field. An increasing number of fruit trees are being planted in fields and around houses in Uganda and Ethiopia, as part of an overall plan towards diversification and to reduce soil erosion. The main cash crops in the HP zone in Kenya and Uganda are perennials, which provide ground cover when well maintained.

It has already been noted that agro-forestry with leguminous species is not widely practised in the case study sites, with limited NGO-led initiatives in this field in Kabarole (Uganda) and Nyeri (Kenya).

Double dug beds

Double dug beds have been promoted by NGOs in Kenya since the late 1980s. The idea is to prepare the ground for cultivation by breaking down the hard pan and creating a deep layer of loose fertile soil. This aerates the soil, improves water absorption and retention, increases rooting depth and allows plants to use available nutrients more efficiently. Compost should be added when the beds are first made. Preparing double dug beds is a very labour intensive process, and they are mainly used for cultivating high value cash crops such as vegetables. In none of the other sites was this technique being practised.

Managing internal flows

In order to make more effective use of the resources available, farmers have to manage the way in which organic materials are transported between different fields, livestock units and the homestead. The need to find and make the best use of available sources of nutrients has prompted some farmers to better integrate their crop and livestock management and to collect household waste on a regular basis, which is composted and then spread on the fields.

The use of manure, slurry and urine

We have already noted that farmers in all the study sites rely on dung from livestock to help maintain soil fertility. The easiest way to get access to manure is to keep animals near the homestead, but some farmers do not own any livestock, while others may not actually care for the animals themselves. In Burkina Faso and Mali, they may entrust them to hired herders and in Ethiopia and Uganda one household's cattle may be tended by other farmers, generally due to a lack of labour availability.

Farmers who do not own livestock have various strategies for acquiring manure. In Ethiopia they come to an arrangement with cattle owners whereby they share the care of livestock in return for manure. The exchange system seems to operate in reverse in Uganda, where livestock belonging to poorer households are looked after by more affluent farmers who keep the manure. In Mali those without sufficient animals of their own provide access to their wells for visiting herds and receive manure in exchange during the dry season. In a nutrient scarce village such as Dilaba, some farmers actually pay children to collect dung from grazing areas. However, manure is rarely purchased outright in any of the study sites.

Livestock held in more extensive husbandry systems feed on crop residues left on the fields, leaving dung and droppings as they graze. However, as the nutrient value of any such waste left lying on the field is likely to be substantially reduced by exposure to the elements, farmers focus on producing more farmyard manure or tend to concentrate manure on particular fields. In Mali and Burkina Faso, animals are penned in the field at night and the dung they deposit is later spread over the surrounding area. Plough oxen and lactating cows spend a large part of the day in a special cattle pen near the homestead, as do livestock in Ethiopia, Uganda and Zimbabwe.

In more intensively farmed areas where fallow and grazing land are in very short supply, animals are kept under zero-grazing conditions, and substantial amounts of manure and slurry are produced in the stall. In Ethiopia, trenches are dug to feed the slurry directly into nearby plots, while farmers involved in commercial dairy production in Kenya and Uganda are starting to sell some of their manure.

Most manure seem to be left in pens until it becomes very soggy, at which point it is removed and stored nearby in a heap, mixed with leftover fodder. A few farmers first compost manure before transporting it to the fields. Some farmers may put down litter in the pen as bedding to absorb urine and to bulk out the manure. All the farmers who were interviewed in Ethiopia reported that they wrapped manure in a mixture of bedding straw and household refuse before taking it to the fields. This helps to conserve nutrients that would otherwise be lost through exposure to the elements.

Recycling and composting organic materials

All the case studies reported that, in addition to manure, other organic materials are also used to improve soil fertility. These include household waste, crop residues, weeds, leaf litter, prunings and other plant matter, which are left in a heap or pit for some time before being transported to the field. The use of such organic materials is on the increase in all sites, and is particularly important for farmers with few livestock.

For anaerobic decomposition to take place, the heap or pit must be carefully layered and regularly watered and turned. In Kenya and Mali, various forms of composting were promoted during the colonial period and the practice gained new impetus in the 1980s, when it was recommended by development projects and NGOs. It has spread remarkably and is now found in all the case study sites, such as in Kenya and Uganda where it is used for growing vegetables for sale. However, making compost is a very labour intensive process and it represents a considerable investment from those involved in producing it, who are predominantly women and younger people. There is clearly a need for further research into labour saving methods for producing and transporting this material (Zimbabwe, Kenya).

The quality of the organic materials used in composting is another issue that needs to be considered. Compost made from crop residues with a limited nutrient content will not have a significant impact on N or P levels in the soil and may even immobilise existing stocks of these elements (as described earlier). In Ethiopia, Zimbabwe, Mali and Kenya the quality of the compost is improved by mixing in ashes, eggshells and the droppings of small ruminants, while farmers in Burkina Faso add rock phosphate to their compost pits.

An enormous amount of organic fertiliser would be required to maintain soil fertility levels in every field, which would clearly be beyond the means of most farmers, who are constrained by lack of time, physical strength, biomass, water during the dry season, and the transport needed to produce and apply large quantities of fertiliser. Combining organic materials with small quantities of mineral fertiliser might improve the efficiency of both types of input (Kenya, Zimbabwe).

Incorporating crop residues into the soil

Few of the farmers in the study sites incorporate crop residues into the soil to improve its fertility, water holding capacity and other characteristics. Zimbabwe was the only country where winter ploughing to incorporate crop residues is common practice. In Ethiopia, some crop residues are chopped and worked into the soil, but they are mostly used to feed livestock and as litter in pens.

The other case studies reported that part of cereal residues are used as fodder, litter or for composting, while the rest is left on the field, where it may be eaten by termites or passing livestock. What is left will be burned before cultivation starts for the next season. Most crop residues from legumes are used as fodder or sold on the market. Crop residues rot faster in the HP zone than in the drylands but what is usable is fed to livestock or composted.

Increasing the efficiency of nutrient uptake

The case studies in this book show how farmers use their knowledge of plant nutrient requirements and the characteristics of the various sources of nutrients at their disposal, to select their strategies for maintaining soil fertility. Farmers may match differences in nutrient requirements and tolerance to stress of different species and plant varieties with the range of soil fertility levels in their fields. They may even accentuate such differences by concentrating nutrients in certain fields and plots. In addition, nutrients may be taken up from the soil most efficiently when they are applied close to the roots of plants or in planting holes, and at timely points in the growing cycle.

Selecting crops to match soil fertility levels

Farmers may match their crops and varieties with the perceived nutrient status of a field or niche. Demanding species and hungry season crops are often grown on the better managed and more fertile fields near the homestead, while crops that are more tolerant to low levels of fertility are planted in less fertile fields (Zimbabwe). Farmers in Siguiné (Mali) use different varieties of millet in the home and bush fields, while in Dilaba (Mali) sorghum is planted in wet spots and fonio (*Digitaria exilis*) on sandy soils, where other crops would do less well. In Zimbabwe and Uganda, demanding crops such as bananas are grown in areas previously used for cattle pens or homesteads and, in Ethiopia, farmers plant enset on the more fertile soils, rootcrops in the transition zone, and cereals in the least fertile outfields. Legumes (Mali) and rootcrops (Ethiopia) are grown on exhausted soils to improve their fertility and quality. Farmers also make use of erosion processes, which generate plots with higher clay contents down the slope, and deposits behind stone bunds and in planting pits (Zimbabwe, Ethiopia, Burkina Faso).

Concentrating nutrients in certain fields

All of the case studies demonstrate that where farmers still have access to sufficient land, they generally create several types of field, which are managed in various ways and which consequently have different levels of soil fertility. In Ethiopia, for example, organic fertiliser is only used on the home fields, while mineral fertilisers, being easier to transport, are applied to outfields. They also try to convert less fertile land into home fields, by investing large amounts of organic fertiliser in these areas. In Mali and Burkina all inputs are channelled into the home or village fields, with the productivity of bush fields maintained only through fallowing. Gardens and vegetable plots in Zimbabwe, Kenya and Uganda also receive fairly large quantities of organic fertiliser, much of which has been composted. In Kenya, mineral fertilisers are used only on tea, and farmers in Zimbabwe also apply most of their fertility inputs to certain cash crops.

In Mali, farmers apply most inputs on fields of certain soil types, such as sandy soils, and those patches which appear less fertile. Sheep and goat droppings are applied to infertile spots in specific fields while, in Zimbabwe, soil from termite mounds may be used on such areas. Research in Niger has confirmed the value of these micro-level practices, and has also found that the effects of sheep and cattle manure vary according to slope and levels of moisture in the soil. This suggests that nutrients could be used more efficiently in the Sahel if application rates are adjusted to small-scale variations in the landscape and field topography (Brouwer and Powell, 1998).

Managing nutrient applications on crops

Where nutrients are scarce, they are not spread evenly over fields but are placed carefully near the roots of plants and protected from run-off rainwater. Compost and small amounts of urea are added to planting pits in Zimbabwe, and also in Burkina Faso, where they capture rainwater and provide a moister growing environment than the surrounding field.

The chapter on Zimbabwe describes how farmers have learned to combine various blends of Ammonium Nitrate and a NPK fertiliser and use split doses, according to the perceived needs of the plants, the development of the rainy season, and the financial resources available to them. They will also adjust this mixture if mineral fertilisers have been acquired rather late in the season.

Organic fertiliser is generally applied at the beginning of the cropping cycle and incorporated into the soil when it is ploughed or hoed, although farmers in Ethiopia fertilise fields near the homestead throughout the year. NGOs in Kenya are developing top dressing products, prepared either from fermented fresh animal droppings in water or from succulent plants fermented in water, that can be applied to growing crops such as vegetables or maize.

Trends in soil fertility management practices

Farmers are changing the ways in which they add nutrients to the soil. The shortage of land caused by increasing population pressure, the expansion of cash crops, and the use of ploughs, has forced farmers to move from reliance on fallowing and grazing in the commons as the main sources of nutrients, to more intensive forms of land and livestock management. Cereals and legumes were traditionally grown in association in most of the sites, but legumes are being phased out as land has become scarcer in the MP and HP zones.

The use of mineral fertilisers varies across the study sites. The number of farmers using this type of fertiliser has increased over the last four decades. Application rates for mineral fertiliser have remained unchanged for lucrative cash crops such as tea but in general the amount applied per hectare has declined considerably in the 1990s, mainly because of the increased cost of fertiliser and problems with input delivery and access to credit. LP areas use the least mineral fertiliser, probably because agriculture is more risky and less profitable. Rock phosphate was only used in one site in Burkina Faso, where access has been facilitated by a project.

As less and less land is available for fallow, and mineral fertilisers are either unaffordable or inaccessible, it is increasingly important for farmers to manage the flows of nutrients within their farms. In all the sites, more attention is being focused on integrating crops and livestock but progress may be hampered for poorer farmers by lack of access to livestock. There are several other sources of organic fertiliser available to those without animals, such as household waste, weeds and ashes, but it is not always possible to obtain enough good quality biomass, or the labour and transport needed to process and transport it. The same constraints apply to the growing interest in composting and improving the quality of organic fertiliser. Some of the farmers in Zimbabwe and Ethiopia incorporate crop residues into the soil in a systematic way. Elsewhere, some crop residues are used for fodder, litter or thatching, but for the most part they are consumed in the field by cattle and termites, or burned.

When inputs are in short supply it is essential that they be used efficiently. Farmers are using fertilisers in an increasingly focused manner, concentrating them on particular fields, plots and spots, selecting crops and varieties to suit specific soil conditions and perceived levels of fertility, and adjusting application rates according to the development of the crop and the rainy season. Such practices often require considerable knowledge, management care and labour.

The steps taken to prevent the loss of nutrients from soil vary according to the prevalent physical and socio-economic conditions. Soil conservation is essential to reduce the loss of nutrients from sites on slopes, which are particularly vulnerable to erosion, but in the past farmers resented the soil conservation programmes that were imposed on them, and consequently often abandoned them once the element of compulsion was removed. However, they recognise the need for some kind of action to reduce the damage caused by erosion and some now have started to invest in implementing and managing preventive measures on their own account.

From a technical point of view, more insights are needed on the most effective ways of combining organic and mineral fertilisers, on the best use of small quantities of mineral fertilisers and on reducing the labour required to produce organic fertiliser. Special attention should be paid to farmers in the drought prone, semi-arid regions where fertiliser uptake is less efficient due to lower soil quality and moisture stress and where risks to farming are higher. Thought is also needed to improve the provision of cost-effective technologies for households with little or no access to livestock, labour or other resources.

Socio-economic and institutional factors

The soil fertility management practices employed by farmers are determined by a wide variety of factors which are largely dependent on location. Three broad categories can be distinguished (Scoones and Toulmin, 1999): biophysical, socio-economic and institutional. Biophysical parameters, which have already been discussed, include climate, soil types, crops and livestock. This section will concentrate on the socio-economic and institutional factors influencing soil fertility management.

Population density

Farmers often mention increasing population density as a factor that triggers changes in farming systems and soil fertility management practices. Population densities have risen in all the study sites. As a result, more land has been brought into cultivation, the length of fallow periods has fallen and there is a marked decline in the availability and productivity of forests and communal grazing areas. As good quality land close to the homestead has become scarcer, farmers have been forced to invest in short and long term soil fertility maintenance. However, the considerable outlay involved in purchasing fertiliser is only economically attractive for crops with a guaranteed cash return, and the only alternative for the rest of the cropping system is to intensify production by increasing the labour input.

Whether it is worthwhile to invest labour in maintaining and improving soil fertility depends on opportunities in other sectors. For as long as there is no alternative, rural households will continue to rely on agriculture for their livelihood, and will have to invest increasingly in soil fertility in order to maintain their yields. As the prospects to earn a livelihood outside agriculture are limited for poorer farmers in the Ethiopian highlands, they invest a large amount of labour in maintaining their small plots of land in an ecologically sustainable fashion, but these holdings are usually too small to provide sufficient food and income to make ends meet. Richer farmers with alternative options invest less labour in their farms and consequently have more negative soil nutrient balances. In the case of Dilaba (Mali), for example, the increasing scarcity of land has also resulted in the adoption of more intensive methods and the use of a wide range of organic fertilisers. However, there is a limit to what can be achieved by carefully husbanding and recycling of nutrients and, because millet, the main crop, does not generate sufficient profits to enable farmers to buy mineral fertilisers, they have to cope with a continuous net outflow of nutrients from the farm.

It is possible that rising population density could generate more opportunities for economic diversification. This changes the relative value of land to labour, and it has been suggested that this is the reason behind the increased investment in soil conservation in Machakos (Tiffen et al., 1994).

Broader livelihood strategies

Most of the case studies note that off-farm activities and remittances make a significant contribution to farm income. A growing number of households are diversifying and engaging in off-farm activities. Members of many families in Zimbabwe, Kenya, Mali and Burkina Faso have migrated to cities or other countries, from where they occasionally send money or goods. In Mali and Burkina Faso, income from off-farm activities and migration is primarily used to meet basic needs, school fees and taxes, while any surplus is put towards livestock, equipment such as carts and ploughs and, occasionally, agricultural inputs. It may also be invested elsewhere, such as in diversification away from agriculture or in social networks. However, while it may provide a source of income, migration also diminishes the pool of available labour and may result in households being unable to muster the manpower required for physically demanding tasks, such as building and maintaining soil and water conservation structures, or producing and transporting organic fertiliser (Burkina Faso).

Soil fertility management should be considered within this broader context of livelihood strategies (Scoones and Toulmin, 1999), as the practices adopted will be largely determined by opportunities to earn income outside farming and by the related process of migration out of rural areas. As farmers rely increasingly on off-farm work for their income, they may decide to spend less time on measures to improve soil fertility, even though the farm is still important for ensuring food security. Those who are confident that they can buy all the food they want locally, and who feel secure in their new activities, may decide to stop farming altogether. Having fewer people active in the agricultural sector could create better opportunities for those who continue to farm, by encouraging them to expand their operations and invest in soil fertility management. A case in point are the farms in the Machakos and Nyeri districts of Kenya, which would hardly be profitable without the existence of other economic sectors which are a source of demand for agricultural produce and provide opportunities for off-farm work.

Macro-economic policies

Changes in macro-economic policies have had an impact on soil fertility management in all the study sites. In the 1990s these practices were particularly affected by structural adjustment programmes and associated policies such as devaluation, the liberalisation of crop and input prices, the abolition of subsidies, changes in input delivery and agricultural credit systems, and the downsizing of government services. Structural adjustment policies may also have reduced investment in infrastructure. Changes in road building and maintenance, public transport or telecommunications, will eventually influence the quality and spread of information and marketing networks, as well as the costs of these services. These policies have altered the cost of inputs for most crops and put mineral fertilisers and credit beyond the reach of many farmers who formerly had access. Most of the case studies therefore conclude that the unintended effect of many structural adjustment programmes has been to reduce the use of mineral fertilisers (see also Naseem and Kelly, 1999).

Marketing support services and credit systems

When deciding whether or not they should intensify production, farmers take account of several factors that affect access to inputs and credit, transaction costs, and the risks associated with production. The economic returns from agricultural activities are largely determined by whether farmers have access to reliable input and output markets, which guarantee a reasonable return to their investments. However, national and international pricing policies may distort the market or introduce unfair competition, exerting a negative influence on the economic prospects of farming households.

Such marketing support services used to be available for groundnuts in Mali, various cash crops in Uganda and Kenya, and for the supply of mineral fertilisers and other services in Ethiopia, Zimbabwe and Burkina Faso. However, input supply services have now been phased out in most of the study sites, although tea farmers in Kenya still have access to some of these services. Several companies in Zimbabwe are offering comparable assistance, as part of contract farming agreements whereby farmers are guaranteed a certain price for their crop and are given seeds, inputs and advice. Farmers in Burkina Faso also continue to benefit from the support provided by projects working with the local extension service.

Where farmers have been able to make a profit from farming and have access to appropriate support services, they continue to invest in soil fertility management as demonstrated by, for example, cotton farming and irrigated rice production in Mali. Cotton farmers benefit from input supply, credit and marketing services provided by the company controling the industrial processing and export of cotton. Consequently, farmers invest in mineral and organic fertiliser, resulting in positive nutrient balances for cotton fields. Irrigated rice farming is also a profitable venture at the moment and farmers apply mineral fertilisers at the recommended rates or above, being confident that they will get their investment back (Scoones, 2000; Defoer and Budelman, 2000; Kater et al., 2000b).

Land tenure

In many of the former British colonies, the arrival of white settlers displaced a large number of African farmers, who were then resettled in so-called 'Native Reserves' (Kenya) or communal lands (Zimbabwe). African farmers were allocated relatively small areas that often had poor soils, and were therefore unable to leave fields fallow for long enough to restore their fertility. When yields started to decline due to continuous cultivation, they had to develop alternative strategies for maintaining soil fertility, such as applying manure. After Independence in the 1960s, farmers in Kenya left the native reserves and obtained land that had formerly been farmed by white settlers. Land tenure did not change much in Zimbabwe after the country became independent in 1980 as the redistribution of land was limited. Most farmers still live in the crowded communal areas, cultivating only small plots of land.

Access to land in the study sites is obtained mainly through customary systems and most farmers feel that their land tenure is secure. However, some of the farmers only have secondary rights to land because they are new to the village. They are deterred from planting trees or establishing constructions to prevent soil erosion because such activities are perceived by the primary rights-holder as acts of appropriation. Others can no longer find fertile land because they have been away from the village for a long time, and are consequently forced to cultivate poor or degraded areas which no one else wants (Burkina Faso). In Ethiopia, changes in land reform policies and the continuous re-allocation of land in some areas have created a climate of uncertainty surrounding security over land that influences the way farmers manage soil fertility, particularly in the fields that they consider most likely to be taken away from them.

Most of the countries featured in these case studies are currently discussing the revision and reform of land tenure. One of the points under consideration is the facilitation of access to private title, as it is argued that this should give smallholder farmers more security, improve access to credit and encourage investment in the improvement and conservation of soils. However, none of the case studies cite the lack of a formal land title as a restrictive factor and other research supports the view that private title is neither necessary nor sufficient to generate greater security, stimulate more investment or increase agricultural production (Platteau, 2000).

The revision of legislation governing land tenure is also likely to affect woodland and grazing areas, locally regarded as common property, which is often crucial for sustaining livestock systems. Farmers in Uganda fear that the new Land Act will lead to the privatisation of grazing lands. In Mali, however, it is hoped that new legislation will provide communities with greater security and the right to manage village woodlands and grazing areas more effectively.

Research and extension policies

In 1995 Ethiopia embarked on an extension policy that encouraged the use of mineral fertilisers and improved seeds for cereals such as wheat and maize, which were delivered on credit. This approach has resulted in yield increases in the well-endowed regions of Ethiopia but seems less suitable for either poorer farmers or areas of the country that are most prone to climate risk. It is also somewhat out of tune with recent thinking on the need for an integrated approach to nutrient management (Smaling, 1998).

Most of the case studies report on collaboration between farmers and various projects, district extension services or NGOs in implementing technologies such as soil and water conservation, the use of rock phosphate, composting, double dug beds, agro-forestry and planting pits. Farmers generally adapt the recommendations made by extension workers to fit their particular situation. Some extension workers focus on promoting a particular technology across a whole region, without acknowledging that it is really only suitable for certain soil conditions. Moreover, the advantages of combining certain technologies with other practices are not always explored (Kenya). Furthermore, soil fertility management should be seen as an integral element of local development and investment in other sectors could be beneficial to agriculture. A proper water system, for example, would also benefit composting.

Farmers carry out their own experiments, developing new technologies through trial and error, and some go on to become respected innovators (Reij et al, 1996). Some promising new practices include combining infiltration pits and composting in Zimbabwe, using *Sesbania sesban* as a live support for passion fruit vines in Uganda, creating planting pits to regenerate degraded soils in Burkina Faso, experimenting with different types of manure in Mali and introducing fruit trees in Ethiopia.

Several case studies also report on joint analysis and action research involving farmers, researchers and extension workers. In Kenya and Uganda, participatory technology trials were developed to compare the effect of treatments involving compost and mulching with current farming practices. Special tools and methods were developed to facilitate communication between farmers, researchers and NGO staff. The results were evaluated using indicators suggested by farmers and criteria put forward by researchers. Researchers and extension workers are generally enthusiastic about these collaborative exercises, and have come away with greater respect for farmers' knowledge, and an increased awareness of their problems and opportunities which should inform future research and extension activities (see also Onduru et al., 1998; Onduru et al., 1999).

Researchers in Mali initiated a well-received programme of participatory action-research to analyse land use and soil fertility management for different categories of farmers. Initial diagnosis, using participatory methods and tools, was followed by discussions, exchange visits and training sessions aimed at identifying and selecting possible alternatives. These were subsequently implemented, and the results were monitored by assessing the inflows and outflows of nutrients. Farmers have now changed certain practices and have started experimenting with new technologies (see also Defoer et al., 2000).

Conclusions

All of the case studies in this book show that farming households actively pursue a range of objectives but which are not exclusively agricultural. Farmers are constantly adjusting to change, and to a range of opportunities and constraints. Their capacity to innovate is influenced by the agro-ecological conditions under which they farm and by their resources, knowledge and energy. In addition, the socio-economic and institutional context, including developments in other sectors of the economy, also determine whether agricultural activities are profitable and secure, and whether they offer incentives to invest in farming and soil fertility management. The impact of these factors varies between households, producing a range of different livelihood strategies and farming practices. This notion of diversity needs to be integrated into interventions and policies (see also Scoones, 1999).

Farming embraces a wide range of practices, capacities, problems and opportunities and people have to be highly innovative to make ends meet. Land is becoming an increasingly scarce resource in all the study sites, while farmers have to contend with degrading soils and declining levels of fertility on part of their fields. Nutrient balances are more negative for outfields and those fields that are subject to erosion and leaching, which may have critical consequences for production when soil stocks are low. A targeted approach that focuses interventions on cropping systems most at risk would enable farmers, policy makers and extension workers to make more efficient use of scarce resources.

The case studies show that changes in soil fertility management practices have not followed a linear trend towards increasingly intensive farming methods with the application of higher and higher doses of nutrients to the soil. This uneven pattern is particularly evident when one analyses the dynamics of the use of mineral fertilisers. These were initially applied by many farmers and then partly replaced by cheaper but more labour intensive organic fertilisers. Productivity can be improved by better integrated crop and livestock systems, recycling crop residues, and the careful use of other available nutrients, but on their own these measures may not be enough to sustain soil fertility in the long run and it will still be necessary to add extra nutrients to the farm.

Instability, variability and transition are inherent characteristics of smallholder farming, particularly in drylands (Mortimore, 1998). Farmers have to assess the possible options and identify solutions to suit their own, site-specific conditions. Whatever the impetus, a large part of any farmer's success will be due to their understanding of the environment in which they live and work. Indigenous knowledge is an immensely valuable asset in this continuous process of adjustment and innovation, and one which may be used to even greater effect when complemented by research into agricultural processes and local practices.

A major question concerns how governments, research institutes, extension services, NGOs, projects and other organisations can best assist farmers in their pursuit of more sustainable and rewarding farming systems. For instance, extension workers can help broaden the range of options available to farmers, enrich their knowledge of the processes at work in soils and plants, assist them in their experimentation and help them disseminate the results. It may be more useful for farmers to gain insights into the concepts and rationale behind certain technologies than to be presented with a standard list of techniques. It has been suggested, moreover, that extension should be geared towards 'facilitating learning' and stimulating discovery, creativity and experimentation and that this could be achieved with methods used in informal adult education. Farmers will also need monitoring tools, so that they can assess changes in soil status. These tools may be inspired by experience with resource flow mapping, local soil classification systems and indicators of soil fertility change. Such an approach to extension will involve reviewing the methods currently used, and will probably require extension workers to learn a new range of skills (Lynam et al., 1998; Deugd et al., 1998).

In addition to the participatory development and adaptation of technologies that are appropriate to the constraints and opportunities faced by farmers, researchers will have to invest more energy in building partnerships, establishing joint experimentation and presenting the insights gained from research to a wider audience. They will also need to see how to develop methods and tools for analysing and monitoring soil fertility which extension agents can use in their work with farmers.

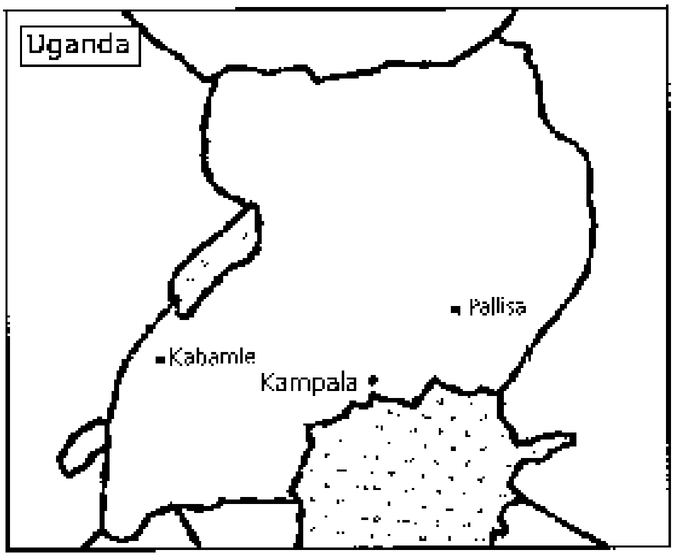
However, investment in soil fertility management will not increase if farming is neither profitable nor essential for maintaining livelihoods. Comprehensive and focused national policies could help to improve access to markets and support services for acquiring inputs and selling produce, finance and information, and help create conditions that make agriculture a more attractive option, giving farmers a reasonable return on their investments. National policies may improve the economics of the farming sector by supporting better access to markets, reviewing pricing policies and regulations, promoting investment in infrastructure and reducing the risks of farming through the provision of safety nets. Such a policy framework needs to be broad-based and multi-sectoral. It should take account of environmental issues and consider the development of non-agricultural sectors, which will need to provide the growing rural population with alternative employment opportunities, while creating more demand for agricultural products. However, structural adjustment policies may seriously limit the government's ability to intervene significantly in this way.

The Soil Fertility Initiative (SFI) is one of several supranational initiatives on soil fertility management that have started debate on the need to address soil degradation in Africa. In certain countries such as Burkina Faso and Ghana, it has led to the creation of a national action plan for soils. Burkina Faso, for instance, has developed a special national policy and programme for soil fertility management, which should be implemented in the near future. Recapitalisation of soils with rock phosphate and agricultural extension are central planks of this initiative but it will also focus on strengthening input and output markets. Other countries, such as Mali and Uganda, have started discussions on the need for a national soils policy, often as a spin off from the SFI. For other African countries, it may be worth embarking on the development of a national action plan for soils if this would help to cross conventional boundaries and perceptions concerning soil fertility decline and how this should be addressed, and to establish a debate among all the various stakeholders involved. Such an initiative would need to avoid adopting a monolithic approach which fails to address the many site-specific issues influencing sustainable soil fertility management.

International initiatives on soils such as SFI are helpful insofar as they attract attention and mobilise funding at national and international levels to address soil fertility management. However, they need to be co-ordinated with other international conventions and policies, such as trade agreements and structural adjustment programmes. Support should also be mobilised for effective local initiatives and networking between various levels and actor groups. Networking by researchers and development workers has generated a body of knowledge about soil degradation and integrated soil fertility management largely based on local level experiences. Networks such as NUTNET[2] are important for building knowledge about the extent of soil fertility decline and approaches for integrated soil fertility management. Regular contacts between a variety of organisations and countries are a central element of this approach as they not only consolidate the learning process but also provide a forum for informed debates that may help determine the future of African soils.

[2] Other examples of such networks in Africa have been facilitated by TSBF and ICRAF in East and Southern Africa, and by IFDC and WARDA in West Africa.

Impact of policy change on soil fertility management in Uganda



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Introduction[1]

In spite of its excellent agro-climatic endowment, crop yields in Uganda are among the lowest in the world. As this appears to be partly due to policy changes which have shaped the agricultural sector over the last century, this chapter analyses current soil fertility practices in Uganda from a historical perspective. After an introduction to Uganda's agricultural sector and a description of farming systems in the Districts of Kabarole and Pallisa (see Map), we consider trends in agricultural policy and their effects on soil fertility management from 1900 to date, and outline the innovative ways in which some farmers have responded to change. After discussing the current state of farming and nutrient balances, conclusions are drawn suggesting a number of new policy initiatives which are needed to complement existing ones.

Methodology

Information for this case study was collected within the framework of the LEINUTS[2] research programme on soil fertility management which started in 1997. In this research participatory methods were used which enabled farmers to themselves analyse their problems and identify

1 We gratefully acknowledge the farmers of Kakoro in Pallisa District, Kiram Kyamuka and Joint Effort to Save the Environment in Kabarole District, for their valuable participation in this research. We also thank the European Union and the Government of the Netherlands for their financial support. Our thanks also go to André de Jager and Siebe van Wyk of LEI-DLO, and Joost Vlaming of SC-DLO, for their contributions and help.

2 LEINUTS stands for: Potentials of low-external input and sustainable agriculture to attain productive and sustainable land use in Kenya and Uganda.

new technologies to resolve them. Researchers held detailed discussions with farmers regarding how they perceive changes in the soil fertility status of their fields, and how these perceptions influence their management practices. This information was triangulated with a survey involving over 100 farmers in each study site. In the two sites, 30 farm households were monitored on a monthly basis for changes in economic characteristics and nutrient flows, and information from the latter was complemented by a laboratory-based analysis of the organic matter content, texture, and N, P and K levels in the farmers' soils. A review of the secondary data published at district and national levels completed the study (cf. Jager et al., 1999).

Agriculture in Uganda

Crop yields in Uganda are low. An index of food production per capita, set at 100 in 1970, had fallen to 67 in 1990 (World Bank, 1993). Farm yields range from only 13% to 33% of the yields obtained at research stations, and data on soil erosion, nutrient balances, availability of fuel wood, silting, and deforestation all point to a gradual degradation of the country's natural resource base (Mukiibi, 1993; MNR, 1994b; Wortmann and Kaizzi, 1998). The growing population in Uganda is heavily dependent on developments in the agricultural sector and the available natural resources. Its degradation will have serious consequences.

Agriculture in Uganda may be described as 'low input, low technology and low productivity'. Purchased inputs such as seed, pesticides and fertilisers account for a small part of the total cost of crop production. Mineral fertilisers are applied in small amounts to tobacco, coffee and tea, which are grown as cash crops (BoU, 1992).

Many factors contribute to the country's low productivity. Most agricultural produce is consumed by the domestic market. The unfavourable socio-economic conditions in which farmers operate are highlighted by the low prices they receive. Maize farmers, for example, only receive 17% of the retail value of their produce because of the country's deficient marketing infrastructure, high transport costs and lack of information on market trends (MFED, 1998). Under these circumstances it is the middlemen who reap handsome profits.

Low productivity may also be due to the facts that farming practices have not been adapted to changing circumstances, farmers have limited access to farm implements and post-harvest losses are high. Farmers used to rely on natural fallow to restore soil fertility levels, sometimes leaving fields for up to 10 years to regenerate. However, long term fallowing is no longer possible as pressure from a growing population has made land a scarce commodity.

There are no long-term studies monitoring the status of soils, nutrient balances and crop productivity in Uganda. However, evidence from various sources indicates that soil fertility is declining as demonstrated by studies on farmers' perceptions of soil fertility change, nutrient balances and on-station fertiliser trails (Rubaihayo, 1991; Tukahirwa, 1992; Opoi-Odongo et al., 1993; Zake, 1993; Nsubuga, 1994; Bekunda and Woomer, 1996; Bekunda et al., 1997; Wortmann and Kaizzi, 1998).

Farming systems in the case study sites

This study was conducted in two districts: Kabarole, which is in western Uganda, and Pallisa in the east (see Map). For the purposes of the study the Kabarole district is considered a high potential area because of its inherently fertile Andosols soils and relatively favourable climatic conditions. Pallisa is a low potential area as it has inherently infertile Ferralsols and less rainfall. The two study areas vary in altitude, mean temperatures, rainfall and population density, all of which influence the nature and productivity of their respective farming systems (Table 1).

