1 Introduction and background

Perceptions of soil fertility decline in Ethiopia

Agriculture is the mainstay of the Ethiopian economy, but production has been stagnating for the last 20 years. Erratic rainfall and drought have affected production in certain years but their influence on production trends is limited. Emerging constraints on agricultural production in Ethiopia include land degradation, soil erosion and decline in soil fertility. Many studies report soil fertility decline for all regions of Ethiopia, and some even suggest that a national disaster is looming on the horizon (Barber, 1984; FAO, 1986; Hurni, 1988; Campbell, 1991; Bojo and Cassels, 1995). It is now generally accepted that there is a decline in the fertility of agricultural soils throughout the country, due to reduction in the length of fallow periods, lower levels of fertiliser application, complete removal of crop residues from fields, use of dung as a household fuel, and lack of adequate soil conservation practices (Bojo and Cassels, 1995).

However, all these reports discuss soil fertility decline at a national scale, while analysis of farmers' soil management practices is mostly lacking. Ethiopia is a large country with a wide diversity of socio-economic and agro-climatic conditions and farming systems. How reliable is this generalised analysis of soil fertility decline? What is the picture at local level? This study analysed the local level via a detailed case study of farmers' soil fertility management practices in the Kindo Koisha district in South West Ethiopia.

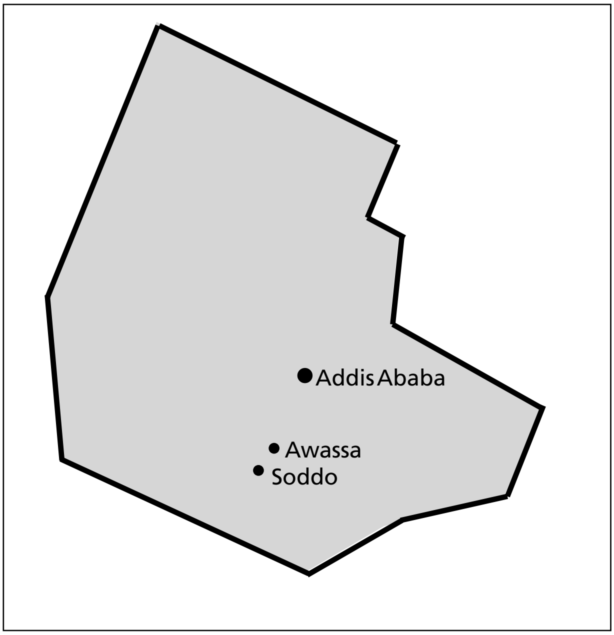
Location, climate and soils

A series of Rapid Rural Appraisal surveys carried out in Wolaita have indicated that agriculture has not progressed over the last 15 years and yields of major crops have dropped significantly. Despite its greenness it is one of the major food deficit and famine prone areas in the country. Since the 1984/85 drought the people have suffered regular food deficits, entailing costly famine-relief operations. Wolaita has therefore been called 'the land of green famine' (FARM-Africa, 1992).

Location

The Kindo Koisha district of Wolaita is located some 450 km to the south of Addis Ababa in the North Omo region of South West Ethiopia (see figure 1). The altitude ranges from 1300 to 2100 meters. The topography is characterised by an undulating plateau marked by a series of v-shaped valleys that accommodate only seasonal and intermittent streams. Very steep slopes (greater than 30%) are common along the valley side (Weigel, 1986; Belay, 1992; Gunten, 1993).

Figure1: Map of Ethiopia



The semi-humid to humid zone, with an altitude ranging from 1800 to 2400 meters, is agriculturally the most important zone in Wolaita. This zone is densely populated and accounts for more than 85% of the total human and livestock population, and over 90% of the total crop production of Wolaita (WADU, 1976). The lowlands have poorer soils and receive less rainfall. Agriculture in these areas started in the 1970s through government settlement programmes that intended to alleviate the problem of land shortage in the highlands. Lowland farmers are more vulnerable because of lower crop yields and a higher occurrence of human diseases (malaria) and livestock disease (trypanosomiasis).

The overall population densities of the district are 375 and 110 people per km^2 in the highland and lowland zones respectively. Densities as high as 520 persons per km^2 have been recorded in some sub-areas in the highlands (Weigel, 1986). Population growth rate in the district is estimated at 4.8 per cent per year. This makes the Kindo Koisha District one of the most densely populated parts of Ethiopia[1]. Dispersed homesteads is the main settlement pattern.

Climate

The average annual rainfall for the area is 1272 and 924 mm/year in the highland and lowland zones respectively. The rainfall pattern is bi-modal. The short rains (*Belg* season) fall from March to May while the big rains (*Kremt* or *Meher* season) fall between June and October. In recent years the area has experienced great variability in the occurrence and volume of rainfall, causing crop failure.

Soils

The dominant soils are Eutric Nitosols, which cover about two-thirds of the area. These soils have a preponderance of kaolinitic minerals and are inherently very low in nutrient and organic colloids, especially in the lowlands. The level of potassium is however generally high. They require inorganic and organic fertilisers to produce attractive yields (WADU, 1976). The soils are also characterised by very deep weathering and intense leaching. They have good physical properties for rooting, are well-drained with a high water holding capacity, and have a homogenous and well developed structure. They are silty clay in texture (Weigel, 1986).

Soil erosion

The estimated average net soil loss rate in Wolaita is 75 mt/ha/year on cultivated fields (Belay Tegene, 1992). Nutrients in the Eutric Nitosols are concentrated in the top 20 cm while the sub-soil is very poor in nutrients. The impact of erosion on soil fertility is therefore severe (Weigel, 1986). Conservation measures, such as soil bunding, tied ridges and terracing, which are common in other parts of Ethiopia, have not been widely adopted in Kindo Koisha. Physical structures are unattractive to farmers because

[1] The national average population density is 84 persons per square km and population growth is 3.0%.

it makes ploughing with oxen difficult, and the large portion of land taken out of production (FARM Africa, 1992). Also, farmers claim that rodents make their nests in the bunds, attack field crops and are difficult to control.