Kabarole is a hilly region and 60% of the homesteads are on steep slopes, 30% in the foothills and valleys, and 10% on the hilltops. Pallisa is generally flat with broad, swampy valleys. Settlements are built in dry areas, and all available land types are cultivated. The settlement pattern is scattered in both districts.

The farming system in Kabarole is known as the montane system[3]. Land holdings here are smaller than in Pallisa, and farmers use hoes to prepare the field. The main perennial crops are bananas, arabica coffee and passion fruit; and the main annual crops are maize, beans, field peas, Irish potatoes, sweet potatoes, tomatoes, onions and cabbage. Most crops in both study areas are produced in mixed stands, except for some vegetables, old banana and rice fields. In Kabarole, 30% of farmers also keep crossbreed cattle in stables, and another 45% of households hold goats, while all of them have chickens. Farmers cultivate fodder, particularly napier grass or elephant grass (*Pennisetum purpureum*). None of the smallholder farmers purchase concentrated animal feed for dairy production.

About 80% of the land holding in Pallisa is allocated to annual crops and 10%, mostly around the homestead, to perennial crops such as bananas. The main crops are cotton, cassava, sweet potatoes, soya beans, beans, maize, sorghum, groundnuts, rice, cowpeas and sesame. Maize, cassava and sorghum, which are more productive and less labour intensive, are increasingly replacing millet. Bananas are also becoming less important, possibly because their cultivation has become more difficult due to perceived changes in local climate conditions.

Livestock consist mainly of cattle and goats, which play a very important role in both the agricultural production system and in local culture. They may be exchanged for land, used to pay bride prices and are also a source of cash in times of need. Of the households in Pallisa 70% own oxen for draught power, mostly local Zebu which are kept under a traditional system of communal management and graze on the village lands. Several families either have no plough or only one ox, in which case they usually join forces to get a complete team of oxen with which to plough and work on each others' farms in turn. However, this is not always possible, and farmers who are unable to get access to animal traction or sufficient labour have no option but to leave some of their land fallow.

The main concerns of farmers in both regions are meeting their subsistence needs, generating cash, and building up savings, particularly in the form of livestock. However, there are considerable differences between the resource base of smallholders in the two

[3] These are high altitude farming systems where mild temperatures allow farmers to cultivate temperate crops such as wheat.

Table 1 Characteristics of the study area

Characteristics	Kabarole	Pallisa
Climatic and Topographic		
Mean temperatures (°C)	13-26	16-30
Altitude (m.a.s.l.)	1500-1800	1070-1160
Rainfall (mm yr^{-1})	1300-1500	800-1200
Average slope (%)	20	1
Demographic		
Population density (Persons Km^{-2})	400	229
Population growth rate (% yr^{-1})	2.70	2.86
Average size of household (No of persons)	6.0	5.4
Soils		
Soil type	Andosols	Ferralsols
Organic carbon	0.66-4.01	0.2-1.9
Total N (%)	*0.16-0.42*	*0.08-0.23*
Total P (%)	0.22-0.53	0.01-0.07
Total K(%)	0.13-0.49	0.10-0.49
pH in water (1:2.5)	5.4-7.0	4.6-6.0
Economic Indicators[1]		
Labour		
Consumer units (aeu[2])	5.9	1.6
Labour units (aeu)	4.9	0.7
Land		
Total cultivated area (ha)	1.6	2.6
Fallow area (ha)	0.7	1.7
Capital		
TLU[3]	1.5	2.4
Value of livestock (Ush $farm^{-1}$)	484,000	856,000
Value of equipment (Ush $farm^{-1}$)	33,000	140,000
Ratios		
Land/labour (ha aeu^{-1})	0.52	0.70
Land/consumer (ha aeu^{-1})	0.42	0.64
Consumer/labour (aeu aeu^{-1})	1.21	1.12
Average economic indicators		
Net farm income (Ush $year^{-1}$)	880,000	359,000
Off-farm income (Ush $year^{-1}$)	72,000	101,000
Family earnings (Ush $year^{-1}$)	*952,000*	*460,000*
Market share (% of gross value sold)	29	30

1) Figures are the averages from 16 and 14 farms in Kabarole and Pallisa districts respectively, and are based on one year of monitoring (1997-1998), 2) Adult equivalent units, 3) Tropical Livestock Units. 1 US $ =1500USh (1999).
Source: LEINUTS survey.

areas (Table 1). Farm households in Pallisa cultivate more land, have more people, more livestock and more farm equipment, mostly ox ploughs. The ratios in Table 1 indicate that farming systems in Kabarole are more labour intensive because there is less land per labour unit available than in Pallisa. The difference in agricultural potential is reflected in Kabarole's net farm income which is nearly 2.5 times higher than that in Pallisa. While farmers in both areas sold roughly the same proportion of their agricultural produce in terms of gross value (29% in Kabarole and 30% in Pallisa), those in Pallisa earned 22% of family income through off-farm activities, compared to 8% in Kabarole.

Trends in soil fertility management since 1900

Uganda's political situation and agricultural policies have undergone major changes this century that have affected the agricultural development of the two study sites. We will be looking at trends in soil fertility management over three broad but distinct periods. These are the colonial period and the first years of Independence, the two decades from 1966 to 1986 and the period since 1986.

The colonial period and the first years of independence (1900-1966)

Uganda was gradually colonised from the 1870s onwards, peacefully in some regions and by force in others. After the British consolidated control over the Uganda protectorate in the early 1900s the colonial administration started to develop the agricultural sector through a series of policies. In 1900 local chiefs and kings signed a series of agreements privatising land in the southern and central parts of Uganda, where Kabarole is situated. Land titles were issued to chiefs, clan leaders and religious institutions, thereby creating two classes: landowners and tenants. This privatised land, known as '*Mailo* Land', may be inherited or sold. In the north and east of the country, which includes Pallisa, land ownership remained customary and passed through clans, although officially it belonged to the British crown.

By promoting cash crops the colonial government aimed to provide raw materials for British industries and hoped to raise enough revenue from taxes and export earnings to pay for the construction of roads, schools and hospitals, and its own administration.[4] The development of the cash crop economies was based on the division of the country into various agro-ecological zones, with each area specialising in the cultivation of a particular crop. The lower lying areas of Kabarole district were reserved for robusta coffee, the middle belt for tea, and the higher zone for arabica coffee. A district like Pallisa was to specialise in cotton production.

The colonial government became increasingly concerned about land degradation and erosion from agriculture and livestock. During the 1930s, three surveys on soil degradation in Uganda were published (Stockdale, 1937; Tothill, 1938; Wayland and Brasnett, 1938). These led to the development of specific soil and water conservation policies for the different regions of Uganda in the 1940s which laid down stipulations for promoting good land management

4 There were no white settlers in Uganda as their installation was strongly resisted by the indigenous leaders of that epoch: Uganda became a protectorate, unlike Kenya which was a colony where European settlers were permitted to farm. This distinction underlay the British changing the borders of Uganda, so that a large part of what used to be eastern Uganda became part of Kenya and was settled by white farmers.

(Kamugisha, 1993; Tukahirwa, 1994). The colonial authorities addressed the problem of soil erosion by implementing district level bylaws specific to 'African-held land' and focused on coffee and cotton, cash crops that had been forced upon farmers. The bylaws were administered by local chiefs, and included stipulations about mulching, crop rotation, fallowing, grass strips, earth bunds, building terraces, cultivating steep slopes, and burning forested areas. The local administrative and agricultural officials rigorously enforced these stipulations and stiff penalties were imposed on farmers who failed to comply with them. For 'non-African' farmers, the assumption was that they were aware of the soil erosion problem and only needed advice from the soil conservation committee. No penalties existed for non-compliance other than a conservation order from the District Executive Secretary which required the occupant of the land to either adopt the specified measures or stop a specified activity.

In Kabarole the mild climate was favourable to European breeds of dairy cattle and in the 1950s and 1960s the government actively promoted dairy production, establishing a livestock-breeding centre in the district. This resulted in large numbers of indigenous cattle being replaced by smaller herds of crossbreed dairy cattle. Pastures were enclosed to control disease and improve productivity, which meant that there was less common grazing land available for the indigenous herds. Introduced Arabica and Robusta coffees became main cash crops in Kabarole. Livestock rearing in Pallisa did not change in this period.

The colonial period also witnessed the development of agricultural institutions and services such as research stations, agricultural colleges, an extension system, an input supply system, and processing and marketing infrastructures. The extension approach remained coercive, but in the mid-1950s a new methodology called 'extension through progressive farmers' was introduced (Semana, 1998). This involved targeting selected 'progressive' farmers with advice and support in the form of inputs and credit. Many of the selected farmers were relatively wealthy, had received some formal education, and were therefore expected to adopt new technologies very quickly. The idea was that this assistance would improve the performance of the progressive farmers. Their neighbours would then follow their example and adopt the new practices, and the country's overall agricultural production and productivity would improve.

After independence in 1962 most of the basic aspects of colonial policies and laws relating to natural resources and agriculture remained intact and continued to be implemented until 1966, when political instability engulfed the country.

The period between 1966–1986

This period started with the abrogation of the constitution that had been put in place at Independence. The numerous colonial laws and regulations which had previously governed soil management were abandoned. Farmers started cultivating on previously prohibited areas such as along rivers and streams, and on steep slopes. Swamps were drained, and measures to control soil erosion (terraces and bunds) were no longer implemented or maintained. Both study areas were affected by these developments, as farmers began cultivating steep slopes in Kabarole and growing rice in Pallisa's swamps.

In spite of these developments, the country's economy and agricultural output continued to grow until the early seventies. This was mainly due to the introduction of new technologies, such as mineral fertilisers and improved varieties, and to new initiatives in agricultural extension. In 1964 the United States Agency for International Development (USAID) introduced an approach based on 'helping farmers to help themselves' (Semana, 1998). This persuasive approach to extension was an almost revolutionary shift away from the previous coercive methods. The new emphasis was on extension as a learning process and practically oriented courses were included in the curriculum of agricultural colleges. Agricultural extension continued to focus on progressive farmers, who received special support.

All this came to a halt in 1971 when Idi Amin's military government declared 'economic war' on Ugandans of Asian origin. Their properties and businesses were expropriated and redistributed to Ugandans of African origin. The distribution system for agricultural inputs broke down, the infrastructure for marketing and agro-processing collapsed, prices dropped and the whole economy began a downward spiral. The government started borrowing money from the parastatal marketing boards for cotton and coffee, which initially delayed payment to farmers and eventually resulted in all payments for produce being stopped. The government extension system declined rapidly as the economic situation deteriorated. This era, marked by political turmoil, ended with a decline in all sectors of the economy and administration, and the breakdown of law and order.

In Kabarole coffee production collapsed, and farmers turned to brewers' banana[5] as a replacement cash crop. The spirit distilled from the brewed ripe banana fruits is sold, while returning the residues to the soil. In Pallisa farmers abandoned cotton as a cash crop and shifted back to cereals which were in great demand in both Uganda and neighbouring Kenya. There was a sharp drop in the use of mineral fertiliser, which probably resulted in increased nutrient mining of the already relatively infertile soils in Pallisa.

The post 1986 period

This period started with the assumption of power by the National Resistance Movement. The early years were marked by civil war in parts of Uganda and the introduction of a policy of economic liberalisation, which meant that the State withdrew from the provision of some services while market forces played a larger part in the economy. Food prices steadily increased between 1988 and 1990 but in the 1990s prices fluctuated according to the size of harvests.

Farming systems in Pallisa were more affected by these events than those in Kabarole. During the civil war between 1987 and 1989 Pallisa district was contested by several warring factions. Livestock and other goods were looted, and by the end of the war, most of the households in Pallisa district were left with no cattle or oxen. The disappearance of cattle affected the farming system and the nutrient balance of soils. Cotton was and still is the main cash crop available to most farmers and production increased as the private sector became more involved in marketing, not only giving farmers a better price for their crop produce but also paying cash on delivery. However, the immediate returns are still relatively

[5] A local variety of banana used to produce an alcoholic drink.

low because cotton requires large amounts of pesticides and is labour intensive. Farmers with access to wetlands can grow rice as a cash crop, but most of District is too dry to grow upland rice or bananas as a source of revenue.

The farming systems in Kabarole have changed more gradually. The civil war barely touched this area and livestock holdings were not affected by it. As population pressure increased during this period land holdings became smaller. Although there were campaigns to persuade farmers to grow coffee again, the impact of economic liberalisation did not send them rushing out to their fields to replant it. Coffee bushes take some time to get established and, with reduced sizes of land holdings, there is not much land left for this crop. In addition, farmers were sceptical about the possible benefits of growing coffee when prices were fluctuating and unpredictable. Farmers continued to replace indigenous cattle with the more productive dairy crossbreed, while enclosing and privatising grazing areas. With the introduction of 'zero-grazing' and 'semi-zero-grazing' systems, in which cattle spend most of the time in the stable, farmers could collect manure more easily and recycle nutrients more efficiently.

Throughout the 1980s and 1990s the extension service remained chronically under-funded and therefore unable to train staff, who consequently are inadequately informed about the range of new technologies available or how to disseminate them more effectively. Although agriculture is the most important sector of the national economy, research and extension activities are still allocated a small proportion of the government budget. In the fiscal year 1998/1999, for example, it was only allocated 1.5% of the total budget (MFED, 1998).

Agricultural policies in the 1990s

Environmental and land use policies

The Ugandan government, with the assistance of international development agencies, has launched several policy initiatives as part of the National Environment Action Plan, or NEAP (MEP, 1988). NEAP was developed to guide the sustainable use of the country's natural resources and to increase the productivity of small holder farms. A National Soils Policy, as proposed in NEAP, is in the making and in 1990 a draft policy was prepared to prevent and reduce soil degradation, and promote sustainable soil productivity (FAO/UNEP, 1990). The legislation that will accompany this policy is in preparation and all stakeholders have been requested to present their point of view. The policy will be implemented through three inter-linked approaches which are:

- Technical–covering land evaluation and management technologies;
- Institutional–covering research and educational institutes, extension services, and the national commission on land use;
- Legal–covering legal arrangements for general land use

Issues concerning soils are also included in the National Environment Management Policy and the National Policy for Management Wetlands Resources (MNR, 1994a; MNR, 1995). A series of other policies have also been designed, such as the policy on agricultural modernisation and land tenure reform, which may be expected to have some impact on the use of soils.

Agricultural modernisation

The Ugandan government has drawn up a medium term plan (1997-2002) for the modernisation of agriculture, with an overall target of increasing the annual growth rate of farm outputs to 7.5%. Priorities include research and extension, marketing, the provision of credit and agro-processing. The plan proposes to change the 'training and visit' extension approach to a more participatory and demand driven system which would make appropriate and sustainable soil fertility management practices available to more farmers.

However, government expenditure in the agricultural sector is still relatively low. The private sector is expected to play a major role and fill the funding gap, but has failed to do so. At the moment therefore, everything hinges on the government raising the necessary resources to finance the programme. But decentralisation and the associated civil service reform of 1993 reduced the number of extension staff from about 4,300 in 1993 to 2,000 in December 1995 (MPED, 1996). These remaining extension workers are inadequately equipped and trained.

Rural agricultural credit schemes in Uganda are very limited and almost exclusively provided by NGO development programmes and Community Based Organisations (CBO), using members' savings. Some banks will provide agricultural credit but not in a way that is accessible to small-scale producers. Farmers need to be literate to apply for a loan as they have to present a business plan, may often have to negotiate with bank staff, and have to provide collateral in the form of land or fixed assets. As a result most of the agricultural credit provided by banks goes to large-scale farmers who use it for dairy production, ranching, or establishing greenhouses for producing flowers. Even when credit is accessible to small-scale farmers it is often inappropriate for their needs as the interest rates are very high (24-30%).

Land tenure reform and management

In the 1900s, a series of land agreements between the British Government and various local kings and chiefs created new systems of tenure based on landowners and tenants. The rest of the country continued to maintain the old customary systems of land tenure. In 1975 a decree was passed vesting all land in the State. This put customary tenants in a very insecure position as they were now regarded as occupiers of crown land from which they could be evicted. Many farmers were indeed forced off their land, as it was common for politicians and government officials to grant themselves leases of large tracts of land regardless of its occupants' customary rights. This decree was reversed by the 1995 constitution, which vested all land in the citizens of Uganda and recognised customary tenure rights to land (Mwebaza, 1999).

The aim of the 1998 Land Act is to strengthen security of tenure for tenants and customary landholders, whose legal ownership is to be recognised by the issue of land certificates. The idea of policy makers is that this will facilitate the emergence of a land market which will attract investment, particularly from outside Uganda, and eventually lead to the country's economic development. It is also assumed that having a title will give farmers access to credit and encourage them to invest in managing their resources by replenishing soil fertility and controlling erosion. The 1998 Act is also intended to bring into production some of the cultivable land that is presently not being used.

However, the link between titling and economic growth is elusive. Much of Uganda's cotton and coffee is grown on land governed by customary tenure, and the process of granting titles has proved tedious, bureaucratic, expensive and socially disruptive. Development also requires investment in infrastructure and the provision of services and marketing outlets. Some observers argue that titling should be selectively implemented where the need arises due to increased pressure on land, land sales, and the increasing incidence of land litigation, such as in urban and peri-urban areas (Mwebaza, 1999).

Empowering women

In 1987 the Government of Uganda adopted a forward looking and enlightened policy to promote the emancipation of women. Activities in this area have included awareness raising, the development of legislation to protect women's rights, and increasing their educational opportunities and representation in decision making bodies at local and national levels. As a result the general population has became more responsive to gender issues, including women's concerns and their role in natural resource management. Women provide more than 60% of the labour force in agriculture and head 30% of rural households (MPED, 1996). The government's policies of empowering women through education, ensuring that gender issues are taken into account when developing technologies and targeting women recruits for the agricultural extension services, should result in more effective development. Many communities are already starting to feel the impact as a growing number of women and men participate in managing their natural resources.

The status of soil fertility in Kabarole and Pallisa

The soil in Kabarole is more fertile than in Pallisa, where N, P, and K levels are very low (see Table 2).

Table 2 Soil fertility status in Kabarole and Pallisa

Characteristics	Kabarole	Pallisa
N stock (kg/ha)	11,800	4,500
P stock (kg/ha)	14,400	2,700
K stock (kg/ha)	12,200	8,800

Source: LEINUTS survey.

The impact of current farm management practices on soil nutrient flows in the two areas is presented in Table 3. Nutrient balances for N, P and K are negative in Kabarole, which is mainly due to leaching, gaseous losses and erosion. In Pallisa the nutrient inputs and outputs at farm level are better balanced. Hardly any mineral fertilisers are used in either area, where most of the nutrients inputs are from organic sources, primarily farmyard manure. In Pallisa

Table 3 Nutrient budgets and balances of farms in Kabarole and Pallisa Districts

Nutrient flows	N (kg/ha)		P (kg/ha)		K (kg/ha)	
	Kabarole	Pallisa	Kabarole	Pallisa	Kabarole	Pallisa
Farm Balance	-173.8	2.3	-60.8	1.5	-41.3	15.0
IN 1	0.0	0.5	0.0	0.3	0.0	0.3
IN 2	18.1	32.1	2.3	3.6	19.8	34.0
IN 3	5.8	3.8	1.0	0.8	3.8	2.5
IN 4	7.5	0.3	0	0	0	0
OUT 1	-3.6	-1.8	-4.3	-0.5	-4.8	-2.8
OUT 2	-7.1	-16.3	-0.8	-1.8	-7.8	17.5
OUT 3	-104.5	-11.3	0.0	0	0.8	-0.50
OUT 4	-28.8	-1.8	0.0	0	0	0
OUT 5	-57.5	-0.3	-54.5	0	-50.8	-0.3
OUT 6	-3.5	-3.0	-4.5	-0.8	-0.8	-0.8

IN 1 Mineral fertiliser/feeds
IN 2 Organic products
IN 3 Wet + dry deposition
IN 4 Biological N-fixationZ

OUT 1 Crop harvests / animal products
OUT 2 Crop residues / manure
OUT 3 Leaching
OUT 4 Denitrification
OUT 5 Water erosion
OUT 6 Human faeces

Source: LEINUTS survey.

livestock depend on crop residues and grazing outside the farm. Farmers in Kabarole feed cattle in zero-grazing units, giving them napier grass grown on the farm and other materials brought in from outside such as purchased napier, maize stover, banana pseudo stems and banana peelings. Only limited amounts of nutrients leave farms in either area through the sale of crop or animal products.

In terms of productivity, the high nutrient stocks in Kabarole's fertile soils pose less soil fertility problems in the short term and can sustain crop production. The stock of N, for example, will be depleted within 68 years at the current depletion rate. Estimations indicate that leaching and erosion are the main sources of N losses, probably due to the porous structure of andosols combined with high rainfall. Some farmers are aware of this and are trying to reduce these losses by installing grass bands and trash lines, using mulch and contour farming.

Since farm income levels in Kabarole are currently relatively good (Table 1), producers have the resources to invest in their farms or for developing off-farm sources of income. It is better to invest now, while production levels are still high and economic returns good, than to wait until soil fertility has declined substantially, production has dropped, and when more significant remedial action will be required. Households should also continue preparing some family members for work outside the agricultural sector, for example by investing in education.

The situation in Pallisa is more complex. Nutrient balances suggest that the farming system is ecologically sustainable at present levels of production, as enough nutrients are imported through off-farm grazing to balance the outflows. In the long term however this may not be sustainable. The rapidly growing population and the recent Land Act are likely to result in the loss of large tracts of common grazing land. The new Act enables individuals to apply for title to common lands, which could result in the enclosure of grazing land. A more imminent problem is that the low level of production in Pallisa's farming systems makes them economically unsustainable (Table 1). Farmers must either diversify sources of income, which they already try, or increase production levels, if they are to maintain livelihoods. Increasing agricultural production will require a considerable increase of nutrient inputs, especially N and P, into the system.

Farmers' response to soil fertility problems

Farmers are not passive observers of change within their farming systems but are continuously experimenting and innovating with new methods as they strive to improve their livelihoods, often in the face of huge obstacles. In the cases discussed in this chapter, the process of innovation was facilitated by NGOs, which provided the communities with technical and financial assistance, but it would also not have been possible without the high level of organisation shown by farmers within CBOs. Innovation is a continuous process: existing local technologies are improved and new technologies modified. Technologies are adopted and adapted according to the returns they bring, labour requirements and availability, the amount of land involved, and the many other demands on farmers' time and resources.

A number of soil fertility management techniques and practices in the two study areas were identified. These can be roughly divided into indigenous technologies developed by farmers with little or no input from formal research, and technologies developed by research institutes. Indigenous technologies include traditional fallow followed by slash and burn, mulching, mixed cropping, crop rotation, manuring, traditional agro-forestry and grass bands to reduce erosion. The technologies generated by research include new designs for agro-forestry, composting, terracing, and the generation of biomass for green manuring.

This section gives a detailed description of three specific technologies and their impact on soil fertility management:

- Intensifying production in homestead fields
- Intercropping *Sesbania sesban* and passion fruit (*Passiflora edulis*)
- Application of compost and mulch

Intensifying production in homestead fields

One response to smaller land holdings and reduced fallow has been to farm the available land more intensively, especially the fields around the homestead (Homestead Units or HSUs). Farmers apply compost and farmyard manure in these gardens and have refined existing technologies such as water harvesting and use of poultry to control pests. HSUs support the widest variety of crop species, including many fruit, ornamental and shade trees, are weeded more thoroughly than other fields, and are less infested by pests and diseases. It may be assumed that such intensive care will reduce nutrient losses while trees feed leached nutrients back into the cropping system. Farmers in both study areas considered soil bunds and terraces as a colonial imposition and abandoned them soon after independence, but have now started using them again to control erosion. In conclusion, the HSUs can be regarded as sites of nutrient concentration and intense utilisation.

The area of HSU fields takes up between 10 and 25% of the whole farm. Their size depends on the availability of family labour, manure and other organic materials, and may be regarded as an indicator of family wealth. The more resources a family has the more organic fertiliser it can produce, which can be used to extend the HSU and even be transported to other fields. When animals graze the outlying fields and common lands outside the farm they transfer nutrients from those areas back onto the farm and particularly the HSUs. This flow increases when the cattle spend more time in pens or *'boma'* near the homestead. In Pallisa some farmers regularly move their cattle pens to spread the manure across the plot (see Box 1).

Box 1. Mobile cattle pens and unequal access to manure

In Pallisa District, some farmers have successfully adapted a labour saving method of applying nutrients. A cattle enclosure (*boma*) is established near the homestead to prevent theft and cattle are kept there when they are not grazing or ploughing. During the rainy period when the *boma* gets soggy, the fence is regularly moved in one direction to bring a new area into the enclosure on which the cattle can rest. The old *boma* is left to 'cool' for about six months before it is planted with crops. This practice is very popular in Pallisa and is used by richer farmers to create niches for banana production.

In Pallisa some cattle are herded collectively and have access to the fallow fields and crop residues of all their owners. The herd is normally kept at the homestead of a richer farmer, who usually has more cattle and land than the others. As they defecate in this farmer's *boma*, the cattle transfer nutrients from the fields of the other owners to a single homestead, effectively transferring nutrients from poorer farmers to richer ones. Additional studies are required to establish how this arrangement benefits poorer families and how this relates to the value of nutrients exported out of their farming systems.

The higher investment of labour into the HSU enables farmers to handle the accumulating organic materials more effectively. Gender issues influence how these resources are managed and a number of activities seem to be almost exclusively done by women and children after school. These tasks include cleaning the stables, collecting dung, gathering fodder, feeding the stabled livestock and preparing and applying compost.

Intercropping Sesbania and passion fruit

NGOs started promoting the cultivation of *Sesbania sesban* in Kabarole in 1988, to produce firewood and fix nitrogen in banana fields. Sesbania is grown along the boundaries of fields planted with annual crops intercropped with banana, and also on erosion control bands. Over time farmers have adapted Sesbania for other purposes and, since the early 1990s, have used it to regenerate soil fertility and as live stakes to support passion fruit plants.

Box 2 Intercropping Sesbania-passion fruit

Mr. Tibesigwa lives in the Kabarole District. He has an area of approximately 0.1 ha near his homestead where his family grows vegetables and annual crops. In 1996 he planted Sesbania seedlings in this plot and later added passion fruit. Mr. Tibesigwa claims that his inspiration for this intercropping system came from observing and combining several practices. He had been taught, and has also observed, that crops perform well on plots where Sesbania has previously grown. More significantly, while visiting a friend in a neighbouring area he saw that only five Sesbania stems could support a heavy crop of passion fruit, while he was struggling to find money to buy wires and poles to construct trellises. Mr. Tibesigwa is all praises for the Sesbania/passion fruit system, and listed its advantages over posts and wire trellises: there are fewer weeds; yields are better because branches don't need to be pruned to prevent trellises from falling down; the system is more resistant to wind throw; the passion fruit plants live longer; plants are less prone to disease; the creation of 'forest-like' conditions rejuvenates soil fertility; and the system provides valuable firewood. Unfortunately he cannot expand the system into outlying fields as he is worried about losing fruit to thieves and naughty children.

Intercropping Sesbania with passion fruit can generate income, provide fodder for small livestock and improve soil fertility. Leaving Sesbania for three to four years seems to enable this tree to extend its roots down into deeper soil layers where they can extract leached nutrients (Hartenmink et al., 1996; Mekonnen et al., 1997; Maroko et al., 1998). Large quantities of organic matter are added to the soil through leaf fall. The interest in using Sesbania as live support for passion fruit is increasing in Kabarole (Box 2), because of a growing demand for the fruit following the Government's policies of economic liberalisation and promotion of export diversification.

Farmers using the Sesbania/passion fruit combination start by interplanting this tree with annual crops like maize, beans, tomatoes and cabbages. They do this for two seasons and then plant passion fruit seedlings which are trained up the Sesbania plants. Depending on the spacing of the trees, the undergrowth may be used for grazing goats. Passion fruit starts to bear fruit after about 8 months and will generally last for at least another four years. The tree will be cut down for firewood when the passion fruit is no longer productive and the field cleared for annual crops: these are grown for the next two to three years before repeating the cycle with Sesbania and passion fruit. It is assumed that annual crops grown in this cycle give higher yields because Sesbania regenerates soil fertility (Kwesiga and Coe, 1994).

Application of compost and mulch

NGOs have trained farmers in both districts to produce compost made from napier, maize leaves, ash, cow dung, weeds and grain husks. The farmers are clear about the benefits gained from this compost and they now are focusing on improving its quality, using it more efficiently and reducing their labour requirements. Researchers, however, wanted more insight into its agro-economic benefits. Farmers, NGO staff and researchers have been collaborating on a systematic approach to improving the use of compost and mulch (see Box 3). They chose maize as the test crop because it produces quick results, although farmers normally prefer to use their compost on bananas. Farmers wanted to compare their normal practices of applying compost (4 tons/ha) with applying a layer of mulch 2 weeks after planting, using either compost only at a rate of 48 tons/ha or a combination of compost (48 tons/ha) and mulch. Testing and evaluating took place on a plot of 25 m² over two consecutive cropping seasons with 14 farmers.

The data on yields showed a significantly positive response to the compost and compost/mulch treatments. However, after one season the economic effect (expressed in gross margin) of these two treatments was less than in the control treatment, but farmers expected to see the residual benefits of the compost over the next 3 cropping seasons. Indeed, there were no significant differences from farmers' normal practice when taking into account these residual effects in the calculation of the average gross margins per season. This illustrates the dilemma between the short-term financial gains versus the long-term impact of most soil fertility management practices. Economic results may improve if crops of a higher value per unit of land are used and by reducing the quantities of organic materials applied.

Box 3 Participatory technology development

Meetings attended by scientists, NGO staff and the participating farmers were held in both study areas to discuss the planning of the PTD activities. These sessions covered the type of experiments, protocol, layout, monitoring procedures and criteria for evaluation. All farmers agreed on the selection of one experiment to implement on their farm, so that they could jointly evaluate the process and to facilitate statistical analysis. Scientists and NGO staff used the experimental protocol to assess the expected impact of the test technology on nutrient flows and economic performance, and farmers drew flow maps to show the anticipated changes compared to current practices. During the experiment a field visit was organised with farmers to observe and discuss the performance of the experiments. Every month NGO staff monitored input/output flows on the experimental plots and took soil samples. After one season a joint evaluation session was organised to assess the results of the experiments and to plan a new round of technology development (cf. Jäger et al., 1999).

Research and extension

Agricultural research in Uganda has largely concentrated on cash crops. During the colonial period it focused on the requirements of these newly introduced crops and when specific research on soil management started in the 1950s it centred on the organic and inorganic fertilisation of cash crops. The research agenda has only recently widened to include important indigenous food crops such as bananas and cassava. The system for transferring agricultural knowledge also leaves a lot to be desired. The practical effects of this are that farmers do not have access to information and extension services and are often unaware of improved technologies and farming methods.

For many years research and technology development have been the exclusive domain of research organisations and professional researchers, with little or no input from farmers. Moreover, the local research organisations themselves only had a minimal role in setting the agenda, which was mostly determined by external funding bodies and international research institutes. The technologies described above represent some of the methods farmers have developed, with NGO support, to overcome problems such as declining soil fertility. Research and extension workers would do well to consider these techniques and innovations when they are developing and promoting technologies for soil fertility management.

Conclusions

This chapter has described the influence of political and historical developments on soil fertility management practices in Uganda, and has examined the present status of soil nutrient balances and the economy of farming in two specific districts. We have seen that there are considerable variations between the two areas.

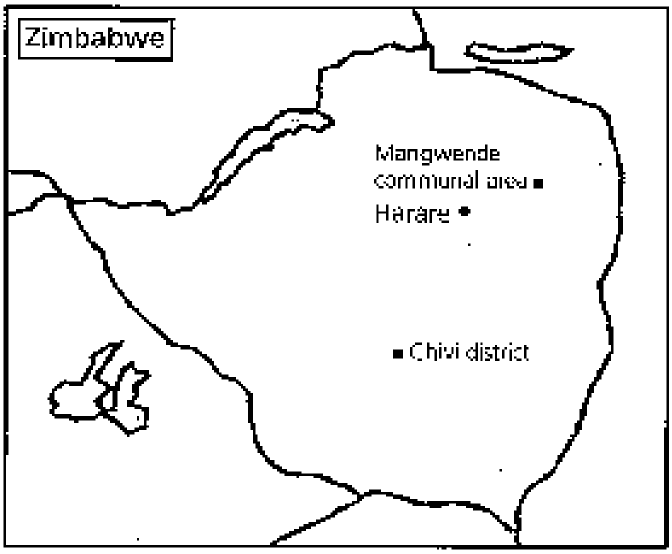
The present farming system in Kabarole is ecologically unsustainable, but this is still compensated for by large reserves of nutrients in the soil. Negative nutrient balances are mainly due to leaching and water erosion. Economically the system is sustainable but under pressure. Individual households have difficulty maintaining livelihoods because landholdings are shrinking as population pressure increases. The current level of farm income in Kabarole is still relatively high and producers should now invest in farming and concentrate on preventing loss of nutrient.

In Pallisa district, nutrient flows are currently in balance from an agronomic perspective. However, from an economic point of view the farming system does not provide for all the household needs and off-farm activities are an important source of revenue. There are occasional famines in the area and household incomes are low. The farming systems currently rely on nutrients being brought in by cattle grazing on common land, but these grazing areas are dwindling as more land goes under cultivation. The situation may further deteriorate if the new land tenure act encourages privatisation and the enclosure of grazing lands. If common grazing lands disappear, the farming systems of some households will be deprived of a major source of additional nutrients. The current low levels of yield and income make capital intensive alternatives such as mineral fertilisers a less feasible alternative option.

The crucial question in Pallisa is whether farmers' management strategies will be sufficient to keep soil fertility decline at bay as the pressure on farming systems increases. The systems of production even need to become more intensive to meet the growing demands for food and income, but the inherently poor soils will be unable to support more intensive crop production systems for long unless additional nutrients are added to the system. NGOs and CBOs promote technologies such as composting and mulching to reduce losses and optimise internal nutrient cycling, but these measures will hardly generate an influx of additional nutrients into the system. Alternatives are stall feeding livestock with fodder from external sources, using additional inputs of organic and inorganic fertilisers, and growing nitrogen-fixing species.

The case studies demonstrated that farmers are actively responding to the situation. Some have started stabling animals to increase manure production and have switched to more efficient ways of using the manure, while others have concentrated their available organic materials and labour on the household plot. These practices are all part of a general expansion of composting, mulching and agro-forestry systems in East Africa (Nair, 1987). Farmers reserve the more capital intensive options for cash crops and only adopt them when the cost-benefit ratios are sufficiently high and they feel that the market for their products is relatively secure.

The dynamics of soil fertility management in communal areas of Zimbabwe



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Introduction[1]

Agriculture in Zimbabwe is divided into two distinct sectors: large-scale commercial agriculture which is mainly privately owned and the communal sector which is dominated by subsistence farming. The communal lands are predominantly found in regions with low rainfall and poor soils.

This chapter focuses on the communal lands and will show how and why soil fertility management strategies have changed over the last decades and how they differ between zones and households. The main issue in the communal areas is the declining profitability of farming, which is mainly due to the rising cost of inputs. As mineral fertilisers have become more expensive, farmers are diversifying and using more organic alternatives. However, they are constrained by pressure on the land and by massive livestock losses sustained during the drought of 1992. The chapter analyses how farmers deal with new pressures and opportunities and argues that this has important implications for research and extension.

First, the case study sites and the historical dynamics of soil fertility management are introduced. After discussing farmers' perception of changes in soil quality and spatial

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variability, changes in their soil fertility management practices are described and illustrated with several examples. Finally, the impact of policy changes and their implications for the research agenda are analysed.

Methodology

Participatory rural appraisals were undertaken to determine the diversity of farmers' circumstances, soil fertility problems and the available options for managing soil fertility. A trend analysis was also done to establish the historical changes in soil fertility management practices before and after independence. Specific research methods included the evaluation of secondary data relating to both before and after independence, and group discussions to gather information about soils and their management, perceptions of changes in soil fertility, the type of crops grown, trends in input use, etc. A survey was done to determine household characteristics such as age, education, head of household, family size, landholdings and ownership of agricultural implements. The research was completed with several case studies on soil fertility technologies.

The study areas

This study was carried out in two communal areas in Zimbabwe: Chivi and Mangwende (see Map). Chivi is located some 350 km south of Harare and has a mean rainfall of 650 mm. The Mangwende communal area is located about 80 km north east of Harare and has a mean rainfall of 850 mm. Both areas have a unimodal pattern of rainfall and a subtropical climate with cool winters and hot, rainy summers. Mangwende has more agricultural potential because the annual rainfall there is higher, more reliable and better distributed than in Chivi where it is more erratic and prone to mid-season dry spells.

Soils in the two areas vary greatly due to differences in parent material and topography. Soils in Chivi are Haplic Luvisols, Haplic Acrisols and Haplic Lixisols (Table 1). There are also some black clays. Farmers in one village in Chivi categorised soils into four broad groups: shallow sands-loamy sands, sandy loam-clay loam, sandy clay-clay and grey-black *vlei* clays. Most households (90%) cultivated on sandy soils and many (60%) also have fields on loam soils. However, the area covered by each soil group differs from one farm to another.

Soils in Mangwende are mainly Haplic Lixisols. Farmers in one village in the area, Hakata, classified their soils into sandy-loamy sands and sandy loam-clay loam. Most farmers (90%) had fields on sandy soils. Relatively few farms (16%) had both sandy and loam soils, while only 10% of the farms were entirely situated on loam soils.

The average size of arable land holdings is 2 ha in Chivi and 3 ha in Mangwende (see Table 1). There are several types of fields according to topographic position, soil type and management. Fields at the top of the catena are referred to as the upland fields and those at the bottom as lowland fields. Some farmers also make a distinction between homestead fields and distant fields. The homestead fields are generally more intensively managed than the distant fields. These field types may differ in nutrient and moisture status.

Table 1 Some characteristics of the study areas

Characteristics	Mangwende	Chivi
Mean annual rainfall and range	850 mm (750-1200) unimodal	650 mm (450-800) unimodal
Main Soil types	Haplic Lixisols	Haplic Luvisols, Haplic Acrisols, Haplic Lixisols
pH($CaCl_2$)	4.2 to 4.8	4.2 to 4.8,
Mean arable land holding (ha)	3	2
Main crops	Maize, groundnut, sunflower, vegetables	Maize, groundnut, sorghum, millet, cotton, sunflower
Population density (Pp./km²)	104	45
Mean no. of household members	6	7
Mean no. of household members providing labour	47	5
Households owning equipment		
Plough	81%	74%
Cultivator	61%	23%
Ox-cart	48%	29%
Wheelbarrow	58%	61%
Households owning livestock		
Cattle	71%	41%
Goats	42%	78%

Sources: Government of Zimbabwe, 1988; Muzvira, 1987; Central statistics office, 1992; Chenje et al., 1998. Surveys conducted in 1998.

Land tenure within communal areas used to be governed by customary rules and regulations. The community was represented by the chief, who allocated heritable rights to households for cultivation and for grazing their livestock on unallocated community land (Holleman, 1952). However, in 1982 the Communal Land Act vested ownership of communal land in the President and devolved the administration to district councils rather than chiefs or herdsmen. The Act regulates that access and use of land continues to be according to customary law.

In Chivi the average homestead houses seven people, five of whom contribute to the labour force. In Mangwende the average household consist of six people, of which three contribute to the workforce (see Table 1). Women head more than a quarter of the households in both regions. Most farmers have completed primary education and some have also finished their secondary education. Only 12% of the heads of households in Chivi and 6% in Mangwende have received no formal education. In both areas many family members have left to find work elsewhere. Assistance in cash or kind from formally employed members was received by 92% of the households in Chivi and 86% in Mangwende. The amount and frequency of assistance differed from family to family and has been declining since the start of the economic crisis of the 1990s.

Resource endowments vary between households. Cattle and the ownership of farm implements were used as the main indicators of wealth, ranking households with more cattle and implements as more affluent. There is also a significant correlation between the number of cattle and size of land holding. Livestock are important in both study areas as a source of manure and draught power. Households in Mangwende averaged six cattle and two goats, while in Chivi the average was two cattle and four goats per household. However, these averages mask wide variations in the number of animals owned by different households (see Table 1). Farmers in Mangwende generally own more equipment than in Chivi. Ownership of implements is a significant factor in overall farm productivity as farmers' capacity to transport inputs or work their land on time is affected by the type of implements they own.

Mangwende is a maize producing area. Farmers here sell more than 60% of their harvest and earn a high proportion of their income from the farm, mostly through the sale of maize and crops from gardens and orchards. The main crops in Chivi are cereals, which are mostly grown for subsistence. Less than 20% of the harvest in this area is sold (Rohrbach, 1987; FSRU, 1994) and farmers only earn a small proportion of their income from selling surplus crop products and poultry. Some smallholders in southern Chivi have areas of heavy soils on their farms where they can grow cotton, which provides a substantial source of income. Other farmers are contracted to grow red sorghum for private companies like the Chibuku breweries. The average maize yield is between 0.8 and 1.5 tons/ha in Chivi and between 2.5 and 3.5 tons/ha in Mangwende.

Policy changes since 1890

In 1890, Zimbabwe was colonised by the British and given the name Rhodesia. During the colonial period the Land Apportionment Act (1930) was implemented, creating 'native reserves' which resulted in overcrowded communal areas that put considerable pressure on the natural resource base.

The use of animal draught power, the plough and maize as a food crop were introduced to local farmers at the beginning of the colonial period and adopted on a large scale between 1920 and 1940. Agricultural extension started in the 1930s. Alvord developed and introduced an extension package to promote permanent small-scale commercial agriculture that is still in use today (Alvord, 1958; Hagmann and Murwira, 1996). The package advocates the use of manure, crop rotation, row planting, monoculture, winter ploughing, removing trees from fields and conservation work in the form of contour ridges. Another aspect of the approach was consolidating arable holdings and separating them from grazing areas. Alvord also introduced a training scheme in which Master Farmer Certificates were awarded to farmers who successfully completed a training course and adopted the package (Hagmann and Murwira, 1996).

After a long and hard fought war Zimbabwe gained independence in 1980. The new government wanted to increase yields and therefore introduced smallholder farmers to high input technology previously only used by commercial farmers. Free seed and fertiliser were handed out to smallholders to help them become established as commercial farmers. This was done mainly through the Department of Agricultural, Technical and Extension Services (AGRITEX). The production of cash crops was strongly promoted, credit schemes were introduced through government parastatals such as the Agriculture Finance Corporation and farmers were offered attractive prices for their products.

However, traditional soil and water conservation methods were discouraged as the authorities advocated Alvord's package of 'clean cultivation'. Farmers were aware that their soils were becoming degraded, but they only had limited ability to address these problems effectively and lacked alternative options. The Village Development Committees (VIDCOs), Ward Development Committees (WARDCOs) and even extension agents were hardly addressing soil degradation in the farming environment (Mukamuri et al., 1997).

The Economic Structural Adjustment Programme (ESAP) was launched in 1991. ESAP and other government policies resulted in the removal of subsidies, the imposition of levies and a rise in sales tax. Input prices increased while producers were still only getting low prices for some of their crops, levels of formal employment fell and poverty levels increased. ESAP had a major impact on the earning potential of farmers in Zimbabwe's communal areas and affected their ability to purchase inputs. Some farmers could no longer afford to buy mineral fertilisers and switched to using organic amendments.

The drought in 1992, occurring soon after the ESAP had been implemented, was considered the 'worst in living memory'. It affected agriculture all over Zimbabwe, and smallholder farmers were particularly hard hit. As crops failed completely in communal areas and huge numbers of livestock died, the government was compelled to import maize in order to avert mass starvation. Unsatisfactory economic performance in the ensuing years contributed to inflation: the local currency had been gradually devaluing since 1990 and in November 1998 it crashed to what was described as an 'all time low'.

Farmers' perspectives on the dynamics of soils

Older farmers in particular tend to be nostalgic about the past. According to oral history the soil was very fertile in pre-colonial times. There were vast tracts of sparsely inhabited land covered with thick forests. Farmers practised shifting cultivation and did not apply any amendments to the soil, abandoning any areas depleted of nutrients so that they could recover naturally through fallow. The soil was not turned over very much as they only used hand tools for cultivation.

However, the turning point was the Land Apportionment Act of 1930. The colonial 'masters' displaced local people from fertile areas and settled them in confined marginal areas called tribal trust lands or 'reserves'. The soil in most of the reserves was mainly sandy with inherently low fertility. All the farmers we spoke to agreed that the restrictions imposed by the colonial authorities on where to cultivate had forced them to farm their land on a continuous basis. The elected government installed after Independence retained these restrictions and farmers reported that soil fertility had deteriorated even more rapidly since Independence. They also pointed out that the policies formulated and implemented by the new government favoured a shift from subsistence to commercially oriented agriculture, which also had a negative impact on soil fertility. Population in the communal areas rose steadily, creating such acute land pressure that some farmers expanded their fields into demarcated grazing areas, sometimes using inappropriate farming methods which resulted in soil erosion and deforestation.

According to farmers their current problems can be traced back too to the introduction of ploughs and fertilisers. These two technologies allowed people to cultivate relatively large areas in the reserves, and farmers explained that it was then that soil fertility started to decline (Hagmann, 1997). They said that although the plough enabled them to prepare the land quickly and easily, the soil lost its 'strength' through being repeatedly turned over. Although adverse economic conditions mean that farmers no longer plough all their fields, some complain that the harm to the soil structure has already been done and that the only solution is to be resettled in other areas where soil fertility is better. Some farmers believe that the introduction of fertilisers 'killed' the soil. They argue that the soil was more fertile before fertilisers were introduced, that nowadays it requires more fertiliser and that nothing can be grown now without using fertilisers.

Changes in soil fertility status

Farmers in the study areas were asked to assess changes in soil fertility and the organic matter content of the soils in their villages since the year of Independence (1980). Most of the 27 farmers with sandy soil in Chivi (82%) indicated that soil fertility had declined to such an extent that no yield could be obtained without applying nutrients (Box 1). The majority of farmers (62%) thought that this was caused by continuous cultivation. Others blamed sheet erosion or insufficient application of nutrients. About 65% of farmers thought that the moisture retention capacity of the sandy soils had declined due to loss of organic matter whereas 22% thought that this was the result of the amount of rain falling in a given season. Only 12% of farmers considered that this parameter had not changed.

For farmers with sandy loam-clay loam soils, 63% noted a slight decline in their fertility, 42% observed a decline in the fertility of loam soils, while 43% stated that clay soils were less fertile than before. Only 13% of the farmers noted a decline in soil fertility for the black *vlei* soils. They all found it harder to comment on changes in organic matter content and some of them said that they did not know whether there had been any changes or not. Others mostly referred to changes in soil colour as a guide to changes in soil quality.

Box 1 Perceptions on soil fertility as related by an elderly farmer in Chivi

Mr Chipungwe is 88 years old. He farms with his wife and claims to be among the first settlers in the local area. He also used to work in the gold mines of South Africa. Mr Chipungwe recounts the old days when water was plentiful and so much land was available that they practised shifting cultivation. Neither cattle manure nor fertiliser was used to enhance soil fertility and the only amendment was the ash produced by burning vegetation after initial land clearance. Mr Chipungwe knew that red or black soils indicated good soil fertility, that some trees and weeds like Munhondo (*Julbernadia globiflora*) and Mupfuti (*Briagstigia boehmii*) were associated with deep, fertile soil, and that the presence of *damba* and *cynodon* grasses indicated good soil fertility.

In the 1950s, agricultural extensionists arrived and settled people in planned villages. Mr Chipungwe vividly remembers the white man who pegged his field and said to him "*Chipungwe, here is your field. You are no longer allowed to cultivate wherever you want. From this field you shall feed yourself, children and grandchildren, so take proper care of it.*" Mr Chipungwe relates that initially the soil was fertile but then crop yields started to decline. He noted that the soil was changing in colour and becoming lighter, indicating that the organic matter content was declining. As yields declined he started applying manure to his field. This sustained soil fertility and he managed to feed his family from the same field for many years. However, he lost all his cattle during the 1992 drought and, as he was not successful in restocking his herd, he has also lost his source of manure. He uses ash, household litter and decomposed leaf litter to supplement the small amounts of dung produced by his only cow.

Mr Chipungwe admits that the soil is now 'tired' due to continuous cultivation and insufficient use of soil amendments. He sees the appearance of certain weeds such as *bise* (*striga* spp) as an indicator of poor soil fertility.

Almost all the farmers (94% n=31) in Mangwende stated that the fertility and organic matter content of sandy soils had declined since 1980 and was now very low (Box 2). Some said that there would be low yields or stunted growth if they did not add any inputs. They attribute the decline in soil fertility to continuous cultivation, soil erosion, increased soil acidity[2] and failure to apply adequate nutrient inputs. Of the farmers interviewed, 45% had observed a decline in the soil's capacity to retain moisture whilst 26% said that they had not noticed any difference. They attributed variations to a decline in rainfall.

Of those farmers with loam soils, 75% explained that, although soil fertility was a bit lower than in the past, it was still satisfactory and they could hope to get some yield without applying inputs. Farmers' perceptions of the organic matter content of the loam soils varied, with half of them believing that the organic matter content had declined while the other half said that it had not changed. Their perceptions of its capacity to retain moisture also varied.

Just over half of the farmers in Chivi judged that soil erosion was on the increase at both catchment and field level. They thought that nowadays people are more reluctant to observe the rules introduced by local authorities or the government regarding soil conservation. Some farmers, however, believed that soil erosion had decreased since the amount of rain falling was less than before. In Mangwende most of the farmers could not judge what impact soil

[2] Soil acidity is mainly due to high rainfall which leaches the exchangeable bases of sandy soils.

Box 2 Perceptions of changes in soil fertility in Mangwende

Mr Hakata is 83. He owns 9 head of cattle, 5 goats and 3.6 hectares of arable land. Maize was not popular when he was young but he remembers bumper harvests of sorghum, finger millet and pearl millet. Farmers never used any inputs then and if soil became depleted they moved on to virgin land, as there was plenty of land and population density was low. Mr Hakata belonged to the ruling clan so his family had the first choice of land.

This changed during colonial times when colonial regulations made shifting cultivation impossible. Through negotiation with the whites, the Hakata family chose a fertile place to settle and their homestead is still on the same site. His father had learned about cultivating maize and using cattle manure in Cape Town, South Africa, after white settlers abducted him as a young boy. The Hakatas started to cultivate maize and for the first five years yields were very high. But when they noticed that the maize yields were steadily declining they began to use cattle manure which was then in abundant supply: this improved maize yields and Mr Hakata used to sell his maize to Harare. He also started using mineral fertilisers and diversified into cotton.

In the 1980s, Mr Hakata noted that organic matter content and productivity, which he calls 'the power of the soil' was changing. The fertility of his soil continued to decline rapidly, even when he added cattle manure and fertilisers, and his maize yield dropped from 5.8 t/ha to 2.7 t/ha. Nowadays, Mr Hakata has fewer cattle and less manure than he did in the past. He prefers manure to mineral fertilisers but has to use the latter because the soil 'has fallen in love with the fertilisers'. A field that used to yield bumper harvests will no longer produce a harvest unless mineral fertilisers are applied to it.

erosion has had on soil fertility but 90% unanimously accepted that soil erosion was on the increase in fields and catchment areas of all soil types, blaming high population pressure and poorly maintained contours in this area of high rainfall.

Spatial variability

Soil variability has been well-documented on national, regional and global levels (FAO-UNESCO Soil Map, 1974; Thompson and Purves, 1978). However, there has been little research on the importance of variability at farm and field level and how it affects productivity in smallholder farming systems. For example, the soil types and niches used by farmers for producing maize vary from the poorest soils, such as gravely, stony, sodic and sandy soils, to fertile sandy clay loam soils. Variations in crop growth caused by diverse soil properties within the farm are generally more pronounced in low-input farming systems where production conditions are less than favourable (Carter and Murwira, 1995). Having illustrated the diversity of land-use patterns along a catenary sequence, Carter (1993) found that farmers' management practices were strongly influenced by variations in topography and soil type.

Since agricultural production is limited by the availability of nutrients and water in subsistence farming systems, variations in soil may actually be an asset to farmers. A seemingly uniform field often contains various micro-environments that are crucial to local farming systems. Farmers recognise these variations and manage them accordingly (Box 3).

Fields surrounding homesteads are generally better managed than the rest of the land due to their proximity to the homestead. These fields are also better protected from livestock. Spatial variations within fields are often associated with ecological features such as termitaria soil, sodic soil patches, seasonally waterlogging, vlei soils and stony or shallow soils. Such variation may also result from human activity especially around homesteads where household litter and ash are strewn on the ground. Other niches constitute old gardens, cattle pens and homestead sites, and tree-soil interactions. Niches also occur when farmers use livestock pens to improve soil fertility in specific areas by shifting them around arable fields. Trees in fields can both depress and improve yields. When species such as *Parinari curatellifolia, Fiscus sur, Strychnos species* and *Mimusops zeyheri* are left in the field they can improve soil fertility and thus constitute important niches.

Other studies have also revealed the tremendous variation in soils within individual fields (Carter and Murwira, 1995). In our experience it is important to identify and map these agro-ecological niches and document how they are used and managed. This allows for specific ecological micro-environments to be properly targeted by soil fertility management technologies. For example, a niche such as termitaria soils will provide the highest yield in seasons with good rains, but generally needs water-harvesting technologies to sustain yields when rainfall is low.

Box 3 Managing localised variations in soils

Mr and Mrs Mafenya have a one-hectare field situated on a gentle slope in Chivi. They distinguish four soil types in their field, which they classify according to colour, texture and organic matter content. According to their descriptions the slope is covered with sandy soil and brown sandy loam, while the lower area is covered with grey hydromophic clays and black *vlei* clays. The black *vlei* clays are the most fertile, and they attribute this to erosion which brings clay soil down from the upper part of the field. They make sure that they plant these soils early. When planted late the crops get waterlogged and yields will be poor. They pointed out that crop yields in the loam soil were especially high in the area surrounding the homestead where household litter and ash have been strewn. Although they apply most inputs to sandy soils, the sandy soil located on top of the slope has remained very infertile and inputs applied were still not enough to improve yields. Mr and Mrs Mafenya constantly monitor and assess the performance of crops on different plots and variations in the soils, and manage them accordingly.

Trends in cropping patterns

Cropping patterns have changed over the last few decades. The sliding devaluation of the Zimbabwe dollar has resulted in agricultural inputs with imported components, such as mineral fertilisers, becoming more expensive. In nominal terms, the price of both inputs and outputs increased between 1980 and 1996. According to farmers input prices for cereals like maize and sorghum rose faster than output prices, particularly between 1990 and 1996 (see Table 2). However, the price of other crops, such as cotton and paprika, increased faster than the price of inputs, giving farmers an incentive to diversify. In Margwende farmers now allocate less land to cereals, mainly because their profit margins have been lowered by high input costs and the relatively low price they can get for their produce. They have now taken up vegetable gardening, which gives higher returns per unit area. Farmers in Chivi have also diversified into other crops such as sunflower, finger and pearl millet, which either fetch higher prices or are thought to require fewer fertility inputs.

Table 2 Farmers' perception of trends in input and output prices for cereals in Chivi and Mangwende, 1980 - 1996

	1980	1990	1996
Inputs	25	100	250
Outputs	140	100	60

Source: Own survey. The year 1990 was taken as the base year with a value of 100.

In Mangwende, another effect of the increase in input prices has been that farmers buy less mineral fertiliser and apply it to a smaller area. This has not only reduced crop production but also resulted in fields being left fallow because of the high cost of inputs (Table 3). The total area under cultivation in Mangwende has dropped from 50,000 ha in 1980 to 45,000 ha in 1996. Many cattle owners have reduced the area they cultivate and now concentrate on smaller and more intensively managed areas (AGRITEX Officers, Personal Communication). When free seed and fertiliser packs were given out after the 1991/92 drought, the area of fertilised crops increased significantly but it dropped again when the handouts were stopped, amid allegations of corruption and misappropriation by the responsible authorities.

Table 3 Farmers' perception of trends in fallow and fertilised land in Mangwende

Year	Fallow	Fertilised area
1980	47	250
1990	100	100
1996	250	50

Source: Own survey. The year 1990 was taken as the base year with a value of 100.

The total area under cultivation in Chivi has actually increased over the years. This is attributed to the low yields per unit area, and also because farmers are diversifying their cropping patterns (Table 4). Maize still occupies the greatest proportion of cultivated land in southern Chivi, but the relative area has declined since 1980. Farmers are switching to more profitable crops, such as cotton or red sorghum grown on contract with breweries, which also provide access to mineral fertilisers. These crops are often grown in rotation with other crops to capitalise on the residual effect of fertilisers or manure.

Table 4 Farmers' perception of trends in land use for various crops in southern and central Chivi, 1980–1996 (in percentages)

Crop	Chivi South (mean 650 mm rain/y)			Chivi Central (mean < 650 mm rain/y)		
	1980	1990	1996	1980	1990	1996
Maize	60	45	38	20	22	27
Finger / Pearl millet	0	0	0	24	19	14
White Sorghum	7	5	0	29	33	13
Red Sorghum	0	0	13	0	0	20
Groundnuts	27	31	27	9	9	13
Bambara groundnuts	13	10	9	7	4	9
Cotton	0	9	13	0	0	0
Sunflower	0	0	0	11	13	4
Total	100%	100%	100%	100%	100%	100%

Source: Own survey.

Changes in soil fertility management

Farmers in both areas use a variety of practices to manage soil fertility. These include winter ploughing to incorporate crop residues and conserve moisture, crop rotation, fallowing, and the application of leaf litter, termitaria soil, compost, manure and ash. Farmers choose their methods according to the amount of material available, labour requirements and the availability of land and draught power. Winter ploughing is practised by 82% of the households in Mangwende and 68% in Chivi, most of these having access to draught power.

Very few farmers in either area rotate their crops as land is in short supply and cereals predominate. Fallowing is used by 35% of farmers in Mangwende and 37% in Chivi, but it is often the farmers' last resort when a fallow is the result of lack of inputs such as labour, oxen and fertilisers, rather than a deliberate way of improving soil fertility.

Farmers' soil fertility management practices are also closely related to their wealth (Campbell et al., 1997). Wealthier farmers generally possess more farming implements, apply more cattle manure and compost and recycle more stover. By contrast, poor households rely more on household waste and leaf litter.

Use of mineral fertilisers

Farmers in both Mangwende and Chivi now use less mineral fertilisers than they did before 1990 (Table 5). Before ESAP most farmers in Mangwende used to apply fertilisers to maize at the recommended rates of 350 kg/ha of compound D[3] and 250 kg/ha of Ammonium Nitrate (AN). Nowadays most farmers only use 250 kg of compound D and 125 kg of AN, which they

[3] Compound D: NPK 8-14-7

apply as a mixture. Although this reduces production costs, farmers are also aware that they are compromising their yields. The amount of fertiliser applied per hectare has thus declined considerably since the 1980s when mineral fertilisers were less expensive. Farmers reported that they used 50% less fertiliser in 1990 than they had in 1980, and that application rates had fallen another 50-60% by 1996 as fertiliser prices increased significantly between 1990 and 1996.

Very little mineral fertiliser is used in Chivi because of its high price and the high risk of crop failure, such that less than 10% of households in Chivi still purchase fertilisers on a regular basis. Most of those who use fertilisers either obtain them through free crop input packs from the government or through contracts with private companies for growing red sorghum or cotton.

Traders in Murewa reported that although the prices have gone up and individual farmers are now buying 50% less than they used to, the total quantity of fertiliser sold has actually increased since 1990. These traders serve both communal areas and adjacent small-scale commercial farms, and benefit from the fact that more people are now engaged in farming since the shortage of work in urban areas has forced many people to return to the land.

Use of organic fertility inputs

Farmers who own cattle use manure as their main method of improving soil fertility. They try to increase their manure production by incorporating grass and stover in the cattle pens. The use of manure has increased in Mangwende since 1980 (Table 5), although farmers used less in 1990 because of the number of cattle lost to drought and disease.

Table 5 Farmers' perception of trends in the use of fertiliser and manure in Mangwende

Year	Fertiliser		Manure	
	Mangwende	Chivi	Mangwende	Chivi
1980	200	200	300	150
1990	100	100	100	100
1996	44	55	600	50

Source: Own survey. The year 1990 was taken as the base year with a value of 100.

A survey done in 1998 in Guti Village showed that farmers used a range of soil management practices, according to whatever resources were available. Some 60% of farmers used ash and household waste and 57% used mineral fertilisers or cattle manure. Only 41% of households owned cattle, so those without cattle were either given manure by close relatives or bought it. About half of the farmers used compost. Leaf litter and termitaria soil were the least used materials. It seems that the mineral fertiliser used during this year was supplied as drought relief by the Government and donor agencies.

Overall, farmers in Chivi used more manure in the 1980s than they do now, as they had more cattle then (Table 5). They have not changed the amount of manure they apply per hectare but it is now applied to smaller areas. Livestock owners apply most manure to sandy soils which have an inherently low fertility status. The use of alternative organic fertility inputs did not change much between 1980 and 1990, but increased by 50% between 1990 and 1996. Where manure is not available in sufficient quantities, farmers in Chivi use more compost and are increasingly turning to ash as a source of fertility. The use of anthill soil and leaf litter have been on the decline in both areas because they are only available in limited quantities.

Over 70% of the manure used in both Chivi and Mangwende is allocated to the main fields rather than the gardens and this proportion is increasing. In southern Chivi the percentage of manure allocated to maize grown on sandy soils fell from 50% in 1990 to 30% in 1996. In Chivi Central the percentage of manure allocated to maize declined from 70% in 1980 to 36% in 1990, and then rose slightly to 50% in 1996. It is difficult to explain why allocation to this staple has declined but, presumably, alternative crops such as groundnuts and cotton offer better cash returns.

Almost all farmers noted that organic fertility inputs are used to improve crop yields and soil fertility, while half of them also mentioned that they enhanced soil structure and increased the soil's organic matter content. Farmers who wanted to use mineral fertilisers said that their disadvantages were that they are expensive and need to be applied every year. Constraints on producing and applying organic fertilisers such as manure, compost and termitaria soil were their high labour and transport requirements. Also, it was not always possible to get adequate supplies of these inputs for composting, especially ash and household waste. Farmers were unable to use cattle manure widely as most of them either did not have any cattle or did not have enough manure to maintain soil fertility.

Manure and fertilisers are increasingly being used in combination rather than as separate applications. Farmers recognise that, as fertilisers are too expensive to be used on their own and as only limited amounts of manure are available, they would be unable to redress the decline in soil fertility with a single type of input alone. In both areas they adjust the use of various sources of fertility according to how the rainy season develops. For example, in 1996 the use of AN during the farming season rose in Chivi and Mangwende because rainfall was good that year.

Management of organic and mineral fertilisers: a case study in Mangwende area

In the village of Hakata, farmers said that their objectives in using certain soil amendments are to raise soil nutrient status, thereby increasing crop yields, to improve soil structure and to cut input costs as much as possible by replacing expensive amendments with cheaper alternatives. These farmers use relatively large amounts of mineral fertiliser, household waste and cattle manure. They use them in varying quantities and a range of ways, depending on their socio-economic status and the spatial and temporal diversity of the farming environment (Campbell et al., 1995).

Of the farmers in the survey, 97% used mineral fertilisers, and 74% cattle manure. Most farmers used them in combination but the major limitation of mineral fertiliser is that it is expensive. Some of the farmers who did not use manure rely on mineral fertilisers because they had no cattle, while other farmers without cattle either bought manure or were given it by relatives. Total yearly manure production per household ranged from one to more than five tons, depending on how many cattle they owned. Most farmers applied all their manure to one particular plot. Application rates ranged from 2.5 t/ha to 12.5 t/ha, depending on availability and the farmer's perception of soil fertility in different parts of the field. Manure is generally spread over fields at the onset of the first rains, although some farmers, particularly those with limited access to manure, dribble it in planting furrows or in every plant hole after germination.

Ash and household waste were considered important by 77% of the farmers although they are only available in limited quantities, and are usually applied to fields near the homestead. Compost, termitaria soil and poultry and goat droppings were used by less than 10% of the farmers, who generally put them on their gardens.

Compound D was used in a variety of ways. Some farmers applied it two to seven weeks after crop germination, timing the application according to crop development and the nature of the season. They put less mineral fertiliser on plots where they had used manure, compost, ash or household waste and, when they thought that crops were growing well, they used cattle manure instead of Compound D. Farmers gave several reasons for using the basal fertiliser Compound D some time after crops germinated, instead of at planting. At the onset of the growing season they are hard pressed for labour as they have to spread manure, plough, open up furrows, drop in seeds and cover them in a very short space of time. Some farmers may not have bought fertiliser at the start of the growing season because it is expensive, while others wait to see how the rainy season develops before investing time and money in applying fertiliser. When fertiliser is applied early, and there is too much rain at the start of the growing season, it will either be leached or washed away, and fertiliser applied when the seeds were sown will be lost if germination is poor.

Top dressing with Ammonium Nitrate (AN) is generally done when the maize crop is about to tassel. Very few farmers follow the recommended rate of 100 kg AN/ha for top dressing because it is too costly. The timing of application depends on the farmer's circumstances. Those who have not previously added any inputs apply AN about 5 to 6 weeks after germination, while farmers who have already applied basal dressing (cattle manure or Compound D) top dress when the crop is tasselling, or sometimes even when it is silking. Farmers cultivating fertile loam soils made a single application of top dressing 6 to 8 weeks after crop germination, while those cultivating sandy soils only use basal fertiliser.

Many farmers (74%) mix basal and top dressing fertilisers into what they call 'Compound X'. Most of them learnt this practice from other farmers, while a few found it by experimenting on their own. Each farmer seems to have their own preferred formulation, application rate and time for using Compound X. Half of the farmers used two parts of Compound D to one part of AN, while the rest of the farmers used a variety of other ratios. The main reasons given for mixing fertilisers were to cut costs, boost crop development and reduce the adverse effects on crops of late procurement and application of mineral fertilisers. Poorer farmers used fertiliser sparingly by only applying it once, about 6 to 8 weeks after germination. They may apply further small amounts of AN, if available, when the crop is silking. Farmers who bought fertilisers late increased the proportion of AN and applied it 4 weeks after germination, with some additional top dressing when the crop starts tasselling.

If farmers think that the maize crop is not green enough, or if there is too much rain, they usually apply two parts of Compound D to one part of AN and will also top dress at the tasselling stage, varying the amount according to the condition of the crop. If they have already applied manure but think that crops are developing poorly, they apply equal quantities of Compound D and AN as top dressing, whereas when crop growth is good they apply AN on its own as top dressing.

Combining water conservation technologies with nutrient management: a case study in Chivi

In the drier parts of Chivi, 90% of the farmers consider that insufficient moisture in the soil and poor soil fertility are the two main constraints on crop production. However, there are only a limited number of technologies available for water management or which address both constraints simultaneously. More than 80% of the farms had contour ridges, which reduce soil erosion by draining off excess water from the fields but do not promote infiltration. Almost all of these ridges had been compulsorily constructed during the colonial era and are, as a result, poorly maintained. However, farmers are gradually realising their importance in reducing soil erosion in their fields.

In 1995, farmers in Chivi started using infiltration pits to harvest and temporarily store water that is intercepted by the contour ridge. These pits are approximately 1.5m x 2m wide and one metre deep and are dug in the contour ridge of a gently sloping field (Fig. 1). Capillary and lateral drainage gradually release the water into the field lower down the slope, improving its moisture status and benefiting the crops growing there.