The farming system

Land use

Farming systems of Kindo Koisha are based on mixed crop and livestock production. In the 1980s, 72% of the area was arable land, 15% covered by bush, grassland and woodlot, and 13% comprised houses and front yards (Weigel, 1986). The houses are surrounded by enset and coffee gardens, inter-cropped with some banana, ginger, pepper, taro root and sometimes even maize. Most households in the highlands depend heavily on this intensively manured garden system for their livelihood. Lack of manure, however, is a major constraint for its productivity.

Cropping pattern

Major crops of the area are enset (*Ensete ventricosa* or *Musa ensete*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), sweet potato (*Ipomoea batatas*), Wolaita potato (*Coleus edulis*), teff (*Eragrostis Tef*), taro root (*Colocasia esculenta*), yam (*Dioscorea sp*), Irish potato (*Solanum tuberosum*), haricot bean (*Phaseolus vulgaris*), barley (*Hordium vulgarae*), and, to a limited extent, wheat (*Triticum aestivum*). Staples are enset, maize and root crops. Enset is cultivated mostly in the highlands and provides food for about ten million people in the southern region of Ethiopia. Enset is a drought resistant, semi-perennial that takes four to seven years to mature. It requires a continuous application of manure. The cultivation of enset has given rise to an intensive production system involving year round cultivation of the land, and greater integration between livestock and crop production systems (Jenden, 1994).

Maize is the major cereal. Early maturing maize varieties are planted on the homestead fields to provide food during the hungry season. Many farmers also grow maize and teff as cash crops. Sorghum is becoming more important in the lowlands because it performs well in poor soils and is more drought resistant than maize. Haricot bean is the only legume crop that is cultivated, particularly in the lowlands. Cassava (*Manihot esculenta*) has recently been introduced and is becoming an important food security crop.

Farmers practice double cropping, inter-cropping, relay cropping, rotation etc., taking advantage of the bi-modal pattern of the rains. Fields are cultivated throughout the year as crop production continues from one season to the next. Hoes are used to cultivate gardens and rocky soils on steep slopes. Other fields are cultivated with a wooden plough, which has an iron point that does not turn over the soil and is drawn by two oxen. Land is ploughed 3-5 times to loosen the soil before planting.

There is an overlap of operations during peak seasons. For example, land preparation for *kremt* crops such as teff and sweet potato coincides with weeding and harvesting of *belg* crops, often causing labour shortages. However, timely preparation of the seed bed and early planting is critical to establish the crop while sufficient moisture is still available. Farmers therefore use a variety of co-operative and traditional labour exchange schemes, in addition to the mobilisation of family labour (see Data, 1998).

Livestock

Livestock are important assets for farmers in Kindo Koisha. Livestock provide traction (oxen), manure, milk and meat products, a source of ready cash to meet emergencies, and fuel when manure is burned. Prosperity and public esteem are gained by owning land and livestock. Cattle are the major animals in the household herd. However, the household herd size has declined since the 1984 drought. Some 15 years ago, farmers used to keep on average 7-8 head of cattle. At present, farmers have on average 2-3 animals per household. It should be noted that 60% of the households in the study area did not own any oxen (FARM Africa, 1992). Over 40% of the interviewees in our sample have no oxen, owned or held, and 55% owned or held one or two oxen (Table 1).

Table 1. Number of livestock (TLUs)[2] held by households of different resource groups in Kindo Koisha

Resource group/zone	Highlands	Lowlands
RG1	7.4	7.2
RG2	3.5	3.7
RG3	1.5	2.5
RG4	0.5	0.8
MEAN	2.0	2.7

Causes of the fall in cattle numbers are the shortage of feed due to drought, conversion of grazing land into farm land, losses due to disease, and forced sale of livestock to pay taxes or fertiliser debts. Feeding livestock has become hard work in highland Wolaita, since few open pastures are left. Tethered feeding in the front yard and the establishment of small private grazing plots at the edge of the farm are now common. Crop residues also constitute a major supply of feed for animals (FARM Africa, 1992).

Lack of draught oxen is one of the major constraints for crop production. Most 'oxen poor' households gain access to animal traction through oxen renting systems. A farmer pays 6-8 labour days for one ox work day. Animal loan systems are also occasionally

[2] Tropical Livestock Unit (TLU) have been calculated as follows: 1 adult cattle or equine = 0.7 TLU; 1 goat or sheep = 0.1 TLU; 1 calf = 0.4 TLU (Jahnke, 1982).

used. A farmer who has one ox can also team up with another farmer in a similar situation. There are more farmers with no access to livestock in the lowlands than in the highlands, because they cannot afford the veterinary medicine. This deters livestock rich farmers from entrusting their animals to them on loan. Those who do not own oxen can also switch to share cropping arrangements if they own a plot of agricultural land.

2 Objectives and methods of the study

Methods and design of the study

Various methods have been used for data collection, such as informal group discussions, farm surveys, resource flow diagrams drawn by case study farmers, and monitoring of nutrient inputs and outputs. The informal interview sessions with farmers took place at village level, using several Participatory Rural Appraisal (PRA) techniques. Discussion topics were the agricultural history of the area and changes in crop yields, soil fertility management, cropping patterns and livestock husbandry. Special attention was given to the driving forces that brought about changes in these practices. A participatory wealth ranking exercise was employed (Grandin, 1988) to stratify farmers into different socio-economic categories. Major local indicators of wealth are draught oxen ownership, herd size and the size of land holdings. The resource groups identified were: 'richer' farmers (RG1), medium farmers (RG2), poor farmers (RG3) and very poor farmers (RG4). A stratified sample of 100 households was then randomly drawn for the farm survey. The questionnaire focused on current soil fertility management practices, the socio-economic variables affecting soil fertility management, and perceptions of change in crop yields and levels of soil fertility.