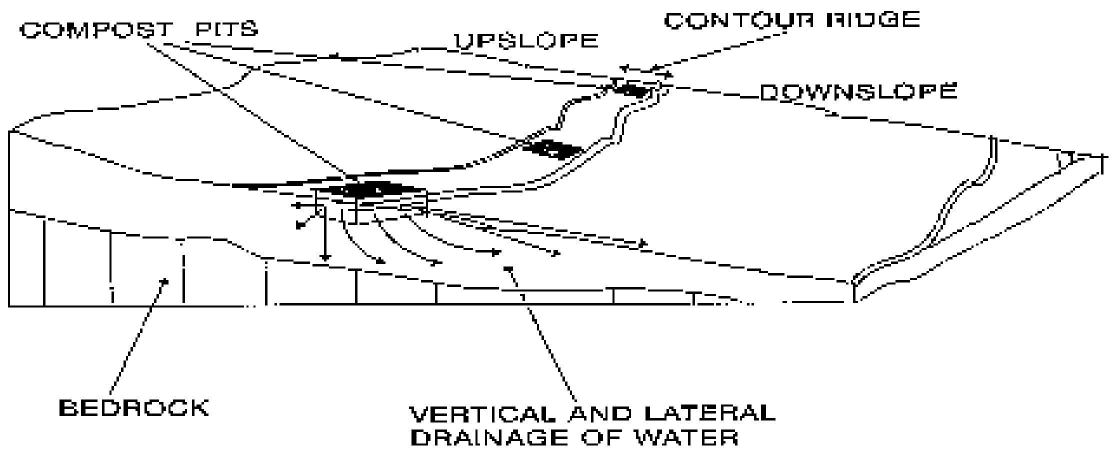
Most of the farmers in Guti village have fields on sandy soils. They have recently developed a new technique using infiltration pits for composting, which makes it possible to combine water harvesting and soil fertility management (see Box 4). After the harvest in March or April they put crop residues in the pits and then water them to facilitate their decomposition. Some farmers alternate layers of crop residue with leaf litter collected from the nearby hills. During the dry season the compost is watered when labour is available for the task, and in the rainy season the pits collect runoff water from the contour ridge, the upper field or from the base of a hill.

Box 4 How one farmer started combining infiltration pits with composting

Mr Mazongoza is a 35 year old farmer who lives in a homestead of nine people, three of whom work on the farm. He attended school up to primary level and obtained an advanced master farmer certificate. Mr Mazongoza first heard about soil fertility management to improve crop yields five years ago, when researchers at a farmers' meeting talked about using cattle manure and compost. As he did not have any cattle manure he tried out the compost and made some progress with his poor soils. A year later another research team started working with him. This team focussed on water management and introduced infiltration pits and tied ridges. Mr Mazongoza particularly liked the infiltration pits as they slowed the rapid flow of water that had been causing soil erosion in his field, so his crops no longer died of moisture stress.

He then thought that he could minimise his labour and transport requirements by using the pits to store both water and compost. This combination of soil fertility and water management techniques enabled him to improve his crop yields dramatically, as seen by his maize yield which rose from 0.9 to 3.2 t/ha.

Fig. 1 Schematic diagram of compost/infiltration pits in contour ridges



Different farmers produce varying amounts of compost, depending on how many pits they have and how much organic material they put in them. The average output was estimated at 1.8 t/yr (range 0.23 to 2.7 t/yr). As compost is a scarce resource, farmers want to use it as efficiently as possible and it is usually carefully placed in planting holes. The average dose used is estimated at 3 t/ha, which is well below the recommended rate of 10 t/ha. However farmers were still pleased with the way their sandy soils responded to these amendments.

Farmers reported that the biomass needed for this technology is easily obtained as leaves, grass and crop residues are readily available in good rainy seasons. However, fires and adverse weather conditions may affect supplies, while access to implements such as picks, shovels and wheelbarrows, has become increasingly expensive and therefore inaccessible. The total labour requirement for producing compost was not quantified but some farmers mentioned limited time as a constraint. They pointed out that many other activities compete for their time, which may also be taken up by illness in the family or funerals in the village.

Despite the benefits of the new technology few farmers in Gutf village had actually adopted it. The two main reasons they gave were lack of knowledge (65% of farmers) and the fact that it was laborious and time consuming (61%). About half of the farmers concurred that laziness was the reason the practice had not been adopted while 30% of them thought that other jobs, such as trading, took precedence. Some farmers (19%) relied instead on supplies of mineral fertilisers or manure.

Implications for sustainability

In the preceding sections we discussed farmers' perceptions of changes in soil fertility, diversity of practice and the importance of spatial variability. We also analysed the dynamics of soil fertility management practices and how they have been influenced by drought, other abiotic stress factors such as poor soil fertility and external factors such as policy change and population pressure. Table 6 details a range of external pressures, their effects on the environment and how farmers respond to them. It is important to realise that decisions about soil fertility management are dynamic and may evolve as the farming season progresses.

Ever since the Land Apportionment Act of 1930 smallholder farming in Zimbabwe has been confined to communal areas with relatively low agro-ecological potential. An annual population growth rate of 3% has created growing pressure on land and resources and farms have become increasingly fragmented with the division of landholdings amongst the farmers' heirs.

There is little doubt that land use has become more intensive following Independence in 1980 when farmers in communal areas were given the opportunity to take up commercial farming, opportunities which had previously been blocked (Carter and Murwira, 1995). Government support and attractive producer prices resulted in a dramatic increase in the production of maize. Many farmers took up planting improved seeds in monoculture but they were less enthusiastic about the soil management practices proposed. Improving soil fertility management seems to be a more intractable problem, particularly as extension programmes have not taken account of the inherent variability of the environment and the resulting variations in soil fertility.

The ESAP which began in 1991 had a major impact on the economic environment faced by farmers and consequently affected their soil fertility management (see Tables 5 and 6). Profit margins have fallen as producer prices failed to keep pace with input prices. But farmers have countered this setback in several ways. In Mangwende they reduced the area planted with maize and shifted to horticultural production, while in Chivi they started growing other more profitable and more marketable crops such as red sorghum, cotton and paprika.

Table 6 Factors affecting soil fertility management

Pressure	State	Response
1. Government Policy on commercial production in communal areas (1980s) This included free fertiliser and seed packs, attractive producer prices and subsidised tillage units	• Increased pressure on land and resources (larger area cultivated) • Decrease in grazing areas and communal wood lots	• Increased use of inputs • Increased production
2. Population increase	• Land shortage • Land degradation resulting in soil erosion and low yields	• Fragmentation of farms • Occupation of grazing areas • Exploitation of productive niches
3. Inflation (1990s)	• Rising production costs, push up price of inputs	• Increased use of organic manure • Decreased use of mineral fertilisers • Establishment of co-operatives (mainly for buying inputs)
4. Adverse weather patterns (1984/87/92) resulting in low rainfall and drought	• Low yields/crop failure • Loss of livestock • Low manure output	• Decrease in livestock numbers • Innovations in soil &water conservation • Farmers combine organic and mineral inputs • Use of stover and grass to increase manure production • Use of alternative nutrients sources e.g. leaf litter
5. Change of government policies in 1991 e.g. ESAP, removal of subsidies, imposition of levies, increased sales tax	• Input prices increase while producer prices remain low for some crops • Retrenchments from formal employment • Increasing poverty	• Fall in cropped area • Drop in use of expensive inputs • Diversification of crops • Mixing of fertilisers • Farmers fine tune methods and timing of input application • Innovations to improve soil and water resources

As the price of fertilisers escalated, farmers in both Chivi and Mangwende responded by using as little mineral fertiliser as possible and replacing it with locally available organic inputs. They fine-tuned their fertilisation techniques and the timing of applications, and began using split applications of ammonium nitrate and selective spot applications on the less fertile parts of a field, mixing organic and mineral fertilisers and withholding fertiliser applications until moisture conditions were favourable. These strategies enable them to use inputs more efficiently. Piha (1993) has shown that such strategies are more economical than the blanket recommendations proposed by AGRITEX. However, the question is whether they are robust enough to sustain soil fertility, and whether they can cope with the increasing strain on soils caused ultimately by mounting population pressure.

Farmers' perceptions clearly play a role in soil fertility management and in decisions about cropping patterns. These perceptions are as diverse as the resources available to farmers, although there seems to be a common view that more is required now to sustain productivity and livelihoods than in the past.

Conclusions

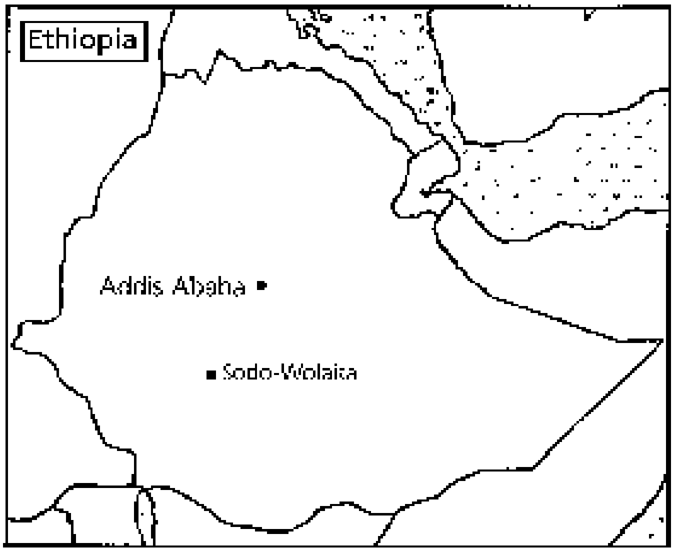
Farmers have responded to shortages of manure and declining soil fertility by using mineral fertilisers and manure more intensively, focusing their use in niches which offer better returns or which are perceived to be infertile. There has been a shift away from mineral fertilisers towards the use of organic inputs and, although there is little difference in the range of organic amendments used by individual households, there are considerable variations in the quantities used. In our opinion, the recommendations made by research and extension have failed to recognise these changes in farming practices, which should be informing the research agenda. Research needs to emphasise the use of a diverse regime of fertility inputs and to develop more flexible fertility recommendations that reflect variations in soil types as well as the capability of crops to reward farmers economically. For their part, farmers need to concentrate on using locally available resources as efficiently as possible, although it appears that there are insufficient organic inputs available to sustain soil fertility in the long term.

It seems that it is hardly ever possible to generate sufficient organic inputs to meet the application rates recommended by research. According to Campbell et al (1995), local sources of inputs such as manure and leaf litter have diminished considerably over the years, largely as a result of very high cattle losses during the drought of 1992 and the progressive disappearance of grazing areas and communal woodlands. Giller et al. (1997) also pointed out that as the supply of organic materials is often limited, they can not provide the nutrient boost needed by farmers unless they are supplemented in some way. Crops rarely yield their full potential, as farmers are unable to fertilise them adequately, because the organic input is either poor quality, insufficient or applied in inappropriate or inefficient combinations.

However, mineral fertilisers are expensive and not always readily available to farmers. Research should aim to support the use of organic inputs as the source for most of the necessary nutrients, making up the shortfall with mineral fertilisers. This is a major challenge because there is very little information about the optimum use of small amounts of mineral fertilisers to supplement nutrients in locally obtained organic materials (Palm et al., 1997). When the available organic materials are poor quality and in short supply, researchers have to investigate alternative methods of generating high quality organic materials that can be incorporated into the farming system, and which are appropriate to farmers' socio-economic conditions.

Our work has shown that the biophysical, economic and political environment heavily influence soil fertility management practices in the two study areas. Each household has reacted to these influences according to its specific characteristics and farming capabilities. Many of the constraints on the use of technologies to improve soil fertility, such as scarcity of inputs, labour, land, capital and to some extent knowledge, require interventions at policy level. It is therefore essential that accompanying policy measures be introduced to ensure that new technologies can be used to their full potential.

Soil enrichment and depletion in southern Ethiopia



Eyasu Elias

Introduction

Following the publication of several influential studies soil degradation has become a major national policy issue in Ethiopia (Barber, 1984; FAO, 1986; Hurni, 1988; Campbell, 1991; Bojo and Cassels, 1995). However, given the great variety of agro-ecological and socio-economic settings, there are no simple solutions to the problematic state of the nation's soils in this vast country. This chapter analyses farmers' soil fertility management practices in a range of contrasting agro-ecological and socio-economic settings in Southern Ethiopia in order to demonstrate the need to understand this diversity.

The case study sites are located in the Kindo Koisha district of Wollaita in southern Ethiopia, one of the most densely populated areas in the country. Variations in altitude, soils and resource endowments at household level have resulted in a range of different farming practices. Food shortages have become a permanent problem in Kindo Koisha and farmers identify declining soil fertility and soil erosion as main constraints on production (FARM Africa, 1992). Local extension services and non-governmental organisations (NGOs) have, however, been unable to tackle these problems properly due to a lack of area-specific information on soil fertility management strategies.

After an introduction to the agricultural sector in Kindo Koisha and the case study sites, we will look at historical trends in soil fertility management before moving on to a detailed description of current soil fertility management practices. We end by examining the sustainability of these farming systems and by considering what conclusions may be drawn from the assessment.

Methodology

Our research focused on how farmers with varying access to resources manage nutrient flows and how they could improve the way they do so. Farm surveys were conducted in three randomly chosen villages from each of the main agro-ecological areas: highlands, mid-altitude zone and lowlands. Key resource people classified households into four socio-economic groups, taking ownership of draught oxen as the main local indicator of wealth (Grandin, 1988). In this participatory form of wealth ranking, 2-5% of households were classified as rich, 17-30% were considered moderately wealthy, 39-46% as poor, and 33-39% were considered to be very poor. The relative proportional size of the various socio-economic groups was similar in the highlands and mid-altitude zone, while there were more moderately wealthy and fewer poorer households in the lowlands than in the other two zones.

A stratified proportional sampling was used to select 50 households from each agro-ecological zone (Coleman, 1995)[1], and we analysed the data using the General Linear Model test (Horton, 1978). The research was completed with a set of case studies of innovative farmers.

Agriculture in Kindo Koisha

The Kindo Koisha District is situated some 450 km south of the capital Addis Ababa (see Map). Table 1 presents the characteristics of the three main agro-ecological settings. The highland and mid-altitude zones have a semi-humid to humid climate and are densely populated. Some 85% of the total human and livestock population, and over 90% of the area's total crop production, are concentrated in these zones (WADU, 1976). Certain areas in the highlands have a population density of 500-600 people/km^2, making Kindo Koisha one of the most densely populated parts of Ethiopia. In the past, population levels in the lowlands were very low due to widespread livestock disease (*Trypanosomiasis*), malaria, poor soils and erratic rainfall. However, in the 1960s the government initiated a resettlement programme moving landless farmers from the highlands into the area, an influx of people which intensified in the early 1970s with the setting up of the Wollaita Agricultural Development Unit (WADU) project (Eyasu, 1997).

[1] Surveys in the highland and lowland zones were conducted during the 1995/96 production season, as part of European Union funded research on the dynamics of soil fertility management in Africa. The case studies of innovative farmers and the survey in the mid-altitude zone were conducted in 1998 as part of the Netherlands funded NUTNET research programme.

Table 1 Characteristics of three agro-ecological zones in Southern Ethiopia

Characteristics	Highlands	Mid-altitude	Lowlands
Altitude (m)	2100	1400	1170
Rainfall (mm)*	1272	1100	924
Population density (pp/km²)	375	281	110
Average land holding (ha)	1.0	0.8	4.2
Main crops	Enset, maize, sweet potato, haricot bean	Enset, maize, taro root	Maize, sweet potato, sorghum, cassava

*Average over 23 years.
Source: Weigel, 1986 and own survey.

Soils

The predominant soils are classified as Eutric Nitisols and cover roughly two-thirds of the study area (Belay, 1992). Sandy shallow soils are also common on the escarpment in the intermediate zone. Nitisols are inherently fertile, but large areas have now been depleted due to many years of continuous cultivation, leaching and erosion. The main limiting factors for crop production are low levels of phosphorus, nitrogen and organic matter, in that order. Potassium levels are generally high. Soils in the highlands have a high phosphorus fixation property, making P availability rather critical. Lowland soils have low chemical fertility levels and are liable to crusting and compacting (WADU, 1974; Weigel, 1986; Westphal, 1975).

Although researchers generally classify Kindo Koisha soils into a single category, farmers identify about seven different soil types in the area, each of which is managed in a particular way. Farmers classify soils according to their fertility, colour, depth, erodibility, capacity to hold water and how easy they are to cultivate (Edjigu et al., 1995; Eyasu, 1997). The key words describing soil fertility are *arada* (fertile soil) and *lada* (poor soil). *Arada* soil is characterised as dark, rich, thick and 'powerful', and *lada* soil as red, poor, thin and 'powerless' (Data, 1997).

Farming systems

The farming system is based on crop and livestock production. Over the last 20 years the per hectare yield of cereal crops has declined and food insecurity has become a severe problem. A farm survey conducted in 1995 showed that 93% of households experience a food shortage every year (Eyasu, 1997).

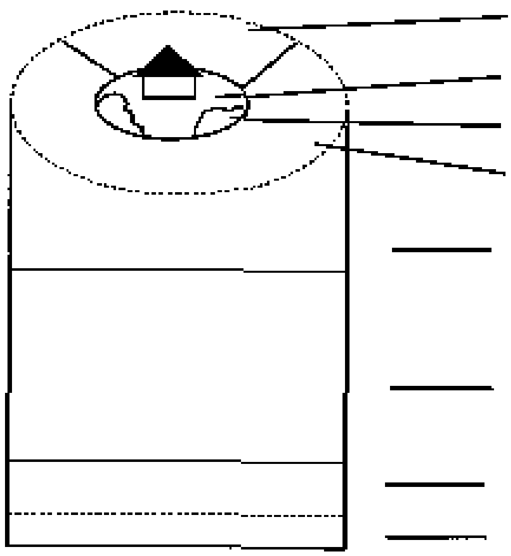
In the highlands and mid-altitude zone, farmers rely on enset (*Enset ventricosum* or *Musa ensete*) to guarantee food security and it therefore dominates the farming system. Other staples are cereals, root crops and tubers. The major cereals are maize and to a lesser extent teff (*Eragrostis tef*), barley (*Hordium vulgarae*), wheat (*Triticum aestivum*) and sorghum. The most important root crops are sweet potato and taro root. Cassava is increasingly cultivated in the lowlands and intermediate zone as it is resistant to drought.

The rainfall pattern is bimodal, resulting in two distinct cropping seasons of different length. Fields are cultivated throughout the year in a multiple cropping system, particularly in the highlands and mid-altitude zone. Farmers prepare their fields with an iron tipped wooden plough drawn by two oxen and use hand hoes to cultivate gardens and rocky soils on steep slopes.

Patterns of land use

Figure 1 shows the land use pattern of an average farm in the highlands. Most farms are rectangular and are located on a slope, with the house and enset garden at the top and *darkoa* fields, taro root fields and *shoka* fields on lower ground.

Figure 1 Field types on an average Kindo Koisha farm in the highlands



The term *darkoa* describes a homestead field which is enriched with organic materials and therefore the most productive. The *shoka*, or outfields, are far from the house and, as they receive no manure, they have low soil fertility and limited production capacity. Table 2 summarises the size of each farm component in each zone. The largest proportion of total cultivated area in most farms is taken up by the *shoka* field. Most of the farm's grain is produced here by various forms of multiple cropping of a range of cereal and root crops. Any part of the *shoka* left uncultivated is used for private grazing.

Between the *darkoa* and *shoka* there is a transitional land unit that is planted with taro root. This field can be seen as a moving 'fertility frontier' as soil enrichment transforms it from relatively infertile *shoka* into a fertile *darkoa* area. In the highlands and mid-altitude zone, a grass plot is left at the foot of the field to produce fodder, mulch and thatching material. This is an important source of nutrients for the other fields, as its biomass and resulting manure are applied to homestead fields. However, as farmers do not invest in maintaining their soil fertility these grass plots are liable to degrade through over-use. In the lowlands, natural pastures remain the major source of fodder and 'transferable nutrients' for use on the farm.

Farmers manage the soil in the homestead areas very carefully, enriching it with manure, retained crop residues, household refuse and crop residues taken from the *shoka* field. As they need to maintain production in the enset gardens during periods of drought, farmers use most organic inputs on these areas, maintaining and gradually increasing levels of soil fertility (Eyasu et al., 1998). Organic and inorganic inputs are generally not used on the same field: farmers do not apply fertiliser on the well-manured homestead fields since they do not expect it to make a noticeable difference to fertility levels. All crop residues are removed from the *shoka* fields and applied to homestead fields. Farmers regard *shoka* soil as poor and infertile but they do not put manure on these fields as they lack both the material and labour to transport it there. The limited nutrient inputs are mainly derived from mineral fertilisers.

Table 2 Area (ha) of various field types in each agro-ecological zone

Zone	Enset garden	Darkoa garden	Shoka outfield	Grass plot
Highlands	0.1 (0.04-0.2)	0.2 (0.2-0.5)	0.5 (0.1-1.8)	0.1 (0.06-0.2)
Mid-altitude	0.1 (0.1-0.3)	0.2 (0.2-0.3)	0.3 (0.2-0.4)	0.07 (0.0-0.2)
Lowlands	N.P.	0.8 (0.7-1.1)	3.3 (2.7-6.5)	N.P.

Figures in parenthesis show ranges. N = 4 per zone. N.P.: not present.
Source: Own survey.

The enset gardens in the highlands and mid-altitude zone produce the most food in terms of total dry matter. On a per hectare basis, the *darkoa* fields in all zones produce significantly higher yields of maize and other grain crops than the *shoka* fields. In the highlands, average maize yields are 2,800 kg/ha from the *darkoa* and 1,500 kg/ha from the *shoka* fields. In the lowlands, the average maize yield from the *darkoa* is about 1,450 kg/ha, compared with 800 kg/ha from the *shoka* outfield (Eyasu, 1997; Eyasu et al 1998).

Institutional setting

The basic administrative unit for farmers is the Peasants Association (PA). The PA's responsibilities include the administration and redistribution of agricultural land and controlling access to grazing areas under its legal jurisdiction. Three to five PAs can join forces to form a Service Co-operative (SC). SCs play an important role in supplying fertiliser, other agricultural inputs and consumer goods, and can also provide credit and marketing facilities in conjunction with the Ministry of Agriculture. Private companies sell fertiliser to SCs against a bank credit and the SCs then sell it on to farmers on credit. Farmers must have collateral in the form of livestock to be eligible for credit and are required to make a 50% down payment when the fertiliser is delivered. The balance, plus interest, has to be paid at harvest, which forces farmers to sell their produce when prices are low. Collective liability for outstanding debts at SC level has recently been introduced. There are also several forms of social support networks based on kinship, neighbours and patron-client relationships that provide informal credit services to farmers. These include traditional saving schemes, local traders and moneylenders.

Land tenure

Prior to the 1975 land reform the land tenure system was feudal. As tenant farmers could be evicted by their landlords there was little incentive for them to invest in long-term improvements to land such as soil conservation and fertility maintenance. When the revolutionary government took power in 1974 it declared that all land belonged to the State. Farmers received users' rights and PA leaders were empowered to redistribute land. Under the land reform, all farmers were entitled to access a particular piece of arable land, but in reality control over their plots was insecure as they were constantly being reallocated by the PA authorities. Farmers also complained about unfair distribution practices and corruption among PA officials.

Overall, land tenure policy has remained virtually unchanged under the Transitional Government (1991-1995) and the current Federal Democratic Republic of Ethiopia. Redistribution continued until recently but generated so much opposition that the government has now halted it. However, as the 'near landless' continue to demand reform and rumours about new land distribution persist, farmers still feel insecure regarding their landholdings.

At the moment the most common strategy for gaining access to land for cultivation is sharecropping, which is practised by 60% of the households in our survey. Sharecropping does not bring secure land rights and contracts often restrict the farmer's choice of crop and methods of cultivation.

Socio-economic characteristics of households

In order to provide a contextual background to farmers' soil fertility management practices and to explain their choice of strategy, this section examines the empirical results of a household survey on the ownership of key productive assets (cf. Scoones and Toulmin, 1995).

Ownership of livestock

Livestock are a key productive asset and a major component of the farming system. They influence soil fertility not only by providing draught power and manure: they provide also collateral for fertiliser credit and can be sold to purchase fertiliser. Poor farmers with no cattle may gain access to manure and draught power through customary arrangements for borrowing animals or in exchange for their labour. Farmers from all resource groups in the lowlands and from most households in the highlands look after animals on loan, belonging mainly to the richest households (Data, 1998; Eyasu, 1997).

Table 3 summarises variation between households in ownership and access to livestock. The average number of cattle owned in all the zones is about 3. However, this disguises wide variations between the different socio-economic groups. Rich farmers in all zones own significantly more cattle than any other group, while 25% of all households do not own any cattle. Poor farmers try to raise goats and sheep and use their dung to fertilise their land.

Table 3 Access to livestock in each agro-ecological zone

Zone	Cattle owned*	Oxen owned	TLU owned**	TLU held
Highland	3.1 (0.3-15)	0.8 (0-3.0)	2.2 (0.2-12)	3.5 (1.0-11)
Mid-altitude	3.2 (0.1-8.7)	0.7 (0.1-3.0)	1.9 (0.2-5.6)	1.9 (0.3-5.6)
Lowland	3.1 (0.5-10)	0.9 (0.5-2.8)	2.1 (0.3-7.2)	4.6 (1.7-12)

Figures in parenthesis show the range of means in each resource group. N=50 per zone.
*Livestock ownership is defined as animals fully owned, plus a half or a third of animals on loan, depending on the kind of share ownership arrangement. ** TLU is calculated as follows: 1 adult cow, horse or donkey = 0.7 TLU; 1 goat or sheep = 0.1 TLU; 1 calf = 0.4 TLU (Jahanke,1982).
Source: Own survey.

As already mentioned, ownership of oxen was the main criteria for ranking farmers' wealth. Average ownership does not vary much across the three zones (see Table 4) and is concentrated among the few resource-rich households. About 34% of all households do not own any oxen. Oxen provide most draught power, and access to this resource determines a farmer's capacity to carry out agricultural activities at the appropriate time. It also creates opportunities to gain access to land through sharecropping or labour exchange, since poor farmers obtain access to draught animals by hiring themselves out to richer farmers.

Land holding

Farmers' soil fertility management strategies are shaped by the size of their farm. Owning more land allows a farmer to grow a wider range of crops and to use different niches, thereby increasing the household's food security. The size of land holding varies significantly across the different socio-economic groups and agro-ecological zones[2]. It is skewed towards the upper two resource groups in much the same way as the pattern of livestock ownership. The rich farmers surveyed obtained their land through PA reallocations and could increase their land holdings through further leasing.

The average land holding is 1.0 ha in the highlands, 0.8 ha in the mid-altitude zone and 4.2 ha in the lowlands, a pattern which reflects differences in population density across the zones. In the lowlands, all settler households were entitled to 5 ha per household but many farmers cannot cultivate all their land because they lack draught oxen and soil fertility inputs.

[2] Survey data referred to in this section have been submitted to statistical analysis (see Eyasu, 1997).

By contrast, 81% of households in the highlands and mid-altitude zone have less than 0.5 ha, and about half of these cultivate less than 0.25 ha.

Household size and labour supply

The average family in the area consists of about 9 people, which is well above the national average of 6. The survey data on the age of household members shows that half of the study population is under 15 years old. The largest families in all zones were found in the resource-rich households which average 10 people per family. Richer farmers are often polygamous, which enables them to cultivate more land and increase their off-farm activities. Our survey seems to suggest that large households have more economic potential than smaller ones.

There are significant differences in land-to-labour ratios across the various agro-ecological zones, the average ratio in both the highlands and mid-altitude zone being 0.2 ha per person. In the lowlands, where farmers cultivate considerably larger areas, the land-to-labour ratio is 0.5 ha per person. These figures indicate that in the lowlands labour is a more important production factor than land, while land is the scarce production factor in the other two zones. Most farmers use their family as the main source of farm labour and they rely on reciprocal arrangements with neighbours to provide extra hands for planting, weeding or harvesting. Hired labour is used by better-off farmers, mainly in exchange for draught power.

Sources of household income and expenditure

Most households (81%) earn money from non-agricultural activities. Only the relatively rich farmers generate any significant income from the sale of crop and livestock produce: farmers in the other socio-economic groups earn very little in this way. Trading is also important for the richer farmers who are usually only part-time farmers. For example, they buy cattle from neighbours, particularly during the 'hungry season', and fatten them up for later sale. Opportunities for paid off-farm employment are limited in the area and there was no evidence for major flows of seasonal labour migration.

Most households in the highlands and mid-altitude zone reported that the largest share of total family monetary expenses goes to meeting basic household needs, followed by expenditure on agricultural inputs such as fertiliser. Both human and animal diseases seem more prevalent in the lowlands, where the largest proportion of household income goes on veterinary services and medication for family members. Fertiliser also accounts for a good deal of money, followed by land taxes, school fees and funerals. Further discussions with farmers revealed that poorer households spent relatively more on food and other basic household needs while richer farmers spent more on fertiliser and improved seeds. This suggests that most farmers have limited financial resources available to purchase inputs for maintaining soil fertility.

The historical dynamics of soil fertility management

Until the 1970s, the national agricultural extension system focused on the high potential cereal producing regions of the northern-central highlands and farmers in Wollaita were largely left to their own devices. Farming mainly consisted of root crop gardening within the homestead areas, where farmers used organic inputs such as manure, household refuse, crop residues and human waste. This intensive use of organic inputs maintained soil fertility and improved the soil's structure and porosity. Soil fertility in the outfields was managed through long fallow cycles and crop rotation with legumes, such as field peas, faba beans and haricot beans.

The first co-ordinated extension activity in Wollaita was launched in 1972 as part of a World Bank funded project called the Wollaita Agricultural Development Unit (WADU). The WADU project brought major changes in cropping patterns and soil fertility management practices in Kindo Koisha. WADU agents believed that using mineral fertiliser on cereals such as maize and teff would rapidly increase food production and thereby improve both food security and family income. By introducing price subsidies and providing credit facilities the project encouraged farmers to grow more cereals and use mineral fertiliser, instead of cultivating root crops in gardens. The major extension activities of WADU included on-farm *demonstrations of fertiliser and improved seeds, and the establishment of soil bunds on* farmers' fields.

Farmers were keen to use mineral fertilisers because they enabled them to cultivate fields that otherwise had to be left fallow, and so to increase overall production. Since they were also much less labour intensive to apply than organic inputs, mineral fertilisers became the major nutrient input for the farm and organic inputs were only applied to the enset garden. Depending on the farmer's economic status, application rates ranged from between 100 to 350 kg per ha of Di-Ammonium Phosphate[3]. Crop production increased rapidly during the WADU period (Eyasu, 1997) but because the project approach was so costly it was phased out in the 1980s. Fertilisers were no longer subsidised and, although the Ministry of Agriculture (MoA) made them available through SCs, supplies were irregular and not always timely.

At present, the Ministry of Agriculture is implementing the Participatory Agriculture Demonstration and Training Extension System (PADTES), which in 1995 adopted the Sasakawa Global 2000 approach. This programme focuses on a package of mineral fertiliser, pesticides and improved seeds for strategic crops, such as maize and wheat. Fertiliser is sold at market prices. However, the package of mineral fertiliser and hybrid seeds is not really financially viable for many farmers in Wollaita because of their limited productive assets and the erratic rainfall in the area. Moreover, these farmers have already developed a farming system based on root crops and use limited external inputs. Unfortunately there has been a certain amount of coercion in the way the extension programme has been implemented. Those farmers who meet the MoA's minimum requirements for land holding and possession of livestock feel forced to accept the package on credit, and some farmers are now saddled with debts which can only be repaid by selling livestock.

[3] DAP: 18% N, 46% P_2O_5

Expanding *darkoa* in the face of declining soil fertility

As mineral fertilisers became more expensive farmers used less of them. However, in the 1970s they had shortened fallow periods and abandoned the traditional rotation of legumes with cereals, because of problems with disease and the legumes' relatively low yields. As a result soil fertility declined, particularly in *shoka* fields, and farmers started noticing changes in indicator plants, physical properties of their soils and crop performance, such that yields were low even in climatically good years (Eyasu, 1998). They responded to the situation by starting to use organic fertilisers again, farming the homestead fields intensively and expanding *darkoa* fields (see Box 1).

Box 1 Creation and expansion of darkoa plots in the lowlands

Eyasu Munea is a moderately wealthy farmer in the lowlands who owns 7 cattle and cultivates 1.25 ha. He used mineral fertilisers until they became too expensive after the closing of the WADU project. By 1985 soil fertility had rapidly declined on his farm and he decided to fertilise his crops with decayed plant material and manure. As he did not have enough to fertilise the whole farm, he concentrated on enlarging the *darkoa* area through organic manuring and by planting 'fertility creating' crops. He initially planted the plot with taro root and Wollaita potato (*Coleus edulis*), applying large amounts of manure and hoeing intensively to earth up the plants and incorporate organic inputs into the soil. Although these root crops do not fix nitrogen they do produce large amounts of easily decomposable biomass, which improves the soil's physical properties such as its density, structure and capacity to hold water. He would not need to manure these enriched plots for 3-4 years and so went on to manure the adjacent shoka plot. Eyasu listed several benefits of this strategy such as improved soil fertility, needing less fertiliser, higher crop yield and farm income, and the efficient use of locally available organic resources.

Farmers do not have enough manure to fertilise both the *darkoa* and *shoka* fields and therefore concentrate on establishing and maintaining the *darkoa* plots. Each year they transform a small piece of *shoka* soil into *darkoa* by combining a specific type of crop rotation with intensive organic manuring and gardening (Eyasu, 1997; Scoones, 1997). The size of the area depends on access to livestock and their manure, and to labour. Farmers now aspire to convert all their fields into *darkoa*, and are trying to push back the fertility frontier marked by taro fields into the less fertile *shoka* land.

While men provide most of the labour in the more distant *shoka* fields, women play an important role in the homestead plot (enset garden, d*arkoa*, taro) where they traditionally do the gardening. They are responsible for weeding and for fertilising crops with a range of organic inputs, particularly animal manure. In return for their hard work on the farm the women have a small patch of land near the homestead, where they grow vegetables, and they are free to use the produce from these patches as they wish.

The continual creation of *darkoa* as a coping strategy is in line with Boserup's hypothesis that new land use systems will develop as population pressure increases (Boserup, 1965). Over the last few years the total area of enriched *darkoa* has augmented in Kindo Koisha. This is partly a result of the population growing, for as new households are established families build houses and gradually expand their *darkoa* plot. In the high and mid-altitude zones in particular, farming systems have evolved towards a type of multi-storeyed garden planted with a range of new income generating crops such as fruit trees or ginger (see Box 2). At the moment, these gardens are ecologically sustainable, but if land fragmentation continues to reduce the size of the plots it is doubtful whether they will be able to sustain the livelihoods of local farmers.

Box 2 Innovations in agroforestry

Mamo Gamo is relatively wealthy and lives with his family of 15 in the mid-altitude zone. He owns about 1 ha of land and 7 cattle. His farm is close to an all-weather road and is situated on a slope where soils are shallow, sandy and fragile. He used to apply mineral fertilisers but stopped when prices went up. However, he thinks that his soils became 'addicted' to them. There is considerable erosion on this farm and a lot of fertiliser was lost through run-off. Mamo used to grow maize and teff but they made the soil more erodible, as preparing the seed bed involves intensive ploughing, while the crop provides only limited ground cover.

The combination of erosion and a limited supply of nutrient meant that soil fertility dropped sharply. About 15 years ago Mamo decided to experiment with fruit trees on his farm. Using seeds from local State farms and nearby towns, he planted species that are compatible with crops and also experimented with spacing. He created a multi-storeyed agro-forestry system, using the home garden to grow avocado, mango, guava and orange in association with enset and coffee plants, and combining these species with annual crops such as ginger, maize and root crops in the outer fields. Traders come to the farm to buy his fruits, which are still rare in the area and fetch a good price. Mamo intends to stop cultivating cereals altogether and buy what he needs at the local market.

As he sees it, tree gardening has several benefits: soil conservation techniques are more effective; leaf fall and organic matter have made the soil more fertile: it has become black, thick, and remains moist. He earns money by selling fruit and seedlings and the fruit provides food all year round. Many farmers are now following his example and have started planting fruit trees. Mamo raises seedlings for sale and his farm is used as a demonstration plot.

Soil fertility management practices

Table 4 shows the main inputs used by farmers in the three zones to maintain soil fertility. It demonstrates that farmers from the two poorest socio-economic groups actually use a wider range of inputs and technologies than those from the two richer groups.

Mineral fertiliser

On average, farmers use at present 65 kg DAP/ha in the highlands, 15 kg DAP/ha in the mid-altitude zone, and 53 kg DAP/ha in the lowlands, levels which are significantly less than the officially recommended dose of 100 kg DAP/ha and 50 kg urea/ha. The major constraints on the use of fertiliser are its relatively high price, lack of credit, and untimely and inefficient supply. Only those farmers who are included in the PADTES 'model farmer' programme have access to urea.

Table 4 Use of soil fertility inputs per socio-economic category and zone

Measure	Highland				Mid-altitude				Lowland			
	RG1	RG2	RG3	RG4	RG1	RG2	RG3	RG4	RG1	RG2	RG3	RG4
	n=5	n=8	n=19	n=18	n=3	n=8	n=23	n=16	n=5	n=14	n=13	n=18
Manure	100	100	95	78	100	100	100	13	100	100	100	55
Min. fertiliser	100	100	80	50	100	63	13	13	100	100	77	72
Residue	0	0	26	90	0	0	70	75	20	50	62	61
Leaf litter	0	0	42	33	0	0	74	94	0	0	46	44
Compost	0	0	16	2	0	0	0	25	40	6	40	16
Termitaria	0	0	16	2	0	0	22	31	0	0	8	6
Fallow	0	0	0	0	0	0	0	0	40	14	46	17

RG = Resource group (1=rich; 2=medium; 3=poor; 4=very poor)
Source: Own survey.

Farmers in the highlands use more mineral fertiliser than their counterparts in the other two zones. This may be because the higher rainfall and longer growing periods in the highlands result in better crop response than in the lowlands, where rainfall is more erratic. Although WADU was not operational in the mid-altitude zone, farmers there knew about mineral fertilisers and the MoA has been promoting them in the zone since 1996. Nonetheless many farmers still prefer to stick to organic manure as there is serious erosion in the area and fertiliser grains are easily washed away by runoff from their steep and rocky fields.

There are significant variations in the amount of fertiliser used by the different socio-economic groups. The richer farmers buy the most fertiliser, while virtually all the non-users come from the poorer socio-economic groups (Table 4). Poor farmers may buy as little as a cupful holding 2 kg at the local market, applying it carefully to small areas and individual plants.

Use and management of manure

Table 4 shows that most of the farmers interviewed in Kindo Koisha applied manure to their fields, although 10% of highland farmers, 30% of farmers in the mid-altitude zone and 18% of lowland farmers did not use any manure. All these farmers come from resource-poor groups whose lack of access to livestock also deprives them of manure. There is no manure exchange system among households and no market for it in the area. High fertiliser prices have made it an increasingly valuable resource, and not even kinship will guarantee a supply of manure. When asked, *'Do you ever receive manure from a relative?'* one woman from the highlands responded, *'Would you give someone your life?'* The only way to acquire manure is to keep livestock. Manure is such a valuable fertility input that it is rarely put to non-farm uses. This is very different from the cereal culture of the northern-central highlands of Ethiopia where manure is normally dried and used as fuel (Gryseels and Anderson, 1983).

There are several reasons why farmers prefer using manure to fertilise their soils. It has '*duba ayana*' or a longer lasting effect, is easy to acquire for those who have livestock and reduces the need to buy mineral fertiliser. Some farmers have conducted simple experiments in their fields, comparing mineral fertiliser with manure (Box 3).

Box 3 Comparing manure and mineral fertiliser

Mr Munae is a relatively rich farmer in the lowlands who regularly uses fertiliser, which he buys on credit obtained through the MoA. MoA extension staff use his farm for fertiliser demonstrations. However, Mr. Munae was of the opinion that mineral fertiliser did not improve soil fertility levels, so he decided to do a simple experiment to compare the value of mineral fertiliser and organic manure. He concluded that organic manuring improves soil fertility more effectively because it increases soil thickness and improves moisture retention. Other advantages are that it can be obtained locally and he does not run the risk of getting into debt to acquire it. He wanted to stop using mineral fertilisers altogether, but extension staff forced him to continue to use their methods, and also forbade him to tell other farmers about his findings in case it made them unwilling to take up the use of the fertiliser package.

There are significant variations in the amount of manure transported to fields by different socio-economic groups (Table 5). Not surprisingly, richer farmers produce more manure, mainly because they have larger herds. However, poorer farmers in the highlands generally apply more manure per hectare because they only cultivate very small areas (see Table 2). There are also significant variations in the amount of manure transported by farmers in the different agro-ecological zones. Lowland farmers can keep more cattle because they have access to larger grazing areas. On average, farmers in the lowlands shift more than double the amount transported by their counterparts in the other two zones, although they use less manure per hectare because their farms are generally bigger.

In the enset garden, farmers put down manure and cover it with soil when they are transplanting, or it is mixed with old leaves and straw and incorporated into the soil during hoeing. Other fields receive their first application of manure when farmers start cultivating, and they are then given further doses every few weeks. Applying the manure gradually makes it easier to incorporate into the soil and also minimises losses.

Table 5 Manure availability per socio-economic category for the three zones

	Highlands		Mid-altitude		Lowlands	
Category	kg/farm	kg/ha	kg/farm	kg/ha	kg/farm	kg/ha
Rich	3600	1333	6114	5095	7280	957
Medium	2250	1730	3456	3456	5585	1298
Poor	1368	1710	2306	3294	4315	1198
Very poor	838	2095	1152	1920	1361	388
Mean	1542	1606	2348	3130	3904	927

Source: Own survey.

All interviewed farmers put bedding materials in the livestock pen to absorb urine and before taking the manure to the fields they wrap it in bedding straw mixed with household refuse. This practice minimises nutrient loss through exposure to the elements and conserves nutrients via microbial immobilisation, while nutrients are gradually released for plant uptake when in the field. Although there may be no significant increase in crop yields the first season the fields are manured in this way, farmers knew that this will be compensated by higher yields in subsequent seasons.

Use of compost, crop residues and leaf litter

Resource-poor farmers, with limited access to manure, use a range of other sources of nutrients, such as compost, crop residues, leaf litter and soil from termitaria, while richer farmers generally only use mineral fertiliser and animal manure (see Table 4). Composting was first introduced by WADU and is now being promoted by the MoA. Only a few farmers in Kindo Koisha produce compost and it is used almost exclusively by farmers from the poorer socio-economic groups (see Table 4). The main constraints on composting are its high labour requirements. Richer farmers regard compost making as too labour intensive and they prefer to invest their time in other economic activities. As it requires neither cash nor livestock it is a better option for poorer farmers who need substitutes for manure and mineral fertilisers (see Box 4). In general, women collect household refuse, cow dung, and chopped enset leaves for making compost, while men collect leaf litter and grass. Both men and women are responsible for taking the compost to the fields.

Box 4 Making compost

Gonosa Alaro is a poor farmer who lives in the mid-altitude zone. He keeps 3 cows on loan and cultivates 0.5 ha of land. His fields are steep, very stony and subject to serious erosion, so when soil fertility declined sharply he started using mineral fertilisers. This was to prove prohibitively expensive, so about 3 years ago he decided to use enset leaves, crop residues, ash, etc. to produce compost in his enset garden. He noticed improvements in the fertility and structure of his soil. Crop yields increased considerably and the soil turned black and spongy, retaining more moisture. The soil was also easier to work as adding organic matter meant that it no longer stuck tightly to stones, which can now be easily removed and used to construct bunds for controlling soil erosion instead of hindering ploughing and plant germination.

After harvest, many poor farmers incorporate crop residues such as chopped cereal straw into the soil (Table 4). This improves the soil's physical properties and also makes it easier to work, which is particularly important for farmers who rely on manual hoeing. Farmers are aware that crop residues are beneficial to soil fertility, but they also need these for fodder and household fuel. Leaf litter is used as a nutrient input on homestead fields by 32% of farmers in the highlands, 80% in the mid-altitude zone and 44% in the lowlands. All the farmers who use leaf litter come from resource-poor groups, for whom it is a relatively new practice which involves cutting branches from selected broad-leaved trees and transporting them to *darkoa* fields where they are left as mulch. Its widespread use in the intermediate zone is probably facilitated by the prevalence there of bushes near farms.

Soil conservation techniques

Land in the highland and mid-altitude zones is particularly vulnerable to soil erosion. Farmers know that this also reduces soil fertility and they use several soil conservation techniques to counteract its effects. Most resource-poor farmers use mulching, construct soil and stone bunds, deal with erosion rills, and install waterways and cut-off drains to discharge run-off water. Another technique involves laying maize stalks, tree branches and enset stems along the contour to control sheet erosion and increase infiltration. Instead of being washed away, soil sediment then collects behind the strip while termite activity under the strips will help improve soil fertility. In the *shoka* fields, women put a mulch of crop residues and grasses on erosion rills. NGOs have introduced grass strips in the area to prevent erosion and farmers are experimenting with various types of hedgerows (see Box 5).

Box 5 Biological and agronomic soil conservation techniques

Mr Tekle is a moderately wealthy farmer who lives in the mid-altitude zone. He cultivates 0.5 ha of land and owns 4 cattle. Soil erosion is a major problem on his farm and, as he found traditional conservation measures such as cutting drains, terracing and stone lines to be ineffective, he started experimenting with other technologies about 8 years ago. He planted cassava along the contours and found that this, together with the addition of fallen leaves and turning the soil at harvest, improves soil fertility. He sees cassava as a multi-purpose crop that can be used to control erosion and improve food security.

An NGO working in the area helped him establish strips of elephant and vetiver grass along the contour and put in pigeon pea hedgerows along farm boundaries. The grass strips not only prevent erosion but are also a source of feed for his livestock, while the pigeon pea hedgerows protect the soil against erosion, provide material for mulching other fields and yield food. Deposits of sediment that build up behind the grass strips are spread over the field.

Ten years ago Mr Tekle started making compost, which he now uses instead of mineral fertiliser. He believes that mineral fertilisers encourage erosion because they make the soil dusty, light and loose, while composted manure makes the soil thicker, stickier and spongy, and therefore more resistant to erosion. He also recycles crop residues. Traditionally, enset leaves are left as mulch in the enset garden, but on Tekle's farm his wife brings the leaves to the shoka field, where they are finely chopped before being incorporated into the soil.

The first soil bunds in the area were constructed on selected farms in 1982 as part of a food-for-work scheme. Other farmers copied the technology and almost all the farmers in the highlands now have soil bunds on their farms, which they have adapted to their circumstances. Although the bunds take up valuable space on the limited land available for arable farming, farmers are convinced that their benefits more than compensate for this loss. Soil bunds are used more in Wollaita than anywhere else in Ethiopia, which may be because land is farmed so intensively in this region (see also Box 6).

Stone lines, known locally as *kella*, are laid along contours at regular intervals to stop soil erosion and are also constructed when fields are cleared. This method has been used for generations on the stony, sloping land in the mid-altitude zone. Both men and women make stone lines, which are gradually extended depending on the amount of household labour available, although some richer farmers organise work parties to construct them in one go. They require continuous maintenance and repair because they are easily damaged by livestock or during ploughing. When deposits of sediment build up behind the *kella*, farmers then dismantle them and rebuild them about 2 meters away, planting crops in the sediment. Stone lines marking farm boundaries are, by contrast, left intact.

Box 6 Drainage ditches, soil bunds and cassava fallow

Mr Adema is a resource-poor farmer in the highlands who owns 2 cows and cultivates a 0.5 ha plot. In 1980 a road was built above his farm, causing serious erosion; and Adema had to adopt several strategies to keep it under control. He dug a cut-off drain to divert the runoff water into a grass plot, and planted mango and avocado in the *darkoa* area. He put micro-basins around each tree into which he feeds some of the run-off from the drainage ditch. Any sediment trapped in the basins is regularly spread on the field. He built soil bunds and planted them with elephant and vetiver grasses which also provide fodder and mulch. When silt deposits start to form a small mound, the bunds are broken and moved elsewhere in the field. Cassava produces food in times of drought, controls erosion and improves soil fertility, and for the last three years Adema has been growing cassava as a 'fallow' on degraded parts of the *shoka* field. Reflecting on his various soil conservation and management strategies, Adema proudly said, "My soil used to be in the Omo river, but now I am able to keep most of it on the farm."

Nutrient balances

Farmers use different soil fertility management strategies for different parts of the farm. Crops grown on the homestead and distant *shoka* fields are very different and so is the allocation of manure and fertiliser. Manure and other organic inputs are applied to the homestead plots while only a limited amount of mineral fertiliser is put on the *shoka* fields. Staple crops like maize and enset require a considerable nutrient input and so are grown on more fertile plots.

The nutrient input and output flows of selected farms were analysed to explore soil fertility decline at field level (Eyasu et al., 1998; Eyasu and Scoones, 1999). The nitrogen (N) and phosphorus (P) balances in fields were calculated from a combination of input and output functions based on the nutrient balance model developed by Stoorvogel and Smaling (1990). Table 6 presents the partial nutrient balances for rich and poor farmers in both the highlands and lowlands, no data having been collected on the mid-altitude zone. These balances are based on data collected for eight farms over a single year and do not provide information on temporal patterns.

The marked variations in N and P balances across farm units reflect differences in soil fertility management and cropping patterns. N and P balances in the enset, *darkoa* and taro fields of most of the farms studied were either slightly positive or in equilibrium, but there was a slight deficit in poor lowland farmers' taro and *shoka* fields, which can be accounted for by their limited access to manure. It seems that farming is sustainable on the homestead fields where farmers invest most in terms of soil fertility maintenance, enriching the soil to sustain food production, particularly enset. The absence of erosion in these fields is probably due to the soil's high organic matter content and stable structure, mulching and intensive management. The data suggests that, if producers farm intensively and improve their management practices, increased pressure on land will not necessarily lead to impoverished soils.

Table 6 N and P balances per socio-economic category and zone

Farm components	Highland				Lowland			
	Rich farmer		Poor farmer		Rich farmer		Poor farmer	
	N	P	N	P	N	P	N	P
Enset garden	12	11	-12	6	-	-	-	-
Darkoa garden	-3	8	-5	4	-4	11	-24	3
Taro garden	4	5	4	6	-7	8	-9	-6
Shoka field	-95	7	-54	3	-20	6	-41	-1

Source: Eyasu and Scoones (1999).

Table 6 shows that the *shoka* fields have the most negative nutrient balances for N in both agro-ecological zones. This is due to the large outflow of nutrients when crops and stalks are harvested and removed, to serious erosion in the highlands and to the fact that lost nutrients are not replaced by any fertility inputs. The greatest proportion of cultivated land is taken up by *shoka*, which is where most of the cereals are grown. If the soil fertility in this area continues to decline, there will be repercussions on the sustainability and the evolution of the farming system as a whole.

Conclusion

The analysis of farmers' soil fertility management practices in Kindo Koisha has demonstrated major changes over the last few decades and a high level of variation between field types, socio-economic groups, and agro-ecological zones. Mineral fertilisers were introduced in the 1970s and dominated soil fertility management until 1982, when the WADU project which facilitated their supply was phased out. The credit scheme introduced after WADU sets conditions which limit farmers' access to mineral fertilisers and also make them more liable to fall into debt. As these fertilisers have also become more expensive and supplies more erratic, farmers have turned increasingly to organic inputs and concentrated on expanding their *darkoa* fields.

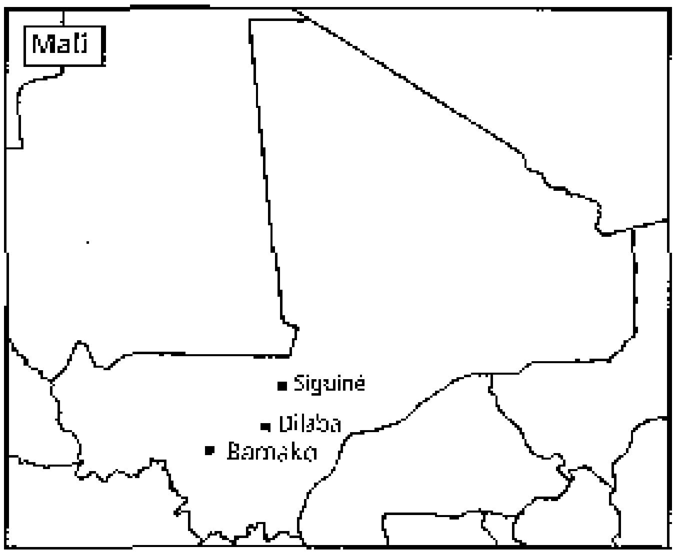
Land fragmentation and the need for food security has driven farmers in the highlands to adopt very intensive management systems in fields near the homestead, at the expense of outer fields where farming methods result in nutrient mining. The soil in the homestead area is enriched by organic inputs and careful gardening. Farming in these areas is intensive and finely tuned, with little room for further improvement. The positive nutrient balances indicate that farmers, particularly the poorer ones, have adopted the best possible options (Eyasu, 1997). However, this type of farming will only be ecologically sustainable if farmers continue to have access to sources of nutrients. The question is whether farms can continue to produce sufficient biomass and manure to maintain soil fertility, and whether this *darkoa* system can sustain the livelihoods of a growing population.

The relative returns from off-farm and agricultural activities are determined by a household's access to cattle, family labour, financial resources and network of economic and social contacts. It is more financially profitable for richer farmers in the highlands to concentrate on off-farm activities than to invest labour in soil conservation measures and intensive soil fertility management. Although they use a greater quantity of manure and mineral fertiliser than do farmers in other areas, they actually apply less per hectare and lose significant amounts through erosion, their *shoka* fields being the most affected by nutrient mining.

There is clear evidence of nutrient depletion in the outfields (*shoka* areas) in all three ecological zones. As these fields account for the largest proportion of arable land where most of the cereal crops are produced, they should be the focus of any intervention promoting integrated soil fertility management. Farmers' socio-economic status influences their access to productive assets, which in turn affects the nutrient balances on their farms, so technical interventions should be carefully targeted to suit the different requirements of poorer and better-off households. Activities should aim at increasing the level of nutrient inputs and reducing nutrient losses by recycling crop residues, controlling erosion and agro-forestry. Farmers may be able to recycle more crop residues if they have alternative sources of fodder and fuel, so it may be appropriate to consider introducing agro-forestry systems using Leuceana and *Sesbania sesban*, pigeon pea, better quality fodder and grasses, wood saving stoves, and possibly biogas technologies.

The greatest weakness of the present extension policy in Ethiopia is its failure to recognise the diversity of the country's farming systems and socio-economic conditions. This research shows that soil fertility management is dynamic and that it varies according to agro-ecological zones, socio-economic groups and field types. A general or blanket approach to extension which does not take account of this diversity will therefore not be able to improve the sustainability of farming systems.

Fallows and field systems in dryland Mali



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Introduction

A number of diagnostic studies have been carried out in Mali showing that farmers are seriously concerned about decline in soil fertility (Maiga et al., 1995; Coulibaly et al., 1997; Koné et al., 1998). This decline is also cited as one of the main constraints on agricultural productivity at national level (MDRE, 1994; van der Pol, 1992; Traoré, 1993; Kouyaté, 1998). However, management practices vary a great deal between regions, farmers and fields and also change over time. The purpose of this research is to present a more detailed picture of soil fertility management in semi-arid regions of Mali, with a particular focus on the dynamics of millet production and the use of organic materials for fertilising the land.

After outlining the methodology, we will describe the region and the research sites and then go on to analyse the diversity of soil fertility management approaches found there, including recent or current changes. We then discuss the sustainability and future prospects of the production systems found and close the chapter with some general conclusions.

Methodology

Our study is based on field research, carried out since 1995, into the evolution of soil fertility management in two case study villages in the central region of Segou. Elements of this research presented here derive mainly from the first stage of an action-research study undertaken by a multidisciplinary team of researchers using a participatory approach (cf. Defoer et al., 1997, 1998).

The team started with an analysis of farmers' problems in the village. To begin with, farmers were asked to map the village's soils and natural resources. The different soil fertility management techniques used in the village were then identified and farmers were asked to classify all households according to the degree to which these techniques were practised. Thereafter, fertility management practices were analysed, using farm maps drawn up by selected case study farmers. The maps were also used to identify and quantify the various flows of nutrient inputs and outputs, enabling researchers to calculate partial nutrient balances. In the final part of this first stage, the results were brought together and discussed with farmers at village meetings where suggestions were elicited as to how soil fertility management could be improved in each category of farm. In following stages new activities, incorporating prior discussions and suggestions, were planned, implemented and evaluated with the farmers.

Next, the team started research on the dynamics of technology adoption and adaptation in the region, using tools such as historical profiles and informal mapping (Macinanké et al., 1998). The results were compared with information available in publications on soil fertility management in the region since the 1960s.

History

Segou, the heartland of the Bambara kingdom, was taken over by the French in 1890. The French imposed taxes, forced labour and military conscription. They also transformed cotton and groundnuts into cash crops and began constructing the Office du Niger irrigation scheme in the 1930s. Also in the 1930s, following several years of drought and crop damage by locusts, young men started migrating to Senegal to earn money by harvesting groundnuts.

Mali gained independence in 1960 and the socialist regime of Modibo Keïta came to power committed to the principle of the state playing a major role in promoting economic growth and development. Policies included control of marketing and distribution of certain key agricultural products, including millet. In 1968 Moussa Traoré seized power in a coup d'état which was the start of 23 years of dictatorship. Traoré's government continued trying to control cereal markets but these were eventually liberalised in 1988. This change was part of a structural adjustment programme agreed with the World Bank, which also emphasised reforming and downsizing government-run rural development institutions.

Farmers in Mali say that since the early 1970s rainfall has been increasingly unreliable. The country has in fact suffered major droughts in the last few decades, the most severe being those of 1972-73 and 1983-84. The first of these led to the loss of some cattle and almost wiped out cash crops in the Segou region (Kater et al., forthcoming). As a result farmers now grow fewer groundnuts and use millet as both a food and a cash crop. The devastating impact of the droughts also marked a watershed in the way people perceive natural resources. Many farmers see 1973 as the year when declining soil fertility started to become a serious problem. The increasing use of manure all over the region since then is an illustration of this change in perception.

A popular uprising in 1991 led to the military dictatorship being overthrown and replaced by an elected presidency. The new government led by President Konaré has pursued a pro-market economic policy, continuing the processes of liberalisation and privatisation. A process of administrative decentralisation was also set under way and culminated in elections for rural communes in 1999. The Konaré government is widely considered to have achieved substantial economic and political reforms and has attracted considerable funds from the main donor agencies. National civil society has prospered too with the re-establishment of a democratic system and the emergence of many new groups and organisations.

Member states of the West African Monetary Union devalued the CFA-franc by 50% in January 1994, under heavy pressure from IMF and World Bank and with the aim of restoring the trade balance. As a result of the devaluation, together with rising world market prices, cotton production increased consistently and Mali is now the second most important producer of cotton in Africa. Devaluation also helped to increase exports of cereals, vegetables and livestock to neighbouring countries. Overall, these changes have altered the terms of trade between town and country, rewarding producers of food, cash crops and livestock but incurring higher prices for those needing to buy these commodities.

The Segou region

This research was carried out in two villages, Siguiné and Dilaba, located in the relatively flat Segou region of central Mali (see Map). Mali is a landlocked country, much of which falls within the Sahara desert region, and it has a total population of about 10 million people. Agriculture plays a major part in the economy and there are basically two types of rain-fed farming systems in the country: pastoral in the north, and agro-pastoral in the centre and south. In the centre, including the Segou region, farmers depend on millet- and legume-based cropping systems, while those in the south of the country grow a combination of cotton and cereals. There are also a number of irrigation schemes producing rice in the Segou region.

Average annual rainfall ranges from 150 mm in the north of the Segou region to 750 mm in the south, although levels may vary considerably from year to year. The rainy season lasts from three to five months and the remaining dry season comprises successive cool and then hot periods. Soils are predominantly sandy and loamy Lixisols and Arenosols with low natural fertility (see Table 1).

Agriculture is the most important sector of the region's economy. About 60% of cultivated land is given over to millet, with average yields approximately between 600 to 900 kg per hectare (DNSI-DNAMR, 1998). Rainfed areas comprise around 700,000 ha of cultivated land and are managed in accordance with customary land tenure systems. About 100,000 ha of

Table 1 Characteristics of the two research sites

Characteristic	Siguiné	Dilaba
Soil type	Gleyic Lixisols, Haplic Arenosols, Gleysols	Gleyic Lixisols, Haplic Arenosols, Gleysols
Rainfall (mm)	350-550	550-750
Pop. Density per km²	15	40
No. of people	400	264
No. of households	35	11
Availability of land	Abundant	Limited

Source: CRRA, 1998.

land is taken up by irrigation schemes: these are managed by the State through agencies such as the Office du Niger and Opération de Segou which allocate plots to farmers on long-term leases.

While the average population density in the Segou region is estimated to be 25 inhabitants per km², this varies considerably between districts. As can be seen from Table 1, population density in Dilaba is more than double that in Siguiné. There is now great pressure on natural resources in the more densely populated southern part of the region and around the irrigation schemes (see Box 1). Natural grazing lands and woodlands are shrinking as more and more land is cleared and planted with cereals. This is partly a result of population growth and the increasing use of oxen-drawn ploughs. Equally, there was in-migration by pastoralists following the droughts and the number of livestock kept by villagers is also increasing, putting more pressure on the remaining grazing areas.

There are numerous weekly rural produce and cattle markets in the region, to which both Siguiné and Dilaba have relatively good access. Villagers in Siguiné, however, have better access to off-farm employment which is available in the nearby Office du Niger irrigation scheme. The main towns have bank branches which administer credit provided by development projects, NGOs and agencies such as the Opération de Segou, thus facilitating in principle farmers' access to agricultural inputs for growing cash crops.

Box 1 Why farmers in Siguiné are expanding their fields

Farmers blame falling productivity mainly on the decline in rainfall, and say that in order to maintain or increase production they need to cultivate more land. They also plough and sow larger areas as a risk aversion strategy, on the assumption that if one part of the field fails to produce a crop another plot may succeed, providing greater food security for their families. Another reason for enlarging the field is that millet is increasingly used as a cash crop, and must produce a good yield to feed the household, cover part of the family's cash expenditure, buy livestock and farm equipment, and pay for marriages (Kater et al., forthcoming). Income from off-farm activities and migrant work are another source of revenue.

Farming in the two research sites

Siguiné

The village of Siguiné is situated about 80 kilometres north of Segou town, close to the Office du Niger irrigation scheme. Located in a semi-arid area, it receives between 350 mm and 550 mm of rainfall per year, and is affected by wind erosion. The village now consists of 35 farming households, its population density having increased from 3.3 people per square kilometre in 1959 to 14.4 in 1987. The main ethnic group is the Bambara, who consider themselves to be farmers although many may also own some livestock. Since the droughts in the 1970s and 1980s people from the Bella ethnic group, who are pastoralists, have settled on the edge of the village territory and graze their herds of small ruminants on village lands.

Farmers in Siguiné cultivate two types of fields: village fields, which are on alluvial soils, and bush fields, which are on sandy soils (see Box 2). Fallow is used in both types of field, although the bush fields are left for 15 years or more. Farmers apply organic fertiliser to millet in the village fields. They have two methods of sowing: dry sowing on the previous seasons' ridges and sowing after the land has been ploughed. Dry sowing is more common in bush fields when a large area must be sown as rapidly as possible to make best use of scarce rainfall.

Box 2 Village fields and bush fields

Most fields around the village are cultivated relatively intensively and are fertilised with household refuse, manure and topsoil from the cattle pen. They are situated within about 2km radius from the centre of the village, and are known as the village or home fields. The bush fields are further away and are managed in a more extensive manner. Their size is usually determined by the availability of ploughs. Depending on the performance of crops and soil quality, bush fields are usually left fallow after about 5 years of cultivation. The distinction between village and bush fields is found in Siguiné and many neighbouring villages, but in Dilaba, there is no such differentiation because so little land is available.

Settlements and their associated village fields are generally found on soils with a relatively high loam content. These soils are, or used to be, relatively fertile and because they are often situated in depressions they are more likely to have permanent water supplies. In years of good rainfall loamy soils usually produce a good millet harvest. However, when rains are poor they produce less than the sandier soils of the bush fields which allow the millet plant to develop an extensive root system that can catch what little water is available (Kater et al., forthcoming).

The average farm household cultivates 43.7 ha in Siguiné compared with 17.2 ha in Dilaba. As can be seen in Table 2, farmers in Siguiné grow millet in association with cowpea on about 50% of the village fields and on 85% of the bush fields. Millet in a pure stand is grown more on village fields than on bush fields. Bambara groundnut (*Voandzeia subterranea*) is the only legume grown in pure stands, although it is sometimes mixed with groundnuts. It serves partly as a hungry season crop, as it is ripe just before the new millet harvest comes in, and it is also sold. Millet yields vary a great deal from year to year, and between households, ranging from 300 to 800 kg/ha. Millet and cowpea are grown for home consumption and the surplus is sold. Nearly all cowpea crop residues are sold in Niono for fodder. Box 3 presents an impression of farming and soil fertility management in Siguiné.

Table 2 Average cropping pattern in Siguiné and Dilaba (hectares and percentage of total area)

Site	Field type	Millet	Millet & cowpea	Maize	Fonio & Sorghum	Cowpea	Groundnut & Bambara groundnut	Total cultivated area	Fallow	Total area
Siguiné	Village fields	4.5 (35%)	5.6 (43%)	0.2 (2%)	0.5 (4%)	0 —	0.2 (1%)	11.0 (85%)	2.0 (15%)	13.0
	Bush fields	2.0 (6.5%)	12 (39%)	0 —	0 —	0 —	0.2 (0.5%)	14.2 (46%)	16.5 (54%)	30.7
Dilaba	Village fields	0 —	13.1 (76%)	0.1 (0.5%)	1.8 (10.5%)	0.4 (2%)	1.3 (8%)	16.7 (97%)	0.5 (3%)	17.2

Average per household for 1995-1997.
Source: Own survey.

Box 3 Soil fertility management strategies in Siguiné

Mr. Diarra is a full-time farmer, close to retirement, who lives with his two brothers, their wives and children. He earns most of his cash by selling millet (about 5% of the harvest), and also sells cowpea hay. His brothers earn income from off-farm activities and invest it in livestock. His farm is classified as category 1 (i.e. indicating the best management of soil fertility – see main text) and has over 20 head of cattle, more than 20 goats and sheep, 2 ploughs and 2 carts, while 14 family members work in the fields. In 1995, Diarra produced about 14 tonnes of millet on his 8 ha village field and 9 ha bush field. In 1996 the same area only produced half that amount due to very poor rainfall.

In the dry season the cattle spend the night on the village field in a pen of about 20m by 10m. After 3 months, Diarra moves the pen and spreads the manure over an area of roughly 1 hectare. To restore fertility in his bush fields, he lets them lie fallow for 5 years. Diarra collects his goat and sheep droppings there and uses them on the village fields. He also stores manure in a pit and may ask his wives to throw used household water into the pit to facilitate decomposition. He produced 2.3 tonnes of organic fertiliser in 1996 and 6 tonnes in 1997, some of which was composted with weeds and the droppings of small ruminants. At the moment he does not use household waste even though there is a heap of it in the compound.

Mr. Coulibaly is a category 3 farmer (least effective manager of soil fertility) who returned to the village about 10 years ago. His farm is the legacy of his extended family breaking up, and consists of village fields only, with 13 ha of millet and 5 ha fallow. He has no access to bush field land and is unable to expand the farm. He owns 2 oxen, 1 plough and 2 carts, and only one of his children is old enough to help on the farm. As the farm does not produce enough millet to feed the family he does a lot of off-farm work as a blacksmith, enabling him to buy grain to meet their food requirements. He grows millet in association with cowpea and sells the cowpea hay. In 1996 he harvested about 4.5 tonnes of millet, but yields in 1995 and 1997 only amounted to about 2 tonnes. He only produces small quantities of organic fertiliser: 1.6 tonnes in 1996 and 0.8 tonnes in 1997. The family uses household waste as fertiliser, and composts the droppings of small ruminants with grasses collected from the bush.

Dilaba

There are eleven households in the village of Dilaba, which is situated 40 km east of Segou town. Its average annual rainfall is between 550 and 750 mm. Population density in the village has increased from 6 people per square kilometre in 1960 to 16 in 1980, and to approximately 40 in 1998.