Thereafter, eight case study farms were selected. They represented each of the four resource groups in both the highlands and the lowlands. Resource flow diagrams were drawn by case study farmers in which they depicted the various field types, sources of nutrients, and the pattern of nutrient flows within their farms. This was followed by a year-long monitoring of soil fertility management practices and nutrient input and output processes (with emphasis on N and P) for the enset garden, '*darkua*'[3] maize field and '*shoka*'[4] maize fields. The data generated were then used to calculate partial nutrient budgets. Composite samples of fresh manure from livestock pens and leaf litter from widely used trees were collected and analysed for composition of N and P and moisture

[3] Darkua is situated near the homestead and refers to all organically fertilised fields.
[4] Shoka fields are situated at a greater distance from the homestead. They receive almost no organic fertiliser but mineral fertiliser may be applied. Some fields are cultivated with no fertility input at all.

content (see annex 1). Sub-samples of harvested products and residues of maize, enset, teff and haricot bean were taken for determination of nutrient composition (see annex 2).

Characteristics of the farm components

The size of the various farm components per resource group is presented in Table 2.

Table 2. Area (ha) per farm component for the case study farms

	Highlands				Lowlands			
Resource group	Total farm size*	*Enset garden*	*Darkua maize*	*Shoka maize*	Total farm size*	*Darkua maize*	*Shoka maize*	*Shoka other***
RG1	1.22	0.20	0.30	0.40	3.0	0.50	1.0	1.4
RG2	1.05	0.20	0.20	0.50	2.65	0.50	1.0	0.9
RG3	0.7	0.10	0.20	0.20	2.28	0.40	0.75	1.0
RG4	0.22	0.04	0.10	0.04	0.53	0.10	0.10	0.2

*Total farm size does not add up because other components such as the taro fields are not included in the Table
**Other crops grown are teff, haricot bean, sweet potato and sorghum

There is considerable variation in total farm size and the size of the components across socio-economic groups. Total farm size varies from 0.2 to 1.2 hectares in the highlands and from 0.5 to 3.0 ha in the lowlands. Richer farmers have bigger areas under all of the components compared to poorer farmers in both zones. They also have a relatively large proportion of the total cultivated area under the *shoka* system, while still maintaining a considerable area as enset garden and *darkua* fields. The *shoka* proportion is lowest for the poorer farmers.

The chemical characterisation of farm components of the eight farms studied is provided in Table 3.

Table 3. Chemical characterisation of the farm components

	Highland Farm Components			Lowland Farm Components	
Parameter Tested	*Enset Garden*	*Darkua Maize*	*Shoka Maize*	*Darkua Maize*	*Shoka Maize*
Total N (%)	0.19-0.37	0.25-0.34	0.17-0.24	0.10-0.14	0.10
Av.P (ppm)	22-69	7-67	3-7	6-7	4-5
Org. Matt (%)	6.0-7.7	5.4-5.9	4.3-5.8	2.8-3.3	2.5-2.8
pH	6.6-7.5	6.0-7.4	5.2-6.4	6.6-7.5	6.2-6.8
CEC	29-34	26-32	25-29	17-19	16-20

Soil test results reveal that most of the fields receiving applications of manure (i.e. the enset-garden and *darkua*) had higher levels of nitrogen, phosphorus, organic matter and CEC relative to the *shoka* (Table 3). The very high levels of available phosphorus in the enset garden are perhaps due to reduced P-fixation as a result of manuring. Many *shoka* fields have received DAP application since the early 1970s. The rather low pH of the *shoka* soil in the highlands suggests the possibility of an acidifying effect of continued DAP use.

3 Constraints on farm production and the role of soil fertility

Yield trends

Farmers recognise three periods when referring to yield trends: before the Wolaita Agricultural Development Unit (WADU) period (pre-1972), during the WADU period (1971-1980), and the present. Farmers' estimates of yields for the above periods for the highland and lowland agro-ecologies, as well as recorded data from other sources, are presented in Table 4.

Table 4. Farmers' estimates of change in crop yields (kg/ha) over time in relation to recorded data and the national average

Period	*Crop*	**Highlands** *Farmers' Estimate*	*Recorded Data*	**Lowlands** *Farmers' Estimate*	*Recorded Data*	*National Average*
Pre-WADU (1960s-1971)	Maize	676	1000	638	800	1200
	Teff	414	600	461	400	800
	Barley	504	700	NA*	NA	1000
WADU (1972-1980)	Maize	1256	2400	1510	2200	1400
	Teff	898	1000	820	700	900
	Barley	756	1200	NA	NA	1200
Post-WADU (1981-present)	Maize	435	1200	380	900	1600
	Teff	270	500	212	300	800
	Barley	272	400	NA	NA	1100

*Barley is not cultivated in the lowlands
Source: WADU publications (1972-1980) and the Soil Conservation Research Project for the period 1981-1993. Both data sets were collected in the same village, using the same method

Pre-WADU period

Both farmers' estimates and time series data indicate that cereal yields were generally low in Kindo Koisha during the pre-WADU project period (Table 4). According to farmers this was due to declining soil fertility. Farmers grew crops by applying organic inputs on homestead fields and used fallow periods on the distant fields. However, land was becoming scarcer due to rapid population growth and fallow periods became too short to restore soil fertility. Moreover, herd sizes decreased as less land remained available for grazing, diminishing the availability of animal manure. Fertiliser was not yet known in the area.

WADU period

WADU launched an extension and credit service for farmers in the early 1970s, demonstrating and popularising the use of fertilisers, pesticides and improved seeds with the aim of boosting productivity through increased input use. WADU regularly supplied farmers with inputs on a credit basis and also provided transport and marketing facilities. Extension services were particularly targeted to the settlement areas in the lowlands. According to farmers, maize and teff yields in both agro-ecological zones doubled during the WADU period. The recorded data showed higher levels of yield increase, particularly in the lowlands where crop production was even above the national average. Farmers explain the yield improvement during the WADU time as the result of increased use of chemical fertiliser and better access to draught oxen. They think that the use of improved seeds or changing agronomic practices was less important.

Post-WADU period

The phasing-out of the WADU in 1980 had a negative effect on agricultural production and crop yields. Following the phasing out of WADU's programme in the early 1980s, subsidies on fertilisers ended in Wolaita[5] and fertiliser prices have increased by over 150%. At present, most farmers do not have the means to buy fertilisers regularly, while lending conditions for institutionalised credit have become stricter. During the WADU period, the area cultivated with improved maize varieties had expanded. However, these varieties suffer without adequate supply of fertility inputs, which partly explains yield decline during the post-WADU period. Farmers are once again reliant on the intensive use of organic manuring, but there is not enough available to fertilise *shoka*-outfields. Crop failures have become common, causing serious food shortages and famine in the area (see Eyasu, 1997).

Farmers estimate that current yields in the *shoka* fields are falling below even the pre-WADU levels. This is not confirmed by the recorded data, which indicate a decline for both agro-ecological zones just after the phasing out of WADU. At present, crop yields remain stable and are above the pre-WADU level. However, it should be noted that these recorded data must be treated with some caution as they were taken from anywhere in farmers' fields without considering variability in soil fertility between *darkua* and *shoka* fields (Eyasu, 1997).

[5] There is government subsidy on fertilisers for the high potential cereal regions such as the central highlands of Ethiopia but not in Wolaita.

Farmers' prioritisation of production constraints

The major constraints identified by farmers in the household surveys are indicated in Table 5 below.

Table 5. Farmers' perceived crop production constraints and their priority rankings in the highland and lowland zones, Kindo Koisha, 1995

Constraint	Priority in highlands (n=50)				Priority in lowlands (n=50)			
	1st	*2nd*	*3rd*	*Minor*	*1st*	*2nd*	*3rd*	*Minor*
Oxen shortage	30	8	7	5	41	3	6	0
Soil fertility	13	21	16	0	4	29	17	0
Erratic rainfall	5	14	23	8	5	18	27	0
Land shortage	16	1	11	22	0	0	0	10
Labour shortage	0	0	0	13	0	0	0	50
Soil erosion	0	0	0	13	0	0	0	0
Crop pests	0	0	0	2	0	0	0	50
Planting material	0	0	0	12	0	0	0	33

The table shows that most farmers listed lack of draught oxen, low soil fertility and erratic rainfall as the three most important constraints to production.

Lack of draught oxen

Shortage of oxen was the first priority problem for farmers in both zones. The farming system is centred on access to or ownership of oxen, or in the words of the lowland farmer Ato Eyasu Munae *"The heavenly God is the God of our soul, but oxen are gods of our earthly life"*. Access to animal traction permits early planting, timely and intensive incorporation of organic residues and animal manure, and better weed control. Access to animal traction also increases the area available for cultivation, through share cropping arrangements. Most of the poorer households in the lowlands cultivate less than half of the land they own, mainly due to lack of draught oxen (see also part 1, section on livestock).

Declining soil fertility

Farmers ranked declining soil fertility as the second most important problem. They perceive their soil as 'sick'. Farmers said that it is not possible to grow a maize or teff crop in Wolaita without adding fertility inputs, even in climatically good years.

Erratic rainfall

The majority of farmers interviewed ranked erratic rainfall as the third most important production constraint. Particularly in the lowlands, farmers feel increasing uncertain about the start of the rains and the length of the rainy season. Moisture is needed for

decomposition of organic manure and residues, and for efficient use of mineral fertiliser. One farmer stated: "*Fertiliser without moisture from the rain is no better than putting a stone or sand in the field. Non-manured or non-fertilised crops are only good as fodder regardless of the rainfall" (*Beyene Anebo, from Dogeshakisho PA).
However, the effect of rainfall on yields should not be overestimated. Kindo Koisha normally receives adequate rainfall, particularly the highlands, where nutrient supply seems more limiting than moisture. In the lowlands, however, both nutrients and moisture supply are limiting factors (Eyasu, 1997).

Farmers' perceptions of changes in soil fertility

The two key words describing soil fertility in the local language are *arada* (fertile) and *lada* (infertile). Farmers characterise *arada* soil as dark, rich, thick and 'powerful', and *lada* soil as red, poor, thin and 'powerless'. Farmers repeatedly stated that soil fertility declined over the last 15 years, particularly in the *shoka* fields. In their opinion, soils have become 'lada' and addicted to fertiliser, needing more of it than in the past. This may suggest that the soil quality is declining. Soil acidification may have become a problem due to the continuous use of DAP over the last 25 years. Acidified soils absorb large quantities of phosphate-fertiliser, reducing yield response. Larger doses of fertiliser are then required to satisfy plant requirements, thus creating the perception of soils becoming addicted to fertiliser.

Farmers' indicators of soil fertility change

Farmers' notions of change in soil fertility are based on observing changes in the physical state of the soil, in weed vegetation, stunted growth and colour change of crops, and low crop yields in climatically good years.