Unlike Siguiné, there are no bush fields in Dilaba due to the scarcity of land (see Box 2). Consequently, and as can be seen from Table 2, the fallow area is very small. The dominant crop here is millet combined with cowpea, covering 70% to 80% of the cultivated land (Table 2). Yields vary from 500 kg/ha to over 1,100 kg/ha and between 1995 and 1997 they averaged 950 kg/ha, which is higher than the average yields in Siguiné. Very little millet is grown in pure stands. Legumes such as groundnut, Bambara groundnut and cowpea occupy around 10% of the land and farmers also grow sorghum and fonio (*Digitaria exilis*). The sorghum is mostly grown in lower-lying areas as millet does not do well in heavier soils that retain more water, while the fonio is cultivated in sandy patches.
Part of the millet-cowpea plot is rotated with legumes and farmers sometimes also grow cassava. Farmers in Dilaba grow more legumes in pure stands than their counterparts in Siguiné, mainly because climatic conditions are somewhat better in Dilaba. They are also less reliant on millet and cultivate larger areas of sorghum and fonio. Millet and groundnuts are grown both as cash crops and for home consumption, while fonio and Bambara groundnuts are used as hungry season crops, as they are in Siguiné.

Table 3 Ownership of livestock and equipment in Siguiné and Dilaba

Site	Cattle	Draught oxen	Sheep & goats	Carts	Family Workers	Ha/worker	Ha/oxen
Siguiné	16 (0-60)	5.9 (0-20)	15 (4-30)	1	11 (4-20)	2.3 (1-4)	6 (2-15)
Dilaba	20 (0-100)	5.5 (0-17)	33 (2-90)	1	11 (1-36)	2.5 (1-5)	4 (2-7)

Average per household for 1995, 1996 and 1997. Maximum and minimum figures are shown in brackets.
Source: Own survey.

Table 3 shows the number of animals, carts and workers on an average farm in Siguiné and Dilaba. There is a considerable variation between individual farms and this affects how each household manages soil fertility on its land. Livestock produce manure and are a source of wealth and security. Oxen are essential for ploughing the fields. The number of family members who can contribute labour also determines what kind of management care is possible. Carts are needed to transport manure, crop harvests and residues to and from the fields, to move clay and bricks and to go to the market.

The average area worked by each draught ox is higher in Siguiné because more land is cultivated there (Table 2). But contrary to what one might expect, the average area cultivated per worker is somewhat higher in Dilaba than in Siguiné. This may be because the number of workers on each farm varies a great deal in Dilaba: some households have only one worker at the farm. Box 4 gives an impression of farming in Dilaba.

Box 4 Soil fertility management strategies in Dilaba

Mr. Kamara is one of the most successful farmers in the village. He is a category 1 farmer (see main text) with a well-endowed farm. He owns 60-80 head of cattle, including 12 oxen, and about 30 goats and sheep. Kamara has enough ploughs and carts to cultivate 22 hectares of millet but, although there are about 30 people in his household, his family workforce is insufficient to meet all his labour requirements and he employs 5 labourers. Between 1995 and 1997 he harvested about 30 ton/year of millet. Both he and his neighbours say that his yields have been increasing.

During the dry season, part of his herd spends the night in temporary cattle pens, set up in the least fertile parts of his fields. The oxen spend the last 3 months of the dry season a pen close to the homestead, where they can be looked after more easily. He gives them crop residues to supplement their feed but does not have enough family labourers to apply litters as bedding in the pen. One source of biomass on his farm are these growing near the waste heap and during the rainy season he hires labourers to cut the weeds and add them to the heap. In 1995 he produced 48 tonnes of organic fertiliser, including household waste and the droppings of small ruminants. He increased this production to 58 tonnes in 1997. He used to burn his fields to clean them before ploughing but, having discussed soil fertility maintenance with researchers, he no longer does so. He has also started to cut the branches and leaves of bushes growing in his fields and incorporate them into the soil.

Mr. Coulibaly and his small family live on a category 3 farm. His daughter helps with ploughing and weeding and his wife does the sowing and manual weeding. In 1996 he had no oxen because one had died and he had sold the second one, so he had to borrow a pair of oxen from his family. He has since bought a young ox and is training it. He has a donkey and cart which are used sometimes by a farmer friend who has no cart, in exchange for helping out at harvest time. Coulibaly has 10 hectares of land. The family is self-sufficient in most years and sells small quantities of millet, groundnuts and cowpea. The family produces organic fertiliser by stabling the ox all year round, collecting the droppings of small ruminant, household waste, and with the debris that is left after threshing and winnowing the millet. Organic fertiliser production increased from 3 tonnes in 1995 to more than 7 tonnes in 1997.

Soil fertility management practices

Farmers in both villages were asked to list a number of soil fertility management practices that they believed to be appropriate for restoring or maintaining soil fertility (Dembélé et al., 1998). The main methods they listed were:

- Fallowing
- Adding organic matter:
    - of animal origin from penning livestock on cultivated land, cattle herds in sheds, cattle grazing on the crop residues
    - compost
    - household waste
    - incorporating weeds into the soil when weeding
- Applying mineral fertilisers
- Rotating crops and growing them in combination with leguminous crops
- Protecting the tree *Faidherbia albida* on cultivated land

Farmers were then asked to categorise every household according to the extent to which it implemented these practices. The first category includes farmers who used most of these methods, the second includes those who used a reasonable number of them, and the third covers farmers who only used a few of these practices. The results for each village are presented in Table 4. About half of all households were classified in the third category, these tending to be farming households with fewer assets.

Table 4 Categorisation of households according to use of soil fertility management practices

Village	No. of households	Cat. 1 Intensive use	Cat. 2 Moderate use	Cat. 3 Limited use
Siguiné	35	31%	26%	43%
Dilaba	11	27%	18%	55%

Source: Own survey.

The following section discusses the key elements of diversity and change in soil fertility management. A comparison is made between the two villages, and between categories 1 and 3 within and across each site, focusing on major differences in soil fertility management and reasons for this diversity.

Fallowing

In the past, farmers in both villages used fallow as the main technique for restoring soil fertility. Because there was plenty of agricultural land available, part of each field could be left fallow for relatively long periods of ten to fifteen years or more. Although fallow periods are becoming shorter, this technique is still used to restore fertility for bush fields in Siguiné where agricultural land remains plentiful (Table 5). Farmers there use the presence of *Eragrostis sp., Zornia spp.* and crusting of soil as indicators of declining soil fertility.

Previously, sandy soils were rarely used for more than three years and sandy-alluvial soils for no more than five years. However, with continuous applications of organic fertiliser the village fields are now generally cultivated for very long periods of twenty years or more. In these fields the area left fallow is much smaller than the cultivated area (Table 5). In Dilaba all cultivable land is now in use as a result of rapid population growth, while the small remaining 'fallow' area is actually used as pasture for draught oxen. In contrast with Siguiné, fallow is not a significant means for managing soil fertility in Dilaba. In both sites the Category 1 farms have the most land under fallow.

Table 5 Proportion of cultivated to fallow land in Siguiné and Dilaba

Site	Category	No. of households	Cultivated area (ha)		Fallow area (ha)		Fallow/cultivated area (ratio)	
			Village	Bush	Village	Bush	Village	Bush
Siguiné	1	4	4.5	24	2	39	0.1	1.6
	3	4	9	3.5	2.5	5.5	0.3	1.5
	Mean	12	11	14	2	16.5	0.2	1.2
Dilaba	1	3	30	0	1.5	0	0.05	–
	3	5	8.0	0	0	0	0	–
	Mean	10	16.5	0	0.5	0	0.03	–

Source: Own survey.

Association and rotation of cereals with legumes

In the village fields, farmers grow millet and cowpea on the same plot year after year. When they find that the fertility of part of the plot has fallen significantly, they change the association to pure stands of groundnuts or Bambara groundnuts. The following year they apply organic fertiliser and then start cultivating millet/cowpea again. Such a strategy is used in both villages.

Groundnuts were heavily promoted as a cash crop in the Segou region by the Opération Arachide et Cultures Vivrières (OACV), the groundnut marketing board, between 1974 and 1981. In Siguiné the area under groundnuts decreased after the withdrawal of OACV, and the proportion of legumes in the cropping pattern has consequently diminished, now standing at 1% in the village fields and 0.5% in bush fields (Table 2). In Dilaba the proportion of total cultivated area per farm under groundnuts has hardly changed since 1976 but the proportion of land under legumes has increased and is currently around 10% (IER, 1977).

Sources of organic fertiliser

The use of organic matter has become a means of restoring soil fertility. Organic matter comes from manure, household waste, compost, or incorporating weeds into the soil. The tasks involved in producing and using organic fertiliser are divided between different members of the household. Young people collect the crop residues, dig compost pits when needed and transport the organic fertiliser to the field, while the head of the family is responsible for managing its production. Women make organic fertiliser from household waste and keep some of it back for use on their own small plots of land.

Grazing crop residues

After the harvest, crop residues are freely accessible to all livestock including those from outside the village. Animals leave their droppings while they graze the stubble so that even farmers without livestock will receive some on their fields. It is difficult to quantify the amount of faeces deposited on the fields but it is unlikely to be sufficient on its own to restore soil fertility, given the quantity of crop residues exported by grazing animals. The quality of the dung also deteriorates because it lies unprotected on the field for up to six months.

Corralling livestock at night in mobile pens

For three to five months, the animals spend the night in pens which are shifted every few weeks as a way of spreading dung in areas that are considered to be infertile. Corralling is mostly done on the village fields that are closest to the wells. The amount of manure applied by this means is relatively small in relation to the total cultivated area, but it requires little labour in contrast to making and transporting compost or manure. Category 1 farmers, who have a herd of cattle of their own, benefit most from this practice. In Siguiné, category 3 farmers can only do it on a rotating basis. A group of farmers get together and for one dry season corral all their animals in a field belonging to one member of the group. The following year another has the herd on their field, and so on.

Manure produced in permanent pens near the homesteads

Throughout the year draught oxen, donkeys, horses and small ruminants are kept overnight in pens in the compound, and the manure they produce is transported to the fields during the hot dry season. In Dilaba the droppings of donkeys, sheep and goats are often added to the heap of household waste. However, farmers in Siguiné keep droppings from small ruminants separate and use them in the home fields to manure certain spots in the millet crop. They say that the manure from small ruminants takes longer to have an effect on crop yields than cow dung, but that once it has started the effect lasts for several years. As category 1 farmers own the most livestock, they tend to be in a better position to produce manure from these pens. Farmers in categories 2 and 3 produce what manure they can get from their small ruminants and oxen.

Composting

During the colonial period French extension workers were based in Siguiné, where they promoted cotton and introduced composting and the use of manure. Compost production was in fact compulsory and done on a collective basis. Villagers used crop residues and cow dung to make compost and also applied crop residues as bedding in the cattle pens, which were at that time communal. The produce was shared between the various farms but only used on cotton and groundnut fields. After the French extension agent left in 1942, farmers stopped producing compost. From the mid-fifties onwards the cultivation of cotton as a cash crop was abandoned in Siguiné, when rainfall levels started to decline.

During the action-research programme, farmers in Siguiné identified declining soil fertility as a major constraint on production. The researchers proposed composting as a method of dealing with the problem and some farmers have now started making compost again, this time of their own free will. They dig the pit in August when the soil is damp and start filling it with household waste, the droppings of small ruminants and sometimes maize residues and fonio hay. They take advantage of the last rains to start watering the materials. Once the pit has been dug it can be used for many years. Two farmers in the village have dug a pit on the edge of the home millet field so that they can compost some of their millet stalks without having to transport them. They fill the pit after harvest, add a lot of water, then close it up and leave it until the new cropping season when they empty it and use the compost on the fields.

The OACV introduced composting in Dilaba, advocating the use of weeds and grasses. The practice was abandoned after the OACV left because farmers said that there were not enough grasses and weeds available in the village area. It was re-introduced as part of the action-research programme, and is being increasingly adopted by farmers. They make the compost by collecting millet stalks, cow dung and small ruminants' droppings, putting them in a pit or heap to decompose, covering them with earth and watering them regularly. Some farmers have also started composting the trunks of fallen baobab trees, which decompose relatively quickly.

Household waste

Household waste consists of partially decomposed waste from a variety of origins. In the past, it played no part in fertility management, but it is now used on village fields in both study sites. Farmers in Dilaba said that they started applying household waste in the 1970s after the drought, combining it with cow dung and small ruminants' droppings. It is now widely used in Dilaba and is starting to gain ground in Siguiné also (see Box 5). The amount applied by different farmers depends largely on how much they are able to transport.

Box 5 Using household waste

The participatory analysis (PA) carried out in Siguiné in 1995 revealed that farmers did not use household waste on their fields. There was a big communal heap in the village where people put their waste but it was not used as fertiliser. Farmers only used manure and small ruminants' droppings on village fields. The PA ended with a discussion about how to improve soil fertility management after which 7 of the case study farmers started to use material from the communal household heap. At present, each household has its own waste heap, no longer putting its rubbish on a communal one. In 1996 one farmer started too to improve the quality of the household waste by mixing it with small ruminants' droppings and by 1997 seven other farmers were also doing so.

Use of organic fertiliser

The use of organic fertiliser is affected by a number of factors, including the fertility of the plot, soil type, plot location and the crop being cultivated. Village fields are manured most frequently because many farmers lack the transport to take manure to more distant fields. Farmers prefer to rely on fallowing to restore the fertility of bush field soils since the investment in transport of organic materials to these would be too great.

Farmers do not produce enough organic fertiliser to cover all cultivated village fields and prefer to apply it to the moderately fertile alluvial and sandy soils, to ensure that they produce sufficient millet. Because rainfall is low, farmers have to be careful not to put down poorly decomposed organic materials, or even too much mineral fertiliser, as this would burn the crops. In Siguiné, farmers in categories 1 and 3 fertilise the same proportion of village field area (see Table 6), which suggests that category 1 farms are not fully exploiting their animals' potential to produce manure. On average farmers in Siguiné manure a lower proportion of their farm land than their counterparts in Dilaba (Table 6).

Table 6 Area of village fields manured on each farm

Category	Siguiné				Dilaba		
	N	Area manured Vil. F.	% of total area Vil. F	% of total cultivated area	N	Area manured	% of total area
1	4	2.3 Ha	16%	9%	3	7.0 Ha	22%
3	4	1.4 Ha	15%	6%	5	0.9 Ha	11%
Average	12	1.8 Ha	14%	7%	10	2.9 Ha	17%

Siguiné: average for 1996 and 1997. Dilaba: average for 1995, 1996 and 1997.
Vil. F = village field; N= Number of households.
Source: Own survey.

Table 7 Characteristics of farms and levels of organic fertiliser production

Variable	Siguiné* Category 1	Siguiné* Category 3	Dilaba Category 1	Dilaba Category 3
Number of households	4	4	3	5
Number of workers	17.3	5.3	29	2.6
Number of carts	1.5	1	2	0.6
Number of cattle and oxen	50	2.6	74	1
Ratio fallow/cultivated area	0.14	0.25	0.05	0.01
Amount of household waste kg/Hh	300	400	14200	2700
Amount of compost kg/Hh	1200	400	0	0
Amount of manure produced kg/Hh	300	0	13400	900
Manure from corralling kg/Hh	5500	900	15900	0
Small ruminants' droppings kg/Hh	1000	500	0	200
Total organic fertiliser production kg/Hh	8300	2200	43500	3800
Organic fertiliser per worker (kg)	480	420	1500	1460
Organic fertiliser per hectare of millet (kg)	620	410	1730	640

*Siguiné: based only on village fields and averaged for 1996 and 1997. Dilaba: based on all fields and averaged for 1995, 1996 and 1997.
Source: Own survey.

Table 7 shows how much of each type of organic fertiliser was used in the two villages. On average, farming households in Dilaba produce three times as much fertiliser as those in Siguiné. This is because farmers in Dilaba corral their livestock for longer, keep their oxen in cattle pens and systematically collect and use household waste. The amount of organic fertiliser applied to fields varies according to the category of farm, rainfall in a given year and the site.

The average farming household in Dilaba uses approximately 1.5 to 3 times as much organic fertiliser per hectare of millet as its counterpart in Siguiné. The availability of fallow land has a major influence on the use of organic fertiliser since the smaller the ratio of fallow to cultivated land the more is used. In both villages, category 1 farms use more organic fertiliser than those in category 3, reflecting their greater capacity to produce and transport this commodity since they own more livestock and more carts (see Table 7).

During the group discussions on soil fertility management farmers listed a number of factors that they felt affected whether and how they used organic fertiliser. These included the availability of labour, water, access to transport, how many animals they owned and how they managed them.

Availability of labour, livestock and carts

The quantity of organic fertiliser produced largely depends on the number of workers farmers have at their disposal, the workers' commitment and the number of livestock. Organic fertiliser is generally made and transported in the dry season, which is when many workers leave the village. Those who remain often do not regard making or transporting organic fertiliser as a proper agricultural activity and they prefer to take up off-farm work to earn some income. In Dilaba, for example, many young men spend most of the dry season away from the village, only returning at the start of the agricultural season. The money they earn is spent on clothes, livestock, radios or taxes.

In both villages, levels of manure use were found to be closely related to ownership of livestock. Category 3 farmers in Siguiné use more material from their waste heaps than manure because they do not have many animals (Table 7). Farmers also seem to adopt more labour intensive methods of producing organic fertiliser when pressure on land increases. In Dilaba most organic fertiliser is produced in the compound and transported to the fields, while in Siguiné about two-thirds of the manure used on fields is produced by livestock in pens. Farmers also said that the shortage of carts prevents them from applying as much organic material as they would like to their fields. This was borne out in Dilaba, where the amount of household waste transported is directly related to the number of carts available. Those without carts had to borrow them from other farms when they needed to transport their organic fertiliser.

Availability of water and grazing areas

Lack of water during the dry season makes it difficult for farmers to compost fully their manure and crop residues. As the only sources of water in the dry season are wells more than 40 metres deep, researchers proposed that farmers try out other ways of recycling these materials, such as rainy season composting.

Livestock play a crucial role in maintaining soil fertility in both villages. In the past, farmers in Siguiné without livestock would provide transhumant Fulani herders with water for their animals during the dry season in exchange for manure obtained by corralling the herd on the least fertile parts of their fields. However, herders abandoned this practice in the 1970s because the village wells and ponds were getting drier each year, while the expanding irrigation scheme nearby offered more abundant water and grazing. When the ponds in the Siguiné bush dry up, the cattle now move to the borders of the Office du Niger irrigation scheme, where they wait until the rice is harvested and then graze the stubble. Today the only animals corralled in Siguiné's home fields during the dry season are livestock owned by the villagers.

For a large part of the year livestock feed on fallow land and in the communal, semi-wooded grazing lands. For the last twenty years or so, livestock herded by Fulani herders have been spending the rainy season on the grazing lands of Siguiné. Many of the cattle they herd now belong to rice farmers in the Office du Niger area. The woodlands have also become an important source of firewood and construction wood for people of Niono-town and from villages within the irrigation scheme.

The sylvo-pastoral zones around Siguiné are being used at the limit of their capacity, as can be seen in the declining ground cover, grasses, herbs, bushes and trees, and are nearing overuse (MDRE, 1999). Farmers in Siguiné, however, blame much of the deterioration of village woodlands on groups of Bella who migrated down from the north with their herds of sheep and goats after the great droughts of 1972/3 and 1983/4. Pressure on these areas is expected to increase further as more land is cleared for cultivation and livestock numbers continue to mount.

Dilaba has access to only one area of overgrazed pasture, which is shared with another village. It is also used by cart owners from Segou, who go to all the surrounding villages to cut hay for livestock kept in the town. The limited pasture and crop residues available in Dilaba are exhausted before the end of the dry season during years with less rainfall, and livestock then have to leave village lands in search of pasture. Their departure to more distant grazing areas removes a significant quantity of nutrients from the farming system, as they will deposit their dung elsewhere. Only draught oxen are kept close to the village, stalled in pens during the dry season, but as farmers only provide a limited amount of litter they can not obtain much organic matter in this way.

It is important to manage the collectively used pasture areas better so that they are not overused and degraded. It is also easier for farmers to produce organic fertiliser if their animals are kept on or close to the farm. In the past villages had customary rules regulating the use of common resources such as the wild fruits harvested in the area. These rules used to be respected by both villagers and outsiders, but unfortunately this is no longer the case. They were partly undermined by the government's declaration at independence that all uncultivated land belonged to the State and would be managed by the forestry service. This resulted in sylvo-pastoral land becoming *de facto* open-access areas, which has not facilitated the development of an effective management system. If land use is to improve, land users will have to change their behaviour. New legislation and local by-laws will also need to be recognised and enforced.

Mali is in the process of implementing a decentralisation policy. This could have an important impact on soil fertility management if it results in grazing areas being better managed. However, the results will largely depend on how the decentralisation take place and the way in which new councils manage natural resources under their jurisdiction. Farmers in Dilaba believe that decentralisation may exacerbate the already unequal access to resources by different villages, as they fear the imposition of more restrictions on using land elsewhere. However, they also said that it could lead to better management of local resources and improve the management of pasture, herd movements and forestry resources. Farmers in Siguiné are of the opinion that they will be in a stronger position to protect their natural resources from abuse by people from Niono and neighbouring villages.

Promotion of cash crops

In the past, farmers in both villages had been encouraged by the government to use manure and mineral fertilisers to increase production of cash crops. In Siguiné the production of organic fertilisers for cotton was promoted during colonial times, but farmers stopped using them when the French extension worker left, and cotton cultivation ground to a halt.

In the 1970s groundnuts were promoted as a cash crop. The OACV delivered seed and mineral fertiliser to farmers on credit and then bought the harvested groundnuts. Both villages were affected by the promotional activities of OACV, although these were lower key in Siguiné than in Dilaba. Such assistance never extended to subsistence crops, like millet, apart from general recommendations on how to grow these crops. The use of mineral fertilisers was largely abandoned when the development agencies withdrew from the village in 1981 and farmers lost access to inputs and an easy and assured marketing channel.

In the second half of the 1980s another extension programme arrived in Dilaba. Groundnuts were once again promoted as a cash crop, and seeds and mineral fertiliser were available on credit. This programme promoted too the use of mineral fertiliser on millet and made it available to farmers on credit. Some farmers were reluctant to use fertiliser as they were worried about not being able to repay their credit if yields were low.

Mineral fertilisers are now being used more in villages around Segou, especially when they can be purchased on credit. Land is very scarce in this area and fallowing is no longer an option for restoring soil fertility. Since farmers cannot produce sufficient manure and there is not enough labour available to produce large amounts of compost, they are gradually using more mineral fertilisers. Farmers in Dilaba are likely to follow this example.

Some of the farmers in Siguiné started experimenting with small quantities of mineral fertilisers. In 1997 a category 3 farmer in the village bought 5 kg of DAP which he mixed with millet seed before sowing, a practice which is widely used in the area to combat striga. He was very pleased with the results. Other farmers saw or heard about what he had done and tried it as well. Farmers in Siguiné could develop this practice further and improve its impact by making better use of available rainfall, reducing runoff and improving infiltration.

Sustainability of farming systems

A farming system can be regarded as stable if resources are exploited in such a way as to maintain the system's technical and socio-economic potential and to guarantee the survival of future generations. The population in both villages has grown substantially since the late 1950s. In Siguiné, for example, the population more than tripled between 1958 and 1998 but millet yields only increased from about 550 kg/ha in 1958 to 700 kg/ha in 1998. Some farmers have increased the size of their farms to meet the food needs of a growing population, but this strategy is not an option for villages such as Dilaba which face a shortage of land.

Partial nutrient balances

One of the objectives of this research was to draw up a partial nutrient balance per hectare of land under millet for each category of farm. The farm maps drawn during the first phase of the action-research programme were used to produce these balances (Dembélé et al., 1998). Partial nutrient balances were calculated according to a model developed by Smaling (1993) and adapted by Defoer et al (1998). An analysis of partial nutrient balances shows that neither field system presents a positive outlook for agronomic sustainability (Table 8). The bush fields in Siguiné are the most deficient in nitrogen and potassium, which is not surprising given that no fertiliser is used on them. However, the effect of fallow has not been included because the study period was too short. If account is taken of fallowing, nutrient budgets for Siguiné are likely to be more positive.

The nutrient deficit for all categories of farm is more pronounced in the village fields in Dilaba than for those in Siguiné. Although Dilaba produces more organic fertiliser it also has higher yields, and the outflow of harvest and crop residues is therefore higher. However, farmers in Dilaba have been cultivating these fields for many decades without any decline in yields (Kater et al., forthcoming). It would seem that outflows are being compensated partially by the nutrient stocks in the soil and by other flows which have not been taken into account, such as atmospheric deposits, weathering, fallow periods and biological N-fixation. Moreover, farming technologies have become more sophisticated and farmers take more care of their crop. Nevertheless, since soils in both villages have inherently low fertility, nutrient stocks are inevitably limited and there is a real risk of soils becoming degraded, particularly in Dilaba where fallow is no longer feasible.

Table 8 Partial nutrient balance for millet-based systems for one hectare (1996)

Village	System	Category 1			Category 2			Category 3		
		N	P	K	N	P	K	N	P	K
Siguiné	Village field	-14	-2	-23	-10	-1	-17	-18	-2	-26
	Bush field	-40	-5	-50	-24	-3	-30	-33	-4	-39
Dilaba	Village field	-23	-3	-36	-29	-4	-43	-24	-3	-38

Source: Own survey.

Promising technologies emerging from the action-research

Farmers and researchers worked together to identify ways of increasing production which are now being used at both sites. Farmers in Siguiné and Dilaba believe that if they are to develop sustainable farming systems they must use more organic fertiliser and grow crop varieties that are better suited to current levels of rainfall. They started with a visit to the cotton growing area of southern Mali where many such methods have been successfully employed for a number of years.

Box 6 Organic fertiliser production in Dilaba

All the farmers in Dilaba produce organic fertiliser but, according to several villagers, three farmers are currently significantly in advance of the rest. These are the people who in 1997 participated in an exchange visit to the south of Mali, where organic fertiliser production is well developed. Composting crop residues particularly impressed the three farmers. They are obviously enthusiastic about improving soil fertility management on their fields and use methods that they saw during the visit. Other farmers are waiting to see what results they get, for as one of them put it "A technology cannot be used by everyone at the same time. Someone has to be the first to test it. When the results are satisfactory others will follow." The action-research has made people in the village much more aware of soil fertility management and the importance of manure, composting, and recycling crop residues. Some farmers now pay children between 300 and 500 franc CFA[1] to go and collect a bag of cow dung from the communal grazing areas.

Given that many draught oxen are stall fed in Dilaba, the researchers suggested that farmers could use their crop residues as a more efficient feed if they were chopped up with a chaff-cutter. This device cuts millet and sorghum stalks in pieces which are then mixed with molasses and urea to increase their fodder value and make them easier to eat. Farmers now store more crop residue as fodder or litter for draught oxen. The manure and leftovers are stored in a pit or heap on the farm. Farmers and researchers have also worked together on recycling household waste and composting the droppings of small ruminants during the rainy season. Both activities are now common practice. However, the quality of the manure and compost could be improved in both villages by adding rock phosphate or urea.

Expansion of the irrigation scheme

Many villages neighbouring the Office du Niger scheme would like to have access to irrigated land. The creation of the Bewani irrigation zone in recent years has turned this wish into a reality for 39 villages so far, including Siguiné. Bewani is still small as there are presently only 1,000 hectares of rice fields compared with the total target of 15,000 hectares. But when complete, the new irrigation scheme is expected to benefit a large number of villages as well as private investors. Households in the scheme have rice fields of between 0.25 and 1 hectare, and farmers are expected to contribute labour or money (300,000 francs CFA per ha) towards the installation costs of the scheme. The government and donors will finance the main infrastructural work such as canals and drainage ditches (Touré et al., 1997).

Access to more irrigated land can make farming systems in Siguiné more stable and financially viable, as cultivating rice and other crops with irrigation is less risky than growing rainfed millet. The Bewani development is thus likely to have major implications for current farming systems in the village and there are several possible scenarios.

If Siguiné farmers can earn a reliable income growing irrigated rice, they may decide to reduce the area under millet and only grow enough to cover their household needs. At village level this would mean that the total area under rainfed cereals would decrease and the area under fallow would expand. Farmers would also be able to invest more labour, management and inputs in these smaller, more nearby village fields.

Bewani could also change the way farmers rear their livestock. If they earn more, farmers are likely to invest their additional income in livestock, which constitute the family's savings. They may continue to rear livestock extensively but are likely to come up against the same restrictions that they do now, as any increase in fallow land that can be used for grazing is likely to be offset by a growth in herd size. If on the other hand they rear livestock more intensively, animals will need to be stable fed, leading to an increase in manure production which they can use to grow vegetables on the irrigated plot during the dry season.

Conclusions

Experience in both case study villages showed that, when long fallow periods are no longer an option, it is not possible to continue farming in a sustainable way unless farmers apply organic and mineral fertilisers. At the moment farmers in Dilaba rely mainly on organic fertilisers and these are increasingly being used too on the village fields of Siguiné. Fallowing remains the most important practice for maintaining soil fertility on bush fields in Siguiné.

However, this study also showed that not enough organic fertiliser is being produced and applied to bring the partial nutrient balances into equilibrium. Farmers find it difficult to produce and transport enough good-quality organic fertiliser for their fields' needs and many of them cannot afford to buy sufficient mineral fertilisers to complement organic inputs.

[1] The current exchange rate is 100 Franc CFA for 1 French Franc.

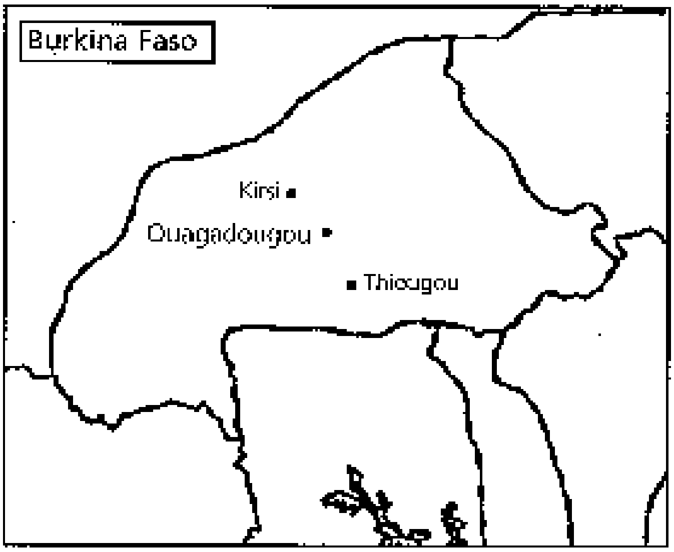
From an economic point of view, low and unpredictable farm-gate prices for millet make it difficult for farmers to find the wherewithal to make such investments. Devaluation seems to have improved the terms of trade for growing millet without external inputs[2], but many farmers still have limited purchasing power. There is thus little incentive as yet to invest in mineral fertiliser to balance the loss of nutrients caused by cultivating cereal crops.

The current outcome is a farming system which clearly cannot support continuous population growth and some people have to find work outside the agricultural sector. Having said this, Siguiné is something of a special case and its future does seem brighter because of the opportunities now offered by the new irrigation scheme. This will also affect the village's rainfed farming system, although the exact consequences remain to be seen.

This study has shown that there is considerable diversity in farmers' conditions and soil fertility management strategies and there is no blanket solution for improving soil fertility management. A more participatory approach to soil fertility management is essential, to take account of the diversity of management techniques, and as illustrated by the two study sites, it generates energy and creativity both within the farming community and among researchers and extension workers.

2 The price of millet in the town of Segou varied between 40 and 50 francs CFA per kg before the currency was devalued in 1994. Prices then almost doubled to 101 FCFA per kg during the 1995/1996 season, before falling to 77 Francs CFA in 1996/1997 (DNS, 1998). The price in December 1998 was 80 francs CFA per kg.

Rehabilitating soil fertility in Burkina Faso



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Introduction

Burkina Faso is a landlocked country in the West-African Sahel. The agricultural sector is the mainstay of the economy but it has to operate in the face of many constraints. Over the last few decades, rainfall has become increasingly unreliable and the country suffered major droughts in the 1970s and 1980s. Pressure on natural resources is increasing. Farmers have to maintain their livelihoods in these unfavourable and changing conditions, and find solutions that will allow them to continue cultivating in a sustainable way. This chapter analyses the dynamics of soil management in two villages and focuses on several promising technologies which include composting with rock phosphate, planting pits (*zaïs*) and methods to control soil erosion.

Methodology

The two case study villages, Thiougou and Kirsi, were selected because they had both been part of ongoing research programmes. A database was available which could be used to study how farming systems have been changing. In addition, secondary data was collected for each region, mostly from the archives of various government services. Supplementary research was undertaken to assess changes in soil fertility management in the case study villages and a nutrient budget was elaborated for Thiougou as part of the VARINUTS research programme[1].

Several projects funded by international donors are operational in both villages. Kirsi benefits from a large soil and water conservation project, the CES/AGF[2], which is active in the densely populated central plateau of Burkina Faso. This project works collaboratively with the Institut de l'Environnement et des Recherches Agricoles (INERA) on the development of new technologies and has greatly influenced soil management and erosion control in Kirsi (INERA, 1989). It has provided technical, financial and material support for manure production, the construction of stone lines and planting pits. CES/AGF has also encouraged the development of cost-effective approaches to anti-erosion works.

Thiougou falls within the intervention zone of the PDI/Z[3], a programme that supports the regional extension service but does not carry out any activities of its own. It has provided training, supported a credit system for purchase of agricultural inputs, supplied farmers with small items of equipment and facilitated the provision of cement for constructing manure pits. PDI/Z also supports the extension service in its work to promote more intensive use of organic fertiliser. This has included organising competitions for 'the best compost producer' in the region.

Overview of policy change in Burkina Faso

In the pre-colonial period, the central plateau was occupied by the Mossi people under the rule of kings and paramount chiefs. They were conquered by the French, who formed Upper Volta in 1897, created a new administrative system, introduced military conscription and recruited labour to build roads. They also imposed a head tax and compelled farmers to cultivate cotton in their most fertile fields, destined for the textile industry in France.