Change in soil colour and weight

Soil colour is an important criterion. Black soils are considered fertile and productive, while red or light soils are viewed as infertile. Farmers complain that their soil has become 'bleached', dust-like and hard to work. Water enters the soil with difficulty as the level of fertility declines. In the past the surface soil was dark and water entered easily but now the surface soil has become red. This may suggest changes in the organic matter content, and the deterioration of physical structure such as the water holding capacity.

Change in weed population and species

Farmers observed a fundamental change in weed flora over the last 15 years. In the 1970s, when the soil was fertile, dominant weed species in the fields were *maga matta*

(*Urochloa panicoides*) and *dalasha* (*Commelina benghalensis*). These weeds are indicators of high levels of soil fertility and also enrich the soil as they supply easily decomposable biomass once pulled out. They are still found in some enriched niches, including enset gardens and *darkua* maize areas which are highly fertile. When soil fertility declined, these species disappeared from the *shoka* fields and other farm areas. These fields are now invaded with *girolea* (*Phalaris eragrostis spp*), notably in the lowlands, and *bisdia* (*Galinsoga parviflora*), *petta* (unidentified species), *lichea* (*Digitaria spp*) and *woche* (unidentified species).

Reduced growth and colour change of crops

Crops grown on good soil will grow fast and are dark green. Those cultivated on a poor soil grow slowly and do not mature on time, show stunted growth and become pale green, yellow or purple-red. Some of these indicators are similar to nutrient deficiency symptoms used in scientific literature. These deficiency symptoms have strong management implications for farmers. Responses are careful timing and targeted application of fertiliser and manure.

Low crop yields in climatically good years

Low yields in a year with a good seasonal distribution and adequate annual volume of rainfall is another important indicator for farmers. However, low crop yields are not perfect indicators of soil fertility decline since these can also be caused by a range of other socio-economic factors, such as a scarcity of draught oxen. Moreover, soil fertility decline (or nutrient depletion) is a slow process that can take place even without noticeable reduction in yields in the shorter term (Smaling, 1993). For example, it has been found that land degradation due to erosion and loss of organic matter has been extensive throughout Ethiopia, but yields have remained more or less uniform, albeit low (FAO, 1986).

Factors causing soil fertility decline

Farmers identified various factors that are causing a decline in soil fertility in their farms (especially on the *shoka* fields).

Decline in manure application

Most Kindo Koisha farmers rely on organic inputs (animal dung, house refuse and sweepings of organic materials) for their soil fertility maintenance. However, the level of manure produced at present is very low compared to the past. Fifteen years ago, an average household in the highlands used to transport 10-15 tonnes of manure per year to the field. The present amount is only 3-5 tonnes per year. The same trend is observed in the lowlands. Reasons given are a decline in herd size (see also section on livestock, part 1). Richer farmers still hold relatively large numbers of livestock and hence have larger amounts of manure to fertilise the soil than resource-poor farmers in both zones. Soil fertility maintenance is thus affected by the wealth status of the household.

The beneficiary crops in the highlands are enset and coffee, the *darkua* maize field, and root and crop fields (sweet potato, taro root and Wolaita potato). The pattern is almost the same in the lowlands, except that they do not grow enset. There, manure is mainly directed to the taro root, and *darkua* maize fields, with some application on infertile patches in more distant fields.

All farmers use bedding materials (straw and crop residue) in the livestock pen and collect the manure. Some farmers also collect dried dung from grazing areas to be used as fuel in the dry season. There is no manure exchange system among households. Farm manure is highly appreciated and a scarce resource which no one is willing to give to his neighbour. When asked if she had ever received manure from relatives, a woman from Doge Shakisho PA responded, *"Would you give someone your life?".* The majority of richer farmers indicated that they would rather give out a calf on a loan basis than a basket of dung to a relative. No farmer reported storage of manure. Currently, manure amounts are so small that it is removed from livestock pens once or twice a week and applied right away to the field.

Manure is transported to different fields largely by women and children using bamboo-made baskets smeared with dung. Men identify the infertile patches for spot application. Even though the task is arduous, poorer farmers rarely weigh the labour costs of manuring. However, a few richer farmers complained about lack of transport equipment to transfer manure to distant fields.

Decline in fertiliser application

The practice of mineral fertilisation was first introduced by WADU in the 1970s and maize became the priority crop. Fertiliser application rates are declining. The average rates applied by households at present and 15 years ago are 43 and 133 kg/ha, respectively (Eyasu, 1997).

The richer farmers in the highlands used the largest quantities per hectare because lowland soils are more sensitive to erratic rainfall. Resource-poor farmers find fertiliser expensive but they still purchase small quantities from local traders and apply it carefully to individual plants. The application of fertiliser right at planting indicates a poor synchronisation with the crop requirements which may result in soil acidification. Fertiliser supply comes under the auspices of the Ministry of Agriculture (MOA) and is distributed via the local Service Co-operatives (SC). However, supply is inadequate and not timely, giving rise to black market retail trading of fertilisers. Many farmers stated that late arrival was a reason for their withdrawal from fertiliser use.

The official price of fertiliser has soared over the last 20 years in Wolaita from 36 birr/q in 1974 to 180 birr/q in 1994, and 'black market' fertiliser is often sold at even higher prices. In the 1970s credit from WADU enabled poor farmers to purchase fertiliser. At present over 30% of the farmers mentioned limited access to credit. A sizeable number of farmers stated that they are not eligible for MOA credit due to lack of oxen ownership and their land holdings being too small. The SC enforce debt payments stringently and there are various forms of penalties for farmers who fail to pay their debts. They also become ineligible for future credit unless they clear previous debt. Farmers who have accumulated debts over several years may be put in jail or their cattle may be sequestered. In the 1994 season, 52% of farmers who received fertiliser from MOA on credit defaulted on their repayments. Some sold part of the iron sheet roofing of their house in order to escape the penalties.