Independence came in 1960 and between that year and 1983 political power changed hands four times as military leaders successively deposed their predecessors. Captain Thomas Sankara came to power in 1983 and in the following year changed the name of the country to Burkina Faso, the 'land of honourable people'. A radical leader, Sankara introduced a new vision of economic and social development based on principles of self-sufficiency, honesty and dignity. In 1987 he was assassinated in a coup which brought Captain Blaise Compaoré to power. Compaoré has since twice been elected as President.

Both Sankara and Compaoré have been actively concerned about environmental degradation and launched nation-wide campaigns such as Sankara's *'trois luttes'* (or three challenges) which focused on bush fires, unsupervised livestock and excessive wood cutting (see Box 1).

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1 VARINUTS stands for Spatial and Temporal Variations of Soil Nutrient Stocks and Management in Sub-Saharan African Systems. This research programme is undertaken in Burkina Faso and Kenya and financed by the European Union.

2 Programme Spécial de Conservation des Eaux et Sol/Agro-Foresterie dans le plateau central, or Special programme for Soil and Water Conservation and Agro-forestry financed by IFAD.

3 Programme pour le Développement Intégré au Zoudwéogo, or Integrated Development Programme in Zoudwéogo financed by the government of the Netherlands.

Compaoré has also launched campaigns such as 'one village, one forest' and supports nationwide competitions between farmers and villages on the adoption of technologies like planting pits, stone lines, composting and the use of locally produced rock phosphate.

Box 1 Les *trois luttes* or The Three Challenges

The three main environmental evils identified in 1985 by the Department of the Environment were excessive woodcutting, unsupervised wandering livestock, and bush fires. The campaign against them was christened 'the Three Challenges' and the main protagonists were rural people organised into 'green brigades' and defence committees. There was initially a noticeable reduction in the number of bush fires that had been devastating the biomass and reducing the quantity of soil organic matter. However, the campaign quickly lost its impetus after the end of the revolution in 1987. There is no more enforcement of these issues at present and emphasis is now on dialogue with the population and elaboration of bylaws.

Agricultural policies

After independence, agricultural policies were sector-oriented and focused on developing cash crops in collaboration with foreign agricultural development agencies and companies[4]. However, the results were disappointing and the exclusive focus on cash crops, such as cotton, seems to have been one of the major factors contributing to the degradation of natural resources.

A new approach to the agricultural sector's problems was developed in the 1970s. This was known as integrated rural development and was implemented through various projects and State supported agencies for rural development. Donor assistance increased substantially after the great drought of 1973 and was channelled into programmes adopting this approach, while on a more general level the government also supported research, marketing, banking and distribution.

A number of projects were also set up to promote the use of mineral fertilisers. Between 1970 and 1976 large amounts of State subsidised fertiliser came onto the market, and from 1976 to 1986 the State also launched a National Fertiliser Programme (PNE) which showed farmers how to use fertiliser on various crops in different agro-ecological zones. The Phosphate Project promoted the use of local rock phosphate and imported phosphates. The Fertilisers for Food Production Project, (PEV) ran from 1986 to 1991 with the objective of promoting the use of organic fertiliser and rock phosphates produced in Burkina Faso. PEV further commissioned INERA to research optimal application rates for fertilisers (Sedogo, 1998).

However, neither the new approach nor the use of mineral fertilisers promoted by various integrated rural development projects seemed able to protect the country's natural resources

[4] These included the *Bureau pour le Développement de la Production Agricole (BDPA)*, *Compagnie Française pour le* Développement des Textiles (CFDT); Compagnie Internationale de Développement Rural (CIDR), Société d'Assurance Technique et de Coopération (SATEC)

from further degradation. Towards the end of the 1980s a more integrated approach towards natural resource management and local development at village level was advocated. Called '*Gestion de Terroir*', or land management within the territory of one or more villages, it was increasingly adopted by programmes and projects in Burkina Faso. It has become the mainstream approach to local land use management, and is often used in combination with participatory methods for analysing problems and planning activities.

In 1991, under the guidance of the International Monetary Fund (IMF) and World Bank, the government started implementing an Agricultural Structural Adjustment Programme (PASA) to reform the agricultural sector. This has involved abolishing subsidies, liberalising markets for inputs and crops, abandoning the minimum grain price and promoting involvement of the private sector in commercialisation of agricultural inputs and outputs. The Government was advised to pull out of the fertiliser sector and cereal marketing, but when the private sector moved in it raised fertiliser prices and lowered the quality of the products on sale. This has had serious implications for the rural economy as producers are now no longer able to obtain good quality agricultural inputs at favourable prices.

In January 1994, all the countries belonging to the West African Monetary Union devalued the CFA franc with 50%. As a result, the price of imported agricultural equipment and inputs doubled. Finding that they could no longer afford to buy mineral fertilisers, farmers cut down on their overall use and no longer applied the doses recommended for particular crops.

The Government decided to tackle the problem of poor soil fertility as a matter of priority. Between 1995 and 1997 the Ministry of Agriculture consulted with interested parties and developed a national policy and strategy for integrated soil fertility management[5]. A programme of activities was prepared by the Ministry in 1997-1998 and is currently being implemented in conjunction with agricultural research and NGOs. Its two main components are technologies for improving soil fertility and the creation of a socio-economic environment favourable to investment in soil fertility (Min. de l'Agriculture, 1996a; Sedogo, 1998).

Land tenure policy

Insecurity of land tenure is a particular concern for the many people who left the disadvantaged zones in the central plateau for areas with higher rainfall and more land in the South. It is also an issue for migrants returning to their villages after long periods in coastal countries.

In 1984, the Sankara government introduced the *Réorganisation Agraire et Foncière* to enact legislation which codified a 'modern' tenure system based on control over land for those who worked it. This legislation radically rejected any role for customary authorities, regarding them as 'feudalistic' (Lavigne Delville, 1999). The government took over responsibility from customary authorities for attribution and retrieval of land. It was to become the task of newly

[5] With assistance of the Africa office of the International Fertilizer Development Centre (IFDC).

elected committees, operating at village level. However, traditional leaders resisted this policy and customary land tenure systems still prevail at village level.

The legislation of 1984 was complex and increasingly considered inappropriate with regard to customary rights. Successive revisions followed in 1991 and 1996 under the heading *Réforme Agraire et Foncière*. This new legislation allowed the privatisation of agricultural land under customary land tenure systems, stating that this would strengthen security of resource tenure and increase agricultural productivity. While customary rights are formally recognised, no legal safeguards are provided and so does not constitute security of tenure for most rural people (Lund, 1996; Lavigne Delville, 1999). Another intention of the new legislation was the desire to facilitate land development, predominantly by clarifying rights between landowners and users about tree planting, anti-erosion measures and the application of fertilisers. However, having been drawn up without the participation of the people it was supposed to help, this legislation has gone largely unheeded.

Characteristics of the case study sites

The case studies covered two different agro-ecosystems. Thiougou is situated 130km south of the capital Ouagadougou, near the Ghanaian border, while Kirsi is about 150km north of the capital. Both villages have easy access to roads and local markets.

Climatic conditions in Thiougou are relatively favourable to agricultural production. There is a reasonable amount of surface vegetation, which limits the erosive effect of rainwater on the soil although when the rains are heavy there is run-off and gullies inevitably form. The rainwater also washes mineral elements down from the high ground to the alluvial plains and bottomlands which, as a result, have fertile soils.

The climatic conditions in Kirsi are less favourable. Production systems there are quite fragile and unstable. Annual rainfall is low and unevenly spread over time and space and in some

Table 1 Characteristics of the villages studied

Characteristics	Thiougou (central-South)	Kirsi (central-North)
Rainfall range (mm/yr)	800-1000	500-700
Soils (FAO classification)	Lithosols and Vertisols	Lithosols and Luvisols
Altitude (masl)	300	300
Population density (pp/km²)	47	57-60
No. of inhabitants	2,612 (232 households)	4,860 (450 households)
Main crops	Sorghum, millet, maize, groundnuts	Sorghum, millet, cowpea, groundnuts
Mean area cultivated per household (ha)	7.3	5.5

Sources: INERA, 1989; VARINUTS, 1997, own survey.

parts of the year crops suffer from water stress. When the rain does fall it can be very heavy and cause erosion. This removes the topsoil leaving bare, crusted land, producing a gravelly hard pan (*zipellés*) which then requires remedial work such as planting pits or stone lines to make it cultivable again. A study in the province estimated that 15% of its total surface area was taken up by bare patches of *zipellé* (Kaboré, 1994).

A variety of crops are grown on the two sites. These include sorghum, millet, maize, groundnuts, cowpea, sesame, cotton, Bambara groundnut and various vegetables. Cotton is grown in Thiougou and sold to SOFITEX (Société de Fibres et de Textiles du Burkina), and this enables farmers to purchase fertiliser on credit. Because of the low levels of soil fertility and adverse natural conditions, farmers cannot always grow sufficient food for their household needs and sometimes have to rely on off-farm income to see them through periods of food deficit. Food security is particularly a problem in Kirsi.

Livestock are reared extensively and include on average a donkey, a few oxen and other cattle, some sheep, goats, chickens, guinea fowl and pigs. Donkeys and oxen are used as draught animals. Cattle ownership in Kirsi is limited: 75% of all households have no cattle. Most households in Thiougou have cattle.

The production systems are essentially managed by large households that farm with a minimum of equipment, use little or no mineral fertiliser and apply only limited amounts of organic fertilisers. The head of the extended family is responsible for managing collectively-worked fields to produce the crops to meet the household's food security and basic needs. He therefore ensures that priority is given to these fields by all family members. As a consequence, individuals within the extended family are not able to spend much time on their own fields. Some large extended families, however, are undergoing fragmentation into nuclear households which farm land autonomously.

Farming systems

Thiougou

The Central-Southern region is a flat area with relatively fertile soils, better rainfall than the North and greater potential for agricultural diversification. Rainfall in Thiougou ranges between 800 and 1000mm a year (see Table 1). There are also substantial reserves of water and exploitable bottomlands..

The population rose from 1,935 people in the 1980s to 2,612 in 1997, 80% of whom are Mossi and 20% Bissa. The amount of land under cultivation in Kirsi has become 5 times larger between 1960 and 1998 and is increasing at an average of 5% per year. Demographic pressure is still relatively low, with a population density of around 47 people per km^2.

There are 232 smallholdings in the village and between them they own 310 ploughs of various types, 300 mechanical weeders and pieces of mounding equipment, and 55 donkey carts. Both oxen and donkeys are used for animal traction. The main crops here are cereals and groundnuts. In 1996 the sorghum yield was 650-700 kg/ha, yields for millet being 550 kg/ha, for maize 350 kg/ha and for groundnuts 650 kg/ha (VARINUTS, 1997)

Land in Thiougou is used by farmers and semi-nomadic Fulani herders. Fulani households are often located away from the village fields to avoid damage to crops by their herds (Holworth, 1999). Some farmers use the large Fulani herds as a source of dung, inviting the herders to corral the livestock on their land in exchange for water and other products. Other farmers buy manure or are given it free by the Fulani.

Land in Thiougou is acquired through family inheritance according to customary law. Farmers there still have a reasonable amount of land at their disposal, although some of them cited lack of land for agriculture and grazing as a constraint on production (VARINUTS, 1997). Fallowing is still used as a method of restoring soil fertility in Thiougou which has 308 hectares of household fields, 185 hectares of village fields, 650 hectares of bush fields and about 6,560 hectares of uncultivated land used for pasture and fallow. This typology of fields, that is, household, village and bush fields, results from the dispersed pattern of Mossi settlement. Household and village fields are near the homestead but bush fields can be located at a distance of over 15 km. The household fields are the best fertilised and support both hungry season crops and the most nutrient-demanding crops, such as maize and red sorghum. Less demanding crops are grown on the village and bush fields, which receive hardly any inputs.

Groundnuts, cowpea, rice, red sorghum and more recently cotton are grown for sale. These products are sold at the large local market, in neighbouring towns and at the nearby borders with Ghana and Togo where inputs can also be bought. Households in Thiougou earn a significant amount of money through trading poultry, small ruminants and cowpea with Ghana, where they also buy mineral fertiliser. Revenues are also used to purchase farming equipment and carts.

The agricultural extension services have identified the main agricultural problem in this area as declining soil fertility and they are helping farmers in Thiougou to address this issue. Farmers are currently trying out new techniques such as improved cereal-legume associations; crop rotation; the use of organic fertilisers, such as manure and compost with Burkina rock phosphate; and combining organic and mineral fertilisers on cereal crops. Local varieties are progressively being replaced with new varieties, particularly maize, cowpea, and rice.

Kirsi

Kirsi is situated on the central plateau to the north of Ouagadougou. It is an area of high demographic pressure, low rainfall, low levels of soil fertility, serious water erosion and environmental degradation. Rainfall varies between 500 and 700mm per year, with significant variations in time and space (see Table 1).

Villagers come from various ethnic groups, including Mossi and Fulani, and are mostly farmers who rear poultry and small ruminants extensively. They use their donkeys and few horses for transport and any cattle are usually looked after by Fulani herders. There is considerable human pressure on land in this region, with around 57 people per km². Lack of land has forced some farmers to cultivate on marginal, easily eroded, soils and in some areas the land has become so degraded that people have left the region and migrated to the South of the country or abroad. Remittances from out-migrants are a major source of income for households here, mostly used to meet basic needs.

Fields are planted with pure stands of cereals such as sorghum or millet (local and improved varieties) and association of cereals with other crops. Most households are not self-sufficient in food. Some agricultural products are sold in local markets and in the provincial capital. In the 1960s cotton, rice and tobacco were important crops but they are no longer cultivated, probably because rainfall has declined in the last thirty years and soils in the village have become less productive. However, farmers are starting to develop market gardening since the construction of a barrage near the village.

Farms in Kirsi have less equipment than those in Thiougou. There are only 48 carts and 92 ploughs (mostly donkey-drawn) in the whole village and none of the farmers have any equipment for mechanical weeding.

The main problems in this area, according to extension services, are the physical and chemical degradation of soils caused by water and wind erosion, and demographic pressure on natural resources. But Kirsi is located in a region which has a very high concentration of NGOs and village associations, and local people have benefited from the services offered by both NGOs and the national extension network. Since the 1980s, this assistance has helped the local people not only to improve the infrastructure but also to do a lot of work on improving soil productivity, rehabilitating degraded land and using valley bottom lands more efficiently (Min. de l'Agriculture, 1993).

Stone lines have been installed on 411 of the 2,454 hectares currently under cultivation and farmers also use planting pits, mulching and anti-erosion bunds to rehabilitate their land. They plant grass strips on watercourses to slow down runoff and help prevent erosion. To improve the soil fertility of planting pits and some household fields they use small quantities of organic fertiliser made from household waste, crop residues and animal dung, but they rarely if ever apply mineral fertilisers. As many farmers lack the transport to carry manure and other organic fertilisers to their bush fields the soil there tends to be poor, particularly in comparison with the household fields whose proximity to the homesteads ensures that they receive whatever organic materials are available.

Trends in soil fertility management

According to local people the land in both sites was very fertile until the 1960s. Vegetation was abundant and this helped maintain fertility as leaves fell and decomposed in the soil. When fields were exhausted farmers either dug in animal dung collected during the dry season or left them fallow. When they cleared new fields they left some trees growing along the edges and along rainwater courses to provide material for roofing, fences and mats. The most useful species include sheanut or karité (*Butyrospermum paradoxum*), néré or locust-bean (*Parkia biglobosa*) and perennial herbaceous plants (*Andropogon sp*) grown in bands. Bare patches or old termite mounds were traditionally covered with mulch to retain moisture and encourage crop growth. All these practices helped to maintain soil fertility and provide good yields that ensured food self-sufficiency.

However, population growth from the 1960s onwards has had a major impact on the production and land management systems in Kirsi. As pressure on productive land grew, farmers abandoned the practice of leaving fields fallow for they could only survive by cultivating continuously even if this exhausted the soil. Herd sizes also increased during this period, putting a further strain on the village's natural resources.

In Thiougou a similar trend was observed. Surface vegetation diminished and the rains became increasingly unpredictable. Although farmers still owned relatively little agricultural equipment, they cultivated larger but less productive fields which they started to fertilise with small quantities of household waste. They also extended the fallow periods when fields were left uncultivated. In the 1970s, agricultural extension was promoting sowing in lines, animal traction, and the use of mineral fertilisers. There was no specific technical training in small villages, such as Thiougou, where hardly any extension work was done. Very few people participated in the extension programmes that were run. They remained largely unconvinced by the arguments for using more organic manure and they hardly used any mineral fertilisers at all.

The major drought of 1973 alerted many people to the fact that their environment and soils were in a critical condition. Farmers noticed that their soils were becoming lighter in texture and that water erosion was increasingly apparent. In Kirsi, they started using preventive and restorative techniques to protect the soil, such as by building earth bunds. Extension agencies also introduced farmers to improved crop varieties that were more productive and whose relatively short growing periods were better suited to the length of the rainy season. Unfortunately, they also required mineral fertilisers that either were not always available or were not affordable, and therefore did not have the desired effect of making local people once more self-sufficient in food.

In the 1980s farmers' mounting concern about declining rainfall and soil fertility led them to adopt new technologies for managing their land (see also Box 2). Some techniques were developed by innovative farmers, others through research and some by extension programmes, projects and NGOs. Agencies trained farmers in new methods, which included: production of compost, ensuring proper decomposition of manure; new forms of tillage, ridging and mounding using animal traction; installing stone lines, planting pits and 'half-moon' rainwater catchment pits; growing sorghum and cowpea in association; and planting trees and protecting young saplings in the field.

Box 2 Farmers views on why they adopt certain technologies

One farmer in Thiougou said: "We saw that our yields were going down. One hectare used to yield 10 bags of cereal and now it only produces 5, so we had to do something. We haven't got enough manure to fertilise all our fields but the extension workers have shown us other ways of fertilising them. Most farmers use compost pits and bunds to stop erosion, as these technologies only require labour and no cash. They are effective, and will not get farmers into debt. We use very little mineral fertiliser because it is expensive and has to be bought on credit, so if yields are low farmers cannot settle their accounts".

A second farmer observed: "if the river changes its course then the crocodile will have to do the same", meaning that when the environment changes people have to adapt accordingly, otherwise they lose out. "At the moment the state of our soils means that we have to use other technologies. We have to adopt what is proposed in order to survive".

In Kirsi one farmer explained: "Whether or not we use a particular method depends on our means and our knowledge. We get help making compost in pits and if we do it properly our yields go up. Mineral fertiliser has become too expensive for us and if we use it in a year with poor rainfall the plants will burn".

Another farmer added "Our soil fertility management strategy depends on our means and on the advice and help we get from development organisations. There are many mouths to feed and we all cope by using methods that suit our circumstances. The stone and earth bunds seem to be working and although the planting pits are new they do work on the zipellé. People are impressed by these techniques. Farmers who don't have any manure have to make compost or buy mineral fertiliser, even if it is expensive".

A third farmer from Kirsi said: "The extension services have a big influence on which techniques we use. In the past we planted grasses and used branches to prevent run-off, but yields are so low and degradation so bad now that we'll try everything. We'll have to work to restore our soil's fertility. People don't really know how to use mineral fertilisers properly, and we've also noticed that during dry spells the crops burn and the soils become drier than they do when we use organic matter".

Soil fertility management practices

Use of organic and mineral fertilisers

In the 1960s most organic matter used on the fields came from crop residues left in the field after harvest. After the drought in 1974, farmers increased the use of dung, collected from pens and rainy season enclosures, and several new methods of producing organic fertiliser through composting were developed. Many farmers started composting crop residues and this is now the most widely adopted method of producing organic fertiliser. Farmers in both study sites, particularly in Thiougou, also add rock phosphate to improve the quality of their compost (see Box 3).

The amount of mineral fertiliser applied per hectare of cultivated land is low in both villages (Table 2). Mineral fertilisers are beyond the means of many farmers. Farmers in Thiougou use more mineral fertilisers than their counterparts in Kirsi, but only 24% of households use them regularly. Farmers in Kirsi have also started putting urea in their planting pits since these have

Box 3 Use of locally produced rock phosphate

The use of rock phosphate (Burkina Phosphate, or BP) has been recommended on the basis of research carried out by INERA, which showed that local soils need a minimum of 25 to 50kg of P_2O_5/ha to improve low levels of phosphorus. BP contains enough phosphorus to redress the balance, but it is linked with calcium in such a way that it requires acid conditions for its release. Adding BP to composting organic matter facilitates this release. Unfortunately the current supplies of natural phosphate are not sufficient for farmers' needs because the factory lacks the necessary production capacity. However, this should be remedied in the near future as the national action plan for integrated soil fertility management has made provision for increasing its production capacity.

Table 2 Use of mineral fertilisers in Thiougou and Kirsi by the village as a whole*

Year	1960		1970		1980		1990		1998	
	Th.	Kir.	Th.	Kir.	Th.	Kir.	Th.	Kir.	Th.	Kir.
Rock Phosphate	0	0	0	0	100	0	8000	2000	5000	0
NPK**	0	0	500	200	300	600	3500	1200	7500	1800
Urea	0	0	150	0	100	0	1500	0	2500	100

*At present the area cultivated in Thiougou is around 1150 ha (300 ha homefields) and 2454 ha in Kirsi; ** N:P:K:S:B 14-23-14-6-1

Source: Ministère de l' Agriculture, 1996b and own survey.

improved soil moisture, which is a more efficient way of using the fertiliser and reduces the risk of damaging the plants.

Rock phosphate is virtually unavailable on the market and can only be accessed through development programmes. Farmers in Thiougou started using BP in the 1980s, when it was introduced through a composting programme implemented by the regional extension service and continues to be supported by the PDI/Z project. This explains partly why farmers in Thiougou are still using it. Farmers in Kirsi started using BP in the 1990s, when the CES/AGF programme promoted its application in areas where anti-erosion measures have been put in place. Burkina phosphate is no longer subsidised and farmers now use ashes as a substitute because they find them equally effective and much more easily accessible (see Table 3).

Table 3 shows that more organic fertilisers are used in Kirsi than in Thiougou, reversing the pattern of mineral fertiliser use. Farmers in this village use all types of organic materials and over the last 10 years they have used increasing amounts of manure and compost. Almost 50% of households compost manure and each one produces an estimated 6.7 tons of organic fertiliser per year. Farmers put compost in their planting pits and on some fields, and also use a significant amount of tampouré, which they have been using for longer than any other organic material.

Table 3 Production and use of various types of organic fertiliser in Thiougou and Kirsi (in number of cartloads used by each village x 100*)

Year	1960		1970		1980		1990		1998*	
Types	Th.	Kir.	Th.	Kir.	Th.	Kir.	Th.	Kir.	Th.	Kir.
Ashes	0	0	0	0	0	0	0	0	0.02	5
Tampouré**	10	3	12	50	13	80	16	150	0.9	220
Manure from pen	0.5	0	5	10	15	15	17	17.5	20	30
Manure from stable	1.2	0	1.2	0	1.5	15	2	2	3	500
Compost	0	0	0	0	0	0	4.5	1000	22	3150

*At present the area cultivated in Thiougou is around 1,150 ha (300 ha homefields) and in Kirsi 2,454 ha. In 1960, Kirsi cultivated 527ha and, in 1980, 1,089ha. **Tampouré is a mixture of household waste and earth.
Source: Ministère de l'Agriculture (1996b) and own survey.

The possession of livestock is a decisive factor in soil fertility management strategies. Dung is usually collected when the herd is kept in an enclosure, or deposited on fields when the animals graze there in the dry season. It is used on maize and sorghum crops in the household fields and in planting pits on the *zipellé*. Some farmers sell manure to others.

The devaluation in 1994 did not noticeably affect the amount of organic fertiliser produced by farmers in Kirsi. As they had never used much mineral fertiliser anyway, they produced roughly the same amount of organic fertiliser after devaluation as they had done before. However, farmers in Thiougou had previously been more reliant on mineral fertilisers than their counterparts in Kirsi, and they started producing more organic fertiliser after 1994 when the price of mineral inputs doubled and they could no longer afford them. Whereas in 1990 only a few farmers in Thiougou made compost, almost all of them produce it now. This is also a result of extension projects in the area. At least 90% of the smallholdings in Thiougou now have a compost site and are able to produce good compost, although they cannot apply it in large quantities because they lack the transport, water and digging equipment to carry it to their fields.

Lack of transport is a main constraint on greater levels of production and use of organic fertilisers. There are 232 households in Thiougou but only 55 carts in the whole village, and this means that most of farmers there do not own a cart. Carts purchase is generally financed by relatives living in the Ivory Coast. The situation is even worse in Kirsi, where 450 households own a total of only 48 carts between them.

A development project working in Kirsi set up a credit system so that farmers without collateral could obtain agricultural equipment. The system operated on the basis of joint liability or group solidarity, but the lending organisations stopped the scheme when they had trouble recovering the money lent. Farmers were also put off by the way in which repayments were sometimes enforced: they are now reluctant to enter into these types of credit agreements as they cannot be sure of the outcome.

Planting pits or *zaïs*

Planting pits are a traditional method of regenerating encrusted and denuded soils. They are prepared in the dry season, and consist of holes 15 to 20cm wide and 10 to 15cm deep. Some of the earth from the hole is mixed with a handful of organic matter and put back into the pit to act as a seed bed, while the rest is put in a pile downhill from the pit. Farmers may also add mineral fertiliser or rely on the wind to blow organic material into the pit. Over the years, local farmers' organisations have carried out a lot of extension work in collaboration with NGOs advocating the use of planting pits throughout the North of the country. One of their most effective promotional methods has been to organise exchange visits between villages. Agricultural researchers have been working on improving planting pits since the late 1980s, laying them out in different patterns and testing the effects of adding mulch and manure.

These pits were first used in the Kirsi zone in 1988, but only really took off in 1992 when they were widely promoted by the CES/AGF Project (INERA, 1992). In 1998, 27% of all households were using planting pits, mainly on impoverished soils that could be brought into cultivation in this way. The pits have increased soil fertility and crop yields. The lack of access to cultivable land has forced some farmers to take up planting pits so that they can start growing crops on the *zipellé* and 739 ha has now been rehabilitated in this way in Kirsi (INERA, 1998).

Stone lines

Although the land is relatively flat, both village sites are subject to serious water and wind erosion, which cause considerable soil degradation and loss of nutrients. Crops also suffer from water stress, particularly at the start of the growing season. Farmers who participated in the survey said that in the past dense vegetation helped to slow down run-off and reduce damage to topsoil caused by torrential rain, but this surface vegetation has badly deteriorated over the last few decades due to intensive land use and adverse climatic conditions.

In the 1970s, research organisations developed tillage techniques aimed at reducing runoff. They included early tillage, ridging, mounding, using animal traction and special equipment. These techniques were promoted by extension agencies but were not widely adopted because of large labour requirements or the need for oxen, even though the farmers who did try them out had better crop yields in years with a poor rainfall (Rodriguez 1987 in Bationo et al,1998).

In the 1980s, a few projects tried reducing water erosion with physical structures such as earth bunds, but they were not particularly successful as local people had usually not been involved in planning, constructing or maintaining them. The next technique promoted mainly by NGOs was stone lines, which slow down runoff, reduce soil erosion and allow the earth to absorb more water. Farmers are now advised to plant a band of vegetation uphill from their fields to consolidate the effects of the stone lines.

Whether or not some of these technologies, particularly stone lines, are adopted may ultimately depend on land tenure. As a general rule making a significant investment in a field or developing a new area implies that the user considers him or herself to have secure rights over that land. If the land is on loan and the borrower improves it with stone lines or tree planting, their action could be seen as an attempt to appropriate the land, which may then be reclaimed by its owner.

Sustainability of farming systems

Nutrient budgets according to type and location of field

Most farmers have access to different type of fields which vary in soil fertility status and distance from the homestead, such as household, village and bush fields. Farmers tend to use most manure and household waste on the fields nearest to the homestead, while the more distant bush fields receive fewer applications of any kind. Table 4 presents the results of a study of partial nutrient balances for different kind of fields in Thiougou. It shows that household fields should be able to sustain production, but that the soil in village and bush fields is becoming exhausted and requires remedial action.

Table 4 Partial nutrient balances for different crops and fields in Thiougou

	Household fields			Village fields			Bush fields		
Crops	N	P	K	N	P	K	N	P	K
Maize	+10.5	+1.8	-33.7						
Sorghum	+3.0	-1.6	-33.5	-5.7	-1.7	-22.4	-16.6	-2.9	24.7
Millet				-13.1	-4.5	-30.4	-24.0	-5.7	-32.4
Cowpea							-49.9	-4.5	-74.1
Groundnuts				-37.7	-2.5	-34.9	-38.6	-2.4	-34.0

Source: Kiema, 1999.

Household fields seem to enjoy the most sustainable soil fertility management with positive balances for N and P. However, they are deficient in K, which may be due to the removal of crop residues. The other types of fields, which cover the largest proportion of the cultivated area, all show negative nutrient balances because they are cultivated without the benefit of either organic or mineral fertiliser. All fields have a negative K balance. To sustain agricultural production, these fields need application of organic or mineral fertiliser and rock phosphate or to be left fallow, which is still possible in Thiougou.

In Kirsi, farmers are trying to rehabilitate degraded areas and improve the fertility levels of exhausted fields so that they can sustain agricultural production. The most sustainable areas are those where farmers have implemented anti-erosion measures and use planting pits with added organic matter, such as manure and compost.

The migration of young people from Kirsi to large urban centres (particularly in the Ivory Coast) has significantly reduced the amount of available labour in the village, as half of the active workforce is absent from most smallholdings all year round. This was particularly marked after 1988, when Kirsi became a gold-mining site using simple surface excavation methods. The gold was exhausted by 1990, but people had become used to earning cash and many young men migrated subsequently in search of employment. Digging compost pits and collecting and transporting organic fertiliser is hard work for the children, women and older people who are left behind in the village. However, in our opinion, agriculture can sustain livelihoods if enough labour is invested in soil fertility management and people organise themselves to install soil erosion control measures. This is only possible if the community is able to keep their young male workforce in the village.

Conclusions

Farmers in both communities invest a considerable amount of effort in improving the quality of their soils. More and more are using soil and water conservation and agro-forestry techniques, and are starting to regenerate degraded land. They use their knowledge to adopt and adapt techniques, combining the use of planting pits with stone lines and the production of compost supplemented by Burkina Phosphate. At present, both villages benefit from the presence of external projects that provide advice and materials.

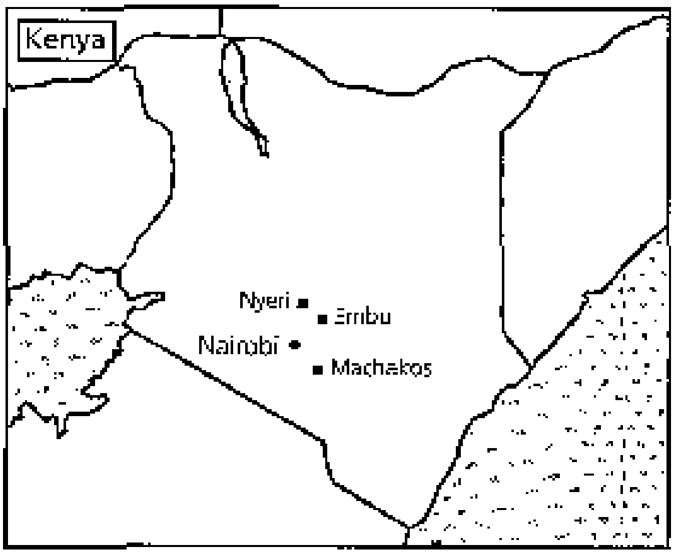
Farm production systems in Thiougou are currently more sustainable than those in Kirsi. They benefit from more favourable agro-ecological conditions and lower population density. At present, N and P balances for home fields are in equilibrium, but those for other types of field are in deficit. Better management of soil fertility in the village and bush fields will become increasingly critical as farmers in Thiougou probably continue to expand their fields, thereby reducing the amount of land under fallow and forest. Farmers will need to apply more organic and mineral fertilisers.

In the past, farmers used imported mineral fertilisers to improve soil fertility but, following devaluation in 1994 and structural adjustment policies, prices have risen so much that they are increasingly beyond the means of most farmers, who now use a variety of organic fertilisers to improve productivity. However, the number of livestock kept is low for most households, though better management may increase the levels of manure production. The application of mineral fertiliser depends on its cost-benefit ratio and on farmers' ability to reduce the risk of 'burning' crops. The use of water-'harvesting' techniques is therefore equally important.

Most of the farms in Kirsi have very low levels of soil fertility and degraded soils that could be improved by anti-erosion measures combined with larger quantities of organic fertilisers applied in a more efficient way. Farmers should also concentrate on using planting pits, as they seem to be the best way to rehabilitate degraded soils and to continue cultivation on exhausted soils. However, although these techniques will improve food security, they are unlikely to ensure that agriculture will provide for everyone's need and villagers will continue to look outside the agricultural sector to gain supplementary incomes to improve their overall conditions.

Research institutes have generated a number of techniques to improve agricultural production capacity, but they have often only been taken up by a limited number of farmers. Future research needs to ask why farmers adopt some techniques and leave other apparently equally viable methods on one side, and it should use a more participatory approach to generating and validating technologies which take account of farmers' knowledge and opinions about reducing soil degradation and raising yields. However, it is not enough simply to develop improved technologies. It is also important to create a more favourable context for agriculture and a good market for agricultural products, so that farmers will have a positive incentive to intensify farm production and invest in their soils.

Soil fertility regeneration in Kenya



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Introduction[1]

Agriculture plays a major role in the Kenyan economy, ensuring that the country is self-sufficient in food, generating income, earning foreign exchange and providing raw materials for the industrial sector. However, soil fertility is declining across the country, affecting many regions with varying biophysical and agronomic characteristics. This chapter describes the developments in soil fertility management in three regions of medium and high agricultural potential. Its focus is on the adoption of new soil fertility management techniques, in particular the use of compost and double dug beds, and their contribution to sustainable farming.