Excessive drying of the soil

According to 55% of the farmers interviewed, severe drying of the soil contributes to a decline in soil fertility. They complain that well-cultivated land is exposed to wind erosion in the dry season, which selectively removes fine and fertile particles of the soil. Furthermore, beetles form tunnels inside the dung applied to bare ground in the dry season, and transport the dung below the rooting zone of crops, thus reducing the nutrient contribution of manure.

Continuous cropping

In the highlands land shortage is a serious problem and farmers almost invariably practice continuous cultivation of the land. Double cropping of teff or sweet potato after maize in the *meher* season is widely practised, even though farmers realise that it exhausts the soil. Intensive cultivation has also meant a continuous succession of cereals and root crops leading to nutrient depletion and decline in organic matter.

Erosion

Some 20% of farmers from the highlands reported erosion as a factor in the decline in soil fertility. In the lowlands the problem is rarely mentioned.

Villagisation

'Villagisation' or resettlement was mentioned only by lowland farmers. They were forced to settle elsewhere between 1986 and 1991, leaving behind their enriched home gardens. They had to reduce the manure inputs because of the distance between the fields and the settlement areas. When farmers were allowed to return to their former location they say that the fertility of the soil, especially the garden plot, had declined during their absence.

4 Nutrient input and output balance of fields and farms

The model used

This section discusses the nutrient balances for eight case study farms in 1995, representing the four resource groups in both the highlands and lowlands. These balances are calculated for identifying areas in the farm where nutrients are lost, accumulate, or in equilibrium, and thereby identify room for improvement. Nitrogen (N) and Phosphorous (P) balances were calculated for four major farm components: enset, taro *darkua* and *shoka*. Four input and five output functions are monitored. The input flows are mineral fertiliser (IN1); organic manure (IN2), comprising animal manure and household refuse (IN2a), and leaf litter (IN2b), atmospheric deposition (IN3), and biological N-fixation (IN4)[6]. The major output flows quantified were removals in harvested products (OUT1), crop residue removals (OUT2), leaching (OUT3), denitrification (OUT4), and water erosion (OUT5) (Stoorvogel and Smaling, 1990). Farm level nutrient balances were calculated by aggregating the inputs and outputs in all the fields within a farm area, and then extrapolated on an area basis (kg/ha).

Major sources of nutrient inputs and outputs

Figure 2 summarises the input and output flows of nitrogen and phosphorus in four farm components in the highland and lowland zones. The major source of N and P for the enset, *darkua* and taro fields was animal manure along with household refuse, leftover feed and organic sweepings from around the house (IN2) (see also annexes 3 to 6). Household refuse and organic sweepings around the house were used on homestead fields more to improve physical structure and nutrient retention than for their nutrient content. Poor farmers also collect leaf litter from selected broad leafed trees such as *Erythrina*, *Croton* and *Cordia* species grown on farm boundaries and grazing areas, and applied it to augment soil fertility.

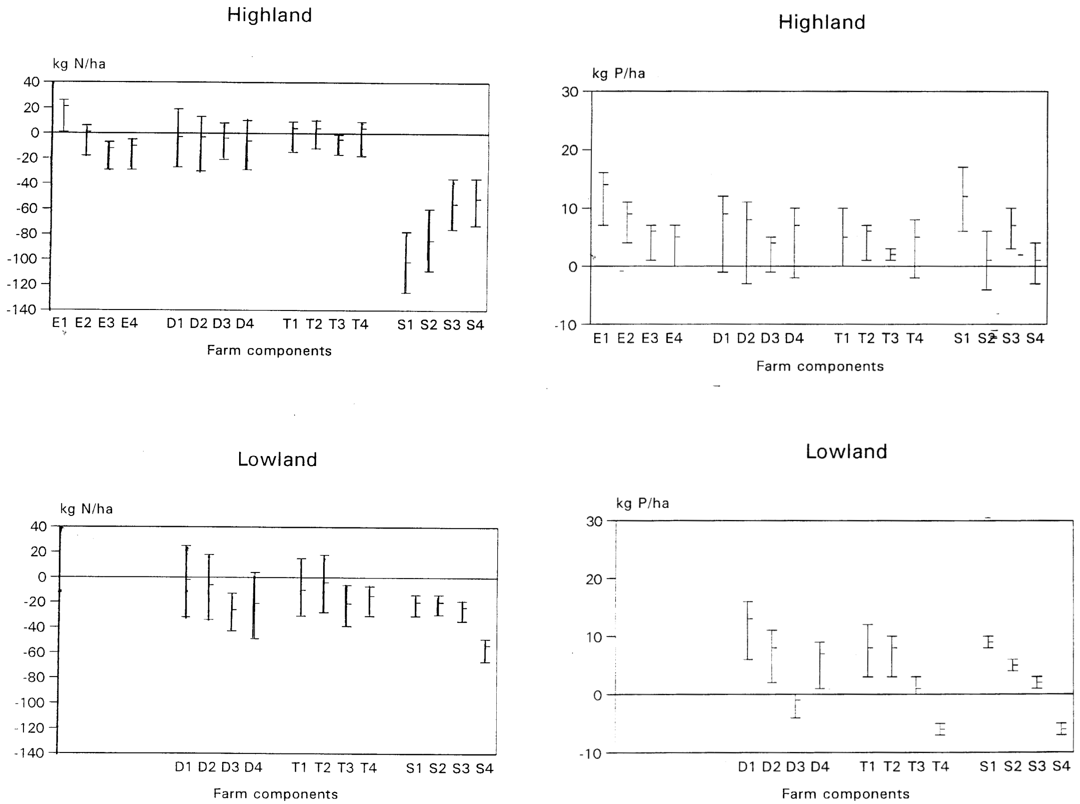
[6] Sedimentation, identified as IN5 in the original model (Stoorvogel and Smaling, 1990), is not relevant in Kindo Koisha since there are no irrigation schemes or flood plains.

The mineral fertiliser used is mainly DAP, which is the main source of nutrient addition to the *shoka* system (IN1). Poor farmers in the highlands also applied judicious amounts of manure as a supplement to the limited input of mineral fertiliser (S4 in annexes 3 and 4). Inputs from atmospheric deposition (IN3) are generally estimated to be small. Input from biological fixation (IN4) was assumed to be zero in the highlands because of the absence of legumes in the rotation, but exists in the lowlands where the haricot bean is commonly planted. However, the quantity of N added through fixation was relatively low (4 to 8 kg/plot in the *shoka*). This is probably because of the low N-fixing potential of the crop, low P availability in the soil and a low pH. All these factors limit N-fixation by legumes.

In most fields, bringing in of the harvest was the major cause of nutrient export from fields (OUT1 and OUT2), followed by leaching (OUT3) and gaseous (OUT4) losses. Crop residue removal was the strongest negative contributor to the N balance in most land use types, particularly in the *shoka* fields (see below). Leaching and denitrification losses were greatest in the manured enset and *darkua* fields due to a relatively larger input of N (IN2). It should be noted that nitrogen release from the manure in subsequent seasons is not taken into account. Leaching and denitrification losses are thus probably overestimated.

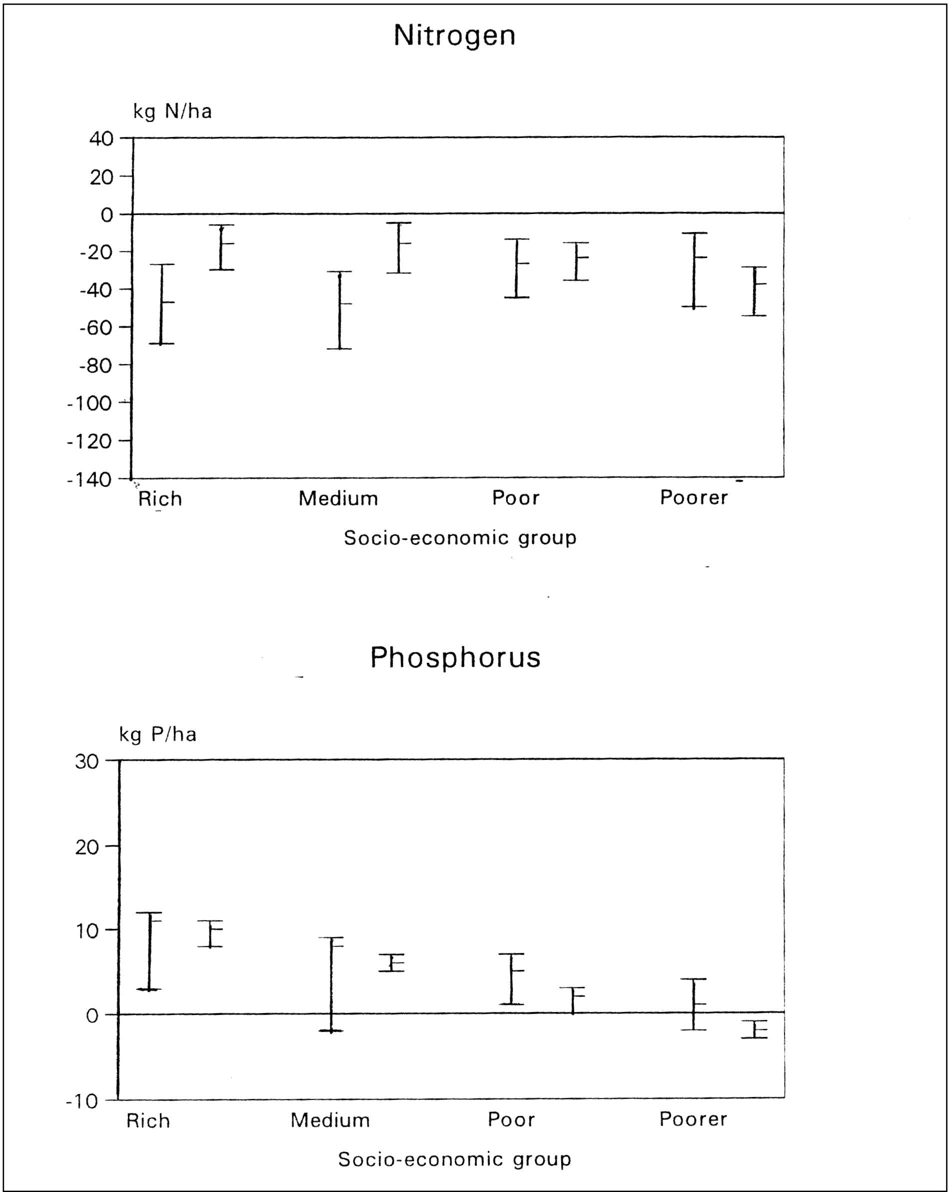
Erosion (OUT5) did not occur in the enset, *darkua* and taro fields, probably because of the relatively high organic matter content and stable soil structure, the presence of mulch material and the care provided by the farmers. This is in agreement with the findings of the runoff experiments conducted in the area (Belay, 1992). Erosion is, however, causing considerable loss of N in the *shoka* fields in the highlands, particularly for the richer farmers (S1 and S2 in annexes 3 and 4). The *shoka* field is mostly planted with small cereals such as teff and barley that require an intensively ploughed seedbed, but which increases the risks of erosion. These cereals also provide limited protection against the erosive force of the rain on the soil. The *shoka* field receives less attention and management care relative to the *darkua* and enset fields where farmers concentrate their labour and manure inputs to produce high value or food security crops. Another factor is the location of the *shoka* field at the bottom end of the farm-slope, where the velocity and eroding capacity of runoff is highest.