The study sites

This chapter is based on the results generated by various research projects on soil fertility management, such as the LEINUTS project (Jager et al., 1998a; Jager et al., 1999) and research on the use of compost and double dug beds (Kariuki et al., 1994; Diop et al., 1997; Hamilton, 1997). The study sites are located in Machakos, Embu and Nyeri (see Map). The lowlands of Machakos are classified as Medium Potential Areas (MPA). Embu and Nyeri fall into the category of High Potential Areas (HPA)[2].

[1] We would like to thank J.G.N. Mutharnia, S. Makokha and C.N. Kibunja from KARI for all their contributions.

[2] According to FAO (1978), HPA and MPA are those areas with a growing period of 150 - 270 days and 90 - 150 days respectively.

Machakos District covers more than 600,000 hectares of the Eastern Province of Kenya and has a population of over 1 million. In the centre of the district, hills of up to 2,100 m rise above the surrounding plateau which slopes from 1,700 m above sea level in the west down to 700 m above sea level in the south-east. Rainfall is bimodal, with an annual average of between 500-1,500 mm depending on location and altitude, and about 85% of the region is classified as semi-arid to arid. There are two growing seasons that each last from 90-119 days (Kassam et. al., 1991).

Soils in the lowlands of Machakos range from shallow to very deep and are well drained, with topsoils of loamy sand to sandy loam in many places (Acrisols, Luvisols and Ferralsols, see Table 1). Most soils are low in nitrogen, phosphorus and organic matter (Jaetzold and Schmidt, 1983). The region has a population density of over 100 people per km². Farming is mainly subsistence-oriented cultivation of crops such as maize, beans, pigeon peas, sorghum and fruit trees. Most farmers also keep local breeds of cattle, goats and poultry. The cattle are usually corralled overnight, which enables farmers to collect farmyard or *boma* manure. The average farming household in the lowlands of Machakos has a freehold smallholding of about 2.5 ha, and earns roughly 22% of its total income from agricultural activities. The remaining money is earned from off-farm activities such as trading, employment in urban centres and casual labour on other farms (Onduru et al., 1998; Jager et al., 1999).

Embu district is also situated in the Eastern province of Kenya (see Map). The altitude of this district ranges from 830 to 2,070 m above sea level. Rainfall is bimodal, with an annual average of 700-2,000 mm, and the predominant soils are Andosols and Cambisols. Andosols are deep reddish-brown friable clays, acidic and suffer from low nutrient availability, especially P, as well as Al and Mn toxicities (Jaetzold and Schmidt, 1983). Population density in Embu is high, averaging over 132 people per km2, which has resulted in land fragmentation and an average farm size of 2.3 ha (CBS, 1996; GoK/UNICEF, 1990).

Table 1 Characteristics of the study areas

	Machakos-lowlands	Embu	Nyeri
Mean annual rainfall	500-900	700-2000	1200-2000
Altitude (m.a.s.l.)	340-1710	830-2070	1100-2400
Main soils	Acrisols, Luvisols, Ferralsols	Andosols, Cambisols, Ferralsols	Andosols, Nitisols Acrisols
Population density per km²	100	132	253
Average land size (ha)	2.5	2.3	0.9
Main crops grown	Maize, pigeon pea, sorghum, beans	Maize, coffee, tea, beans and vegetables	Tea, coffee, maize, vegetables
Cattle/HH	5	2	2
Contribution of agriculture to total household income	22%	32%	36%

Sources: CBS, 1989; CBS, 1996; FURP, 1989; GoK/UNICEF, 1990.

Nyeri district is situated in the Central Province and lies between 1,100 and 2,400 m above sea level. Rainfall here is also bimodal, and the mean annual rainfall ranges between 1,200 and 2,000 mm. The most important soils are Andosols and Nitisols, which are well drained and deep, containing clay with an acid, humic topsoil. Their fertility status is inherently fair to good, but intensive cultivation has mined them of their nutrients. Soils with a high acidity are marked by a low nutrient availability, P-fixation and Mn and Al toxicities. The population density in the district is much higher than in the other two study sites and is estimated at over 250 people per km². Average farm size is 0.9 ha. Agricultural activities provide only 36% of total household income, while the rest is generated by off-farm activities, remittances from migrant family members and pensions (Gem, 1998; Jager et al., 1999).

The dominant elements of farming systems in Nyeri and Embu Districts are coffee, tea and dairy production. The staple crops are maize and beans, but farmers also cultivate Irish potatoes and a wide range of vegetables, spices, fruit and flowers. Within a typical farm, 60% of the land is used for growing coffee or tea, 15% for potatoes, 10% for pasture and napier grass and 10% for horticultural crops. Only 5% of the land is used for producing maize and beans for household consumption (Kilambya et al., 1998).

Livestock holdings mainly consist of dairy cows (cross breeds), sheep and poultry, and are used as a source of income, protein and manure. Most of the manure is used on high value crops such as coffee and horticultural crops. Most smallholders started keeping dairy cows in zero-grazing units when the amount of land available for cultivation and grazing decreased, which forced them to look for alternative methods of livestock husbandry. Dairy farming started in the 1950s and was supported by extension services. Milk prices were high then and the area is close to some big towns. Prices declined over the 1980s but have been picking up again following the liberalisation of the market for milk products.

Influence of policy change on soil fertility management

When Kenya was colonised by the British at the end of the 19th century many Europeans came and took up farming. African farmers practised shifting cultivation on a large scale and transhumance was widely followed. The colonial government's land use policy resulted in the resettlement of large numbers of African farmers and pastoralists, assigning them to restricted zones, or Native Reserves, of limited agricultural potential. Tiffen et al. (1994) noted that in the early 1930s a dual economy was established in Kenya, in which strict territorial demarcation gave European settlers and African smallholders unequal access to land and markets.

Colonial administrators justified government control over African lands by pointing to the land degradation which was becoming increasingly apparent as human and livestock populations grew in the native reserve areas. European settlers also used the conservation argument to promote expansion of European landholdings. There were some areas marked by deforestation, soil erosion and siltation, where the colonial government imposed regulations. Farmers were not allowed to plough steep land, cultivate along stream channels or clear forests. Other policies encouraged contour farming, tree planting on hillsides, terrace strip cropping and destocking of herds in certain areas. Compulsory communal work was organised for terracing and grass planting, and large areas were closed off to prevent grazing (Tiffen et al., 1994). Local chiefs, headmen and technical assistants were employed to ensure that these policies were followed by the rural population (Thomas et al., 1997).

The Swynnerton plan of 1954 encouraged the consolidation of scattered plots and individually registered titles. This Plan also initiated a switch of government resources to higher-potential areas in Kenya. European farmers secured most government attention in the form of credit facilities, marketing services, agricultural research directed to tea and coffee, and free veterinary services.

After a bloody struggle in the 1950s, Kenya became independent in 1963 and this resulted in the exodus of many Europeans. In the high potential areas, the so-called 'Million Acres Scheme' was launched to provide for orderly division of the large European-held mixed farms into smallholdings. Many people also settled illegally in former crown lands without support from government agencies. Cattle ranches dominated lower potential areas but these were not included in the Scheme. With the drought of the mid-70s, however, lower-potential areas were recognised as needing further attention and various donor agencies have been supporting integrated rural development programmes in semi-arid districts (Tiffen et al., 1994).

In 1970, President Kenyatta called for the creation of a land use commission to address the increasing degradation of natural resources. But the commission, only established in 1976, made slow progress and this triggered the drafting of a paper by various directors of government departments for the United Nations Conference on Desertification held in 1977 in Nairobi. They outlined guidelines to provide for more effective land use, including issues of soil and water conservation, destocking of large herds, and the protection of forests and watersheds. This initiative resulted in the creation of a presidential commission on soil and water conservation and afforestation, which still exists. This commission oversees government activities in these areas and fosters coordination between ministries.

After independence, Kenya's economic growth was initially impressive but was not sustained. The decline in economic growth in the mid-1970s was triggered by a combination of the international oil price crisis and serious structural constraints within the economy and public services. As the supportive policies that had boosted productivity during the 1960s lost their impetus, agricultural growth slowed down. The second international oil crisis and the collapse of the East African Community in 1977, which eliminated traditional market outlets for Kenya's industry, exacerbated this. A severe drought in 1984 further undermined the economy, slowing growth and causing high inflation and a deterioration of the balance of payments (GoK, 1997). The government had to undertake a series of structural adjustment programmes in the agricultural, industry, trade and financial sectors in the 1990s, to restructure the economy. Financial support for agricultural extension has been decreasing following the phasing out of a World Bank support programme in the late 1990s, although it seems that at district level the level of the qualifications held by extension workers is improving since they now consist of graduates instead of people with an agricultural diploma.

Farming systems in Nyeri and Embu

In the past, most of the land in Nyeri and Embu was used to cultivate staple crops such as potatoes, cassava and pulses, while the lower lying areas were grazed by livestock and wildlife. In the colonial era, white settlers had started growing coffee and tea as cash crops on land which was taken over by African smallholders after Independence. As the area under tea and coffee has increased between 1960 and 1980, the land available for staple crops has fallen and put food security at risk, especially when revenues from cash crops deteriorated in the late 1980s. Farmers often had to wait for several months before being paid by the co-operative societies. Between the 1930s and 1990s, yields of unfertilised maize fell by over 60% in Embu and Nyeri to around 1,000 kg/ha. There has also been a 20-40% decline in coffee yields since the 1960s, reflecting its declining profitability. Coffee yields in Embu and Nyeri were on average 1,300-1,500 kg/ha in the 1960s but had dropped to around 900 kg/ha in the 1990s (Department of Agriculture, 1930 and 1962; FURP, 1989; FURP, 1994).

Most farmers in Nyeri and Embu have seen their incomes drop and their livelihoods deteriorate over the 1990s. Consequently, as legally prohibited from actually removing any bushes, they reduced input use and management in their tea and coffee plots. More recently, tea prices have picked up again and farmers are re-applying mineral fertilisers, available on credit. Coffee prices have not improved and farmers now intercrop coffee with staples such as beans, maize, bananas and fruit trees. Although they continue to harvest coffee some do not invest in maintenance of the bushes.

Farmers have different soil fertility management systems for their cash and food crops. They tend to use most of their inputs to fertilise cash crops, while the fields where food crops such as maize and beans are grown receive almost no nutrient inputs. The credit and input supply systems[3] have made mineral fertilisers more easily accessible to many farmers in the Embu and Nyeri districts and all farmers use them for tea. Even when supplies of manure and compost are plentiful farmers still prefer to use organic inputs on the napier grass they grow to feed their dairy cows, an important source of income. However, the prolonged and heavy use of sulphur-based mineral fertilisers, particularly where tea has been growing, has made the soil more acid, a problem which is aggravated in areas that receive only limited applications of organic matter.

Several community-based organisations and NGOs started programmes in the 1980s, particularly in Nyeri, to promote vegetable production and better land husbandry. Farmers are intensifying production by means such as replacing bush beans by climbing beans (see Box 1) and by diversifying into horticulture. They also began rehabilitating degraded soils and are now increasingly using organic inputs to supplement mineral fertilisers and improve organic

[3] Tea and coffee are marketed through cooperative societies that also supply mineral fertilisers and pesticides on credit.

matter content of their soils. Some farmers buy manure from pastoralists outside the area while others make use of manure produced in zero-grazing units. They have also taken up planting legumes and multipurpose trees along field boundaries and in home gardens for fodder, firewood and biomass for green manuring.

Box 1 Climbing beans in Embu district

Bush beans (*Vigna unguiculata*) are a significant source of food for many people in the central and eastern highlands of Kenya and are therefore an important staple crop. However, bush bean production has declined over the last twenty years, probably because intensified land use has resulted in low soil fertility and an increasing presence of a number of soil-borne diseases that cause root rot and bean stem maggot.

Several research projects have investigated the causes for this decline in bean yields and identified possible solutions to the problem. One proposal is to introduce climbing beans (*Phaseolus vulgaris*), which make better use of limited space but require some kind of support. Climbing beans were first introduced to Western Kenya in 1996, where they produced impressive yields in biomass and grains (5t/ha compared to less than 1t/ha obtained from bush beans). On-farm research in Embu District showed that they produced better yields and economic results than bush beans. Farmers and researchers also thought that they were more tolerant to insects, birds and diseases, cooked more quickly and tasted better than bush beans. The use of climbing beans is now spreading in the area.

Farming systems in Machakos

Colonial land use policy forced people to migrate from high potential areas such as Nyeri and Embu to less well-endowed regions like the lowlands of Machakos, where difficult conditions and low yields reduced many farmers to poverty and dependence on famine relief programmes. Over the last sixty years, the most significant change in this area has been the shift from the extensive livestock-oriented systems of the 1930s to more intensive crop production today. While cropping systems used to be based on sorghum and millet they are now dominated by maize and pulses. In the 1930s, sorghum and millet occupied 30% of total cultivated area and maize only 16%. This pattern was reversed in the 1950s with maize taking up 40% of the land under crops. By the 1990s, maize and pulses accounted for over 90% of land under crops (Gem, 1998).

Farmers have invested in extensive soil and water conservation (SWC) measures and water harvesting techniques to conserve fragile soils and increase crop production. According to Tiffen et al (1994) there is a long-term commitment to soil and water conservation in this district. Investment in bench terraces started in the native reserves of colonial times, where land tenure was perceived as more secure. It was facilitated by its profitability for high-value crops and the demonstrated increase in maize yields under dry conditions. Terraces have been constructed by groups of farmers with help of "food-for-work" and "tools-for-work" schemes. Some farmers also hired labour, occasionally financed with revenues from off-farm employment. Although mineral fertilisers have been introduced and actively promoted in Machakos from the 1960s onwards, hardly any farmers use them for food crops, applying farmyard manure instead (Tiffen et al., 1994). Maize yields in Machakos have increased from 200-500 kg/ha in the 1960s to around 700kg/ha in the 1990s (Department of Agriculture, 1962; FURP, 1989; FURP, 1994).

Trends in soil quality

Farmers in the study sites regard the increase in soil erosion and the decline in soil fertility as the main constraints to crop production. Farmers in Machakos cited shallow soils and poor water retention as additional problems, while their counterparts in Embu and Nyeri also have to contend with soil borne pests (Onduru et al., 1998).

Table 2 Fertility changes in unfertilised, continuously cropped Kenyan soils

	Temporal variation of soil properties (0-20 cm layer)							
Site	Organic C $g\ kg\ kg^{-1}$		P-Mehlich $mg\ kg^{-1}$		Exch.K $mmol\ kg^{-1}$		pH-H_2O	
	t=1	t=2	t=1	t=2	t=1	t=2	t=1	t=2
Alfisol (clayey)	30.7	29.9	25.8	25.2	7.2	8.1	5.1	4.9
Alfisol (sandy)	6.8	4.8	30.6	24.7	2.7	3.5	7.0	6.9
Oxisol	20.5	20.1	17.2	13.4	2.0	1.7	5.1	4.7
Psamment	7.9	6.7	27.0	25.1	4.9	2.9	7.7	7.0
Ultisol (clayey)	26.2	24.9	27.7	24.5	18.7	13.0	5.8	5.
Ultisol (clayey)	15.7	15.8	14.8	13.2	4.6	4.0	5.4	5.3
Ultisol (loamy)	13.0	12.1	12.9	14.7	6.8	5.1	5.6	5.3
Ultisol	4.9	3.9	5.8	5.5	1.6	1.4	6.3	5.8

t=1:1987 or 1988; t=2: 1990, 1991 or 1992
Source: after Smaling and Braun, 1996.

The decline in soil quality is present in all three regions, but most dramatic in the Machakos district, where nutrient stocks in particular have sunk to very low levels since the 1970s. K and pH levels fell in Nyeri, probably because of the use of sulphur-based fertilisers in tea fields. The reasons for this depletion are as many and varied as the sites and fields where it has occurred. Rates also vary according to soil properties, with the sandier soils of Machakos sustaining higher losses than the predominantly clayey soils of Nyeri and Embu (Sanchez et al., 1997). There is evidence that the main causes of nutrient depletion are the removal of crop residues, leaching and soil erosion combined with low inputs of organic and mineral fertilisers (Jager et al., 1999).

Promotion of soil fertility management technologies

Farmyard manure and compost

When African farmers were resettled in the 1930s, they could no longer practice shifting cultivation and had to find new ways of replenishing depleted soil. The colonial government therefore promoted the production and use of *boma* (farmyard) manure in Machakos and a so-called 'chief's act', a type of bylaw, was introduced to promote its use. Since colonial times, the use of manure has steadily increased but widespread adoption only took off in the 1980s (Tiffen et al., 1994).

Promotion of compost production also started in the 1930s, but farmers stopped in the 1940s because producing *boma* manure, which included the incorporation of crop residues and bedding, was an easier alternative. In the 1960s, several NGOs reintroduced composting as a way of increasing the use of organic inputs and reducing the adverse effects of insufficiently decomposed *boma* manure and crop residues, which could 'burn' crops and cause problems with pests and diseases. Composting was also taught in schools as part of rural science and in the 1980s it received a new impetus due to NGOs working on the dissemination of Low External Input and Sustainable Agriculture (LEISA) practices (see Box 2). The Kenya Institute of Organic Farming (KIOF) is one of a group of NGOs that since the late 1980s have been promoting LEISA in Kenya. This is defined as managing the currently available agricultural resources in a way that satisfies changing human needs while maintaining the quality of the environment and conserving natural resources. These NGOs see composting and double-dug beds as key elements in the fight against declining soil fertility and for developing sustainable farming systems.

The promotion of compost and farmyard manure in Nyeri and Embu also dates back to the 1930s and the adoption pattern is similar to that in Machakos. Mineral and organic fertilisers have been used extensively in Nyeri and Embu over the last thirty years, particularly on cash crops. A recent survey indicates that 72% of farmers apply a combination of organic and inorganic inputs, while the rest use either one or the other. Compost was produced by 32% of the farmers interviewed (Woomer et al., 1998).

Box 2 Composting

According to extensionists, composting is done by first digging a pit 1.3 x 2.4 m wide and 0.3m deep, and filling it with layers of organic material, which are left to decompose. The materials are watered regularly and turned twice during the decomposition process. A pit this size can produce one tonne of organic fertiliser or compost. The recommendations of extension workers are geared towards an improvement of the product quality and a shortening of the time needed for decomposition.

Extension programmes have focused on composting in pits rather than in heaps. Farmers have tended to adapt this technique and dig shallow pits. They use additives such as wood ash, ground-up eggshells and various sources of biomass to improve the quality of compost and speed up the rate of decomposition. They also cover the heap with dry grass and topsoil to reduce gaseous losses. The compost is then incorporated into the soil at planting time, instead of applying it around the base of the plant as promoted by extensionists.

In 1996 a nation-wide survey was carried out to see what farmers thought about composting and other LEISA technologies (Hamilton, 1997)[4]. A total of 68% of the farmers interviewed were positive about pit composting, while 32% were generally negative about it, saying that digging the pits, collecting plant materials and then watering them made it too labour intensive for many individuals and that it was only practicable as a communal venture. The other constraints mentioned were the shortage of organic materials, insufficient cattle, lack of transport, limited water supplies (particularly in Machakos) and lack of information on how to produce large amounts of good quality compost.

Farmers who were more positive stressed the beneficial effects of compost on soils and yields. They noted that it improved soil characteristics such as water-holding capacity, structure and fertility, and buffered sinking pH levels. They concluded that in comparison with mineral fertilisers compost produces higher yields, better tasting vegetables and longer lasting effects on the soil, while containing no harmful chemical substances. As well as being cheaper than mineral fertilisers, they also observed that composted manure is better suited to dryland farming than poorly decomposed *boma* manure, as it carries less risk of 'burning' crops and fewer infestations of pests and diseases (Hamilton, 1997; Onduru et al., 1998).

Double dug beds

The idea behind double dug beds (DDBs) is to prepare the soil for cultivation, by breaking down the hard pan[5] and creating a deep layer of loose, fertile soil. This aerates the soil, improves water absorption and retention, allows plants to use available nutrients more efficiently and increases rooting depth. These beds can be used for intensive cultivation and will produce higher yields than shallow tillage. Extensionists recommend that a double dug bed be about 1.5 x 7m wide and 60 cm deep. The bed should be filled with about 6 wheelbarrows of compost and can be used for four consecutive cropping seasons before it has to be redug. Farmers have adapted this method in various ways, digging less deeply when the soil is rocky or when labour is scarce, changing the length of the beds, and adding a variety of organic materials.

Double dug beds have been promoted by NGOs since the late 1980s in all three study sites, where they are mainly used for cultivating high value cash crops such as vegetables. Their adoption and subsequent adaptation are closely linked to increased production of compost, which should be added when the double-dug beds are prepared. One survey found that 22% of farmers who had been trained in LEISA farming technologies, use double dug beds (Hamilton, 1997). Another survey on the adoption of LEISA practices found much higher adoption rates and reported that respectively 77% of participating farmers in HPAs and 56% in MPAs used double dug beds (Kariuki et al., 1994).

Hamilton (1997) found that 75% of the farmers interviewed were positive about double dug beds. They reported that breaking up the hard pan and loosening compacted soils improves

[4] The survey used group interviews and some questionnaires. The sample size is limited and does not permit statistical analysis. The entry point were NGOs and long established farmers' groups working with LEISA technologies.

[5] Hardpans in Machakos can result from ploughing or are an inherent feature of the soil, for example in Luvisols.

drainage and capacity to retain water, and that the shape of the beds makes them easy to water and harvest. They also said that they had fewer problems with weeds, higher yields and better quality produce (Hamilton, 1997; Onduru et al., 1998). Other farmers (25%) were more negative about double dug beds because they are labour intensive and require fairly large amounts of compost. Maize lodging is often a problem in the first season of DDBs due to the loose soil, but the beds are in fact mostly used for growing vegetables. Some farmers said that in the dry season they preferred sunken beds rather than raised as they retained more moisture.

Composting and DDB seem more widely used in higher than in medium potential areas. This may be because water is more easily available in HPAs and manure can be readily obtained from zero-grazing units. Tests, however, show that DDB and composting produce higher yields of maize, and better gross margins and returns to labour, in a medium potential area such as Machakos when compared to high potential Nyeri. This is probably because hard pans are more frequent in Machakos (see Box 4). Market outlets for vegetables are comparable in both sites.

Farmers of different economic status adopt these practices for a variety of reasons. Richer farmers are better able to use them because they have easy access to labour and manure, although they may decide not to since they can afford to buy mineral fertilisers instead. Poorer farmers practise these techniques because they cannot afford to buy mineral fertilisers, although some can not use them because they face tight labour constraints and need to concentrate on finding their next meal (Hamilton, 1997).

Box 3 Double dug beds compared to conventional tillage

On-farm trials in Machakos and Nyeri compared the effect of double dug beds with the conventional practice of shallow tillage. In Machakos, the double dug beds produced greater maize yields and net cash benefits than land that had been conventionally tilled. Maize yields after conventional tillage were 2,018 kg/ha, compared to 3,745 kg/ha from the double dug beds. However, in Nyeri maize yields and net returns were better with conventional tillage. Maize yields here were 8,331 kg/ha after conventional tillage and 6,707 kg/ha in the DDB.

The positive results in Machakos seem to be mainly due to the hard pan being broken up, allowing water to penetrate the soil and plants to take up available nutrients. Organic materials added to these beds also improve the soil's capacity to retain water. Although the double dug beds are more labour intensive than shallow tillage, they still gave farmers a better return on their labour in Machakos (Diop et al., 1997).

Effects of composting and double dug beds

To evaluate farming methods, farmers use various criteria, such as crop yield, labour and input requirements, colour and vigour of crops, incidence of infestation by pest and disease, the effect on soil characteristics and cash savings made on inputs. Researchers' parameters include the effects on yield, income, labour requirements, and the efficient use of nutrients

(Onduru et al., 1999). The most straightforward benefit of composting and double digging is that they facilitate a more efficient use of nutrients and produce higher yields than conventional methods with a similar input of nutrients. Composting and double dug beds seem to be most successful in areas where many nutrients are lost through leaching and erosion. A study on maize, comparing the impact of compost with a combination of *boma* manure and Di-Ammonium Phosphate (DAP), showed a yield increase of about 20% in MPAs when using compost. In HPA, however, the treatment with compost yielded 40% less (Diop et al., 1997; see also Box 4).

Box 4 Comparing compost with a combination of manure and DAP

Thirty-six farmers in Machakos and Nyeri conducted a trial to compare how maize responded to applications of compost and a combination of *boma* manure+DAP. Both treatments were applied at the rates normally used in LEISA farming systems. They compared the use of 16.2t per ha compost with 17t per ha *boma* manure+57 kg per ha DAP. The second combination contains more N, P and K.

In Machakos the compost performed much better than the combination of *boma* manure+DAP, giving a higher maize yield, greater net cash benefits and a better net return on labour. The maize yielded 2,018 kg/ha with the combination of *boma* manure+DAP, and 2,449 kg/ha when treated with compost. However, the results in Nyeri showed the converse with the combination of *boma* manure+DAP performing better than compost. The maize here yielded 6,331 kg/ha with *boma* manure+DAP, and 5,071 kg/ha with compost (Diop et al., 1997).

These results could be due to differences in soil and climatic conditions in the two areas. Soils in Machakos have a poor structure and a hard pan, and rainfall is more limited than in Nyeri. It seems that compost is better suited to these adverse conditions than the combination of *boma* manure+DAP, and that it may have enabled plants to use nutrients more efficiently and reduced losses caused by erosion and leaching. As the soil and climatic conditions are more favourable in Nyeri, crops can use the higher nutrient content of the *boma* manure+DAP mixture more efficiently than in Machakos.

In a subsequent study in Machakos, liquid manure[5] was tested as an input for maize. It was tried in combination with compost and compared with single and double doses of compost on its own. Yields and net cash benefits were highest for the combination of compost with liquid manure, although the return to labour for this method was the lowest of the three treatments tested (Onduru et al., 1999). This study showed that the combination of compost with a readily available source of nitrogen might be effective in increasing agronomic and economic performance.

Nutrient balances for different crops and farms

One year measurements in Machakos and Embu reveal that full nutrient balances at farm level are negative for nitrogen (respectively -53 and -55 kg N/ha/yr) and to a lesser extent for potassium (respectively -10 and -15 kg K/ha/yr). The phosphorus balance seems to be neutral to positive (Bosch et al., 1998; Jager et al., 1998b; Jager et al., 1999).

There are significant variations in nutrient balances between crops and individual farms. A study in Embu found that considerable amounts of mineral nutrients are applied to high

[5] Liquid manure is prepared by mixing fresh animal droppings with water. It has a high N-content, and is applied to soil near the plant roots when the crop is knee high.

earning cash crops, such as tea and coffee, as these crops give the best economic return for money spent on fertilisers (Jager et al., 1998b), and as a result nutrient balances are neutral to positive (Table 3). Very few inputs are applied to fields of staples, such as maize and beans, where the negative nutrient balance results in declining soil fertility and serious infestation by pests and diseases. Contributing factors include the removal of all crop residues from the fields for sale by 14% of farmers, limited access to markets and inputs (64%) and shortage of labour by 98% (Jager et al., 1998b).

Farmers in Nyeri and Embu consider napier grass to be a high value crop as they use it as fodder for milk production. They apply fairly large quantities of manure to land under napier grass but it still has a significant negative balance because so many nutrients are lost when biomass is removed from the field, while the manure produced with the fodder is applied to other areas of land. The most seriously depleted nutrient in all fields is nitrogen, which is lost in large quantities through leaching, volatilisation and erosion (Bosch et al., 1998).

A wealth ranking exercise was carried out by farmers in Embu, basing their judgements on the amount of land held by each farmer, the number of tea/coffee bushes cultivated, the system for rearing livestock, diet, level of food security, quality of housing, size of family and potential to educate their children (see Defoer et al., 1998 for more details on the method used). Farm level nutrient balances were calculated for individual farmers in Embu and comparisons were then made between farmers of different economic status.

Table 3 Nutrient balances and economic results for various crops (N = 15)

	Embu District				Machakos lowlands
	Tea	Coffee	Napier	Maize	Maize
Inputs					
Mineral fertilisers DAP (Kg/ha)	200	50	0	19.5	3
Manure (t/ha)	0	5	8	0.5	4
Outputs					
Yield (Kg/ha)	3,298	2,867	35,020	1,808	312
Nutrient balance					
N (Kg/ha)	-14	-1	-121	-44	-34
P (Kg/ha)	+30	+20	0	+8	-2
K (Kg/ha)	+13	+50	-126	-15	-13
Economic results					
Variable costs (Ksh/ha)	15,361	16,588	14,389	3,586	6,450
Returns (Ksh/ha)	34,002	74,587	35,485	13,014	26,000
Gross margins (Ksh/ha)	25,836	61,287	23,946	9,428	19,600

Source: Jager et al., 1999.

Table 4 Nutrient balance for tea/coffee/dairy landuse system in Embu (N= 15)

Nutrient (Kg/ha)	Economic status		
	Better-off	Average	Poor
Nitrogen	-16	-40	-53
Phosphorus	48	25	19
Potassium	6	5	4

Source: Jager et al., 1998b.

The nitrogen balance at farm level was consistently negative, and worsened with increasing levels of farmers' poverty (Table 4). Phosphorus balances were positive for all but again declined with a decrease in farmers' economic status. There did not seem to be any such difference in potassium levels between classes, probably because the most commonly used fertiliser (di-ammonium phosphate) hardly contains any potassium. Wealthier farmers have better access to external inputs and use more mineral fertiliser than their poorer counterparts, who cannot afford them. Poorer farmers tend to use organic fertilisers instead, although many of these have a low nutrient content.

Farmers manage their cattle according to their means. Poorer farmers let their animals graze on communal lands and along the roadside, and some nutrients may return to the farm although much of the dung will remain on communal lands. Richer farmers stall-feed their cattle in zero-grazing units, which facilitates the collection and storage of manure and ensures that the manure remains on the farm. Stall feeding also enables farmers to supply the animals with better quality material so that their manure contains more nutrients.

Conclusions

This chapter focussed on composting and double dug beds as technologies that could improve soil fertility management and the sustainability of farming systems. Their impact is site-specific. Double dug beds and composting both seem to be more effective in MPAs than in HPAs. NGOs and farmers should take note of this and consider carefully where the two technologies may be most effectively implemented.

Whether or not farmers produce compost depends to a large extent on their resources. These not only include labour, capital and transport, but also the availability of good quality materials for composting, and enough water to stimulate decomposition. This is obviously an important factor in arid and semi-arid areas.

More research needs to be done into the quality of the compost and other organic fertilisers produced by farmers and to establish the nutrient fertiliser equivalent of organic inputs (Palm et al., 1997). This will help understand how best to combine different types of organic and inorganic fertilisers. NGOs assumed, for example, that compost contained more nutrients than *boma* manure but this was not always the case (Onduru et al., 1999).

Our research showed that composting and DDBs can improve grain and vegetable yields and thereby contribute to improving food security. Farmers can also earn extra income from selling vegetables, although a continuous increase in production could flood the market and cause prices to drop. The continued use of these technologies will partly depend on the stability of markets and prices, so work could usefully be done on diversification into a broader range of crops developing agro-processing technologies, adding value through direct marketing to consumers and organising marketing cooperatives.

Composting and DDB have the potential to contribute to more sustainable farming systems by facilitating more efficent use of nutrients and reducing nutrient losses. However, they will not be sufficient to stop nutrient mining completely, since most farmers do not have enough compost or other organic inputs to fertilise all their fields. These two technologies mainly redistribute nutrients, concentrating them in some areas at the expense of others. As so many nutrients are lost through the sale of crop and livestock products the only way to achieve a zero balance is to apply external inputs such as mineral fertilisers or to grow nitrogen-fixing crops. Efforts are needed, not only to make the most efficient use of existing resources, but also to find ways of making external nutrient inputs available, particularly for poorer farmers.

Some NGOs have focussed on one or two technologies without considering the possibility of combining them with others. However, experiments have shown that a combination of compost and a top dressing of liquid manure can increase crop yields and net cash income. NGOs should therefore foster a participatory approach that stimulates joint efforts to make better use of existing resources and skills. Work has been done in Machakos and Nyeri to build partnerships between government, NGOs, the private sector and community groups, who are now collaborating on the development of technologies and monitoring soil fertility management (Onduru et al., 1998; Jager et al., 1999). It is also important that farmers receive continued support in implementing technologies promoted by the extension services and other organisations, and that these should be considered in relation to other community needs such as the provision of water.

The wide variations in nutrient balances and economic returns observed between farms and crops demonstrate how soil fertility management is affected by socio-economic factors. This should be taken into account when developing strategies to promote technologies for sustaining or improving soil fertility. The 'best' solution for any farmer will depend on his or her situation and available resources, so any new strategies for soil fertility management must not be only technically feasible but also have the flexibility to fit in with farmers' circumstances.

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Nutrients on the move

The last decade has witnessed rising concern over the extent to which soils in Africa are becoming degraded and the threat that this poses to agricultural production, livelihoods and the environment. However, while studies of soil fertility at national level present negative nutrient balances, the picture is more varied at field and farm level where households have developed a wide range of management strategies. Measures to support better soil husbandry need to consider what is actually happening at farm and field level, how the management of soil fertility varies between different fields, farmers and locations, and the implications of this diversity for design of interventions aimed at improving the management of soil fertility.

This book presents a series of case studies on soil fertility management strategies from six African countries: Burkina Faso, Ethiopia, Kenya, Mali, Uganda and Zimbabwe. This research was carried out in the context of the project *Improving Soil Fertility in Africa: Nutrient Networks & Stakeholder Perceptions*, also known as NUTNET, which is a network of several African NGOs, universities and national agricultural research centres, and their counterparts in the UK and the Netherlands.

The case studies provide details of the wide range of soil fertility management practices currently implemented by small-scale farmers in Africa. They underline the importance of niche management, where certain fields are deliberately nurtured at the expense of others. They also illustrate the dynamics of soil fertility management and analyse the factors affecting incentives to maintain and replenish soil nutrients at farm level. Consideration is given to how certain socio-economic and institutional conditions may either facilitate or hinder good practice, and to the requirements needed to increase the effectiveness of policies and interventions to support farmers. The studies show that single monolithic policy approaches are seldom the best response to the diverse and often site-specific problems and opportunities faced by farming households.

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