Figure 2. Nitrogen balances (kg/ha) and Phosphorus balances of four farm components and four socio-economic groups in the highlands (a) and the lowlands (b)



Key E=Enset; D= darkua; T=Taro; S=Shoka; 1= richest and 4 = poorest The optimistic value is at the top of each bar and the pessimistic value at the bottom. The most probable estimate is indicated with a small line

Figure 3. Nitrogen balances (kg/ha) and Phosphorus balances at farm level for four socio-economic groups in the highlands (left bar) and the lowlands (right bar)



Key The optimistic value is at the top of each bar and the pessimistic value at the bottom. The most probable estimate is indicated with a small line

Field and farm nutrient balances across agro-ecological zones

The N and P balances (kg/ha) for different farm components in the highlands and lowlands are summarised in Figure 2, while the whole farm balances (kg/ha) are presented in Figure 3. The assessment of the N and P balance is based on a classification given by Smaling (1993) for arable fields in sub-Saharan Africa. Nutrient depletion is great when losses are higher than 40 Kg N or 7 kg P per hectare per year and moderate when N losses are between 10 and 20 kg and P losses between 2 and 4 kg. Nutrient depletion is slight when losses are less than 10 kg N or 2 kg P.

Nitrogen balances

Our data showed that the N balances in the enset, *darkua* and taro fields of most of the highland farms studied were either slightly positive or at equilibrium (Figure 2). The level of inputs and outputs are thus sufficiently balanced and neither high accumulation or soil mining of N was found in these fields. This was also the case for some of the *darkua* and taro fields in the lowland farms (Figure 2). However, negative N balances were found in the *shoka* fields of all farmers in both agro-ecological zones, and were most pronounced in the highland farms. The *shoka* area is important, both in terms of cultivated area and total output, and a decline in soil fertility can affect the sustainability of the entire farming system. The N balance for the farm taken as a whole was highly deficient for both highland and lowland farms (Figure 3). This mirrors the substantial negative N balance observed in the *shoka* field, which occupies the most significant area (Table 2). The aggregated farm-level balances thus disguise the marked differences in nutrient balances between field components.

The limited N input from fertiliser (IN1) and absence of manure input (IN2) combined with insignificant inputs from fixation (IN4) largely explains the N deficit in the *shoka* field. The N balance remained deficient even when leaching, denitrification and erosion losses were assumed to be zero, suggesting that inputs were inadequate to replenish even production related outputs alone (OUT1 and OUT2). Nutrient drain in the form of crop residues is the strongest contributor to the N imbalances in the *shoka* fields (Annexes 3 and 5). All crop residues were removed from *shoka* fields and used as fodder for livestock. However, the manure is not returned to the *shoka* but used to fertilise other fields (enset and *darkua*). Finally, crops such as teff and barley have a high N content in the harvested product leading to further nutrient losses.

Nutrient balances also differ across agro-ecological zones. N depletion is higher in the highland than in the lowland zones. Yields in the highlands are double those in the lowlands due to more favourable climatic conditions and better soils. The removal of N via crops (OUT1 and OUT2) is thus higher. In addition, erosion is another source of N losses in the highlands, which is not a significant problem in the lowlands.

Phosphorus balances

Phosphorus balances were close to the equilibrium in all highland and lowland fields. We observed a slight accumulation in enset, taro and *shoka* fields of resource-rich farmers (Figure 2) and a slight deficit in the taro (T4) and *shoka* (S4) fields of very poor farmers in the lowlands. The positive balance for P in the enset, taro and *shoka* fields of resource-rich farmers is caused by the application of relatively large volumes of manure in the homestead fields and of DAP in the *shoka* fields.

The overall farm balances for P are also slightly positive (Figure 3). The P balance is better than the N balance because less P is removed in crop produce and residue. P is also less susceptible to leaching and denitrification losses; and losses of P because of erosion are only slight to moderate. The P balance is better in the lowland farms which may be caused by the limited availability of N, so that applied P cannot be efficiently used for plant growth. However, fertiliser trials in the area have shown a significant response to the application of P-fertiliser (WADU, 1977). This is probably caused by the high P-fixation capacity of the Nitosols, thus rendering P unavailable for plant uptake. More research is needed to improve the role and efficiency of P-fertiliser.

Nutrient balances by socio-economic groups

The average nutrient balances for enset, taro and *darkua* plots were all in equilibrium. However, they varied amongst the four socio-economic groups and across agro-ecological zones. The N balance was more positive in the enset-garden of the richer farmer in the highlands (E1 in Figure 2) primarily due to more continuous application of manure and less rapid harvesting of enset than in the case of poorer farmers.

Little difference was observed in the N balances of *darkua* and taro plots between the socio-economic groups in the highlands. There were however differences between these plots in the lowlands as a result of different levels of manure application. The poorer the lowland farmer, the greater the trend towards a negative N balance when going from *darkua* to *shoka* fields (Figure 2).

The *shoka* fields of all four socio-economic groups in both the highlands and lowlands were very deficient in N. P balances of *shoka* fields are generally positive, especially for the richer farmers who use larger amounts of fertiliser than poorer farmers. However, significant differences were observed in the rate of N depletion for *shoka* fields across socio-economic groups. The N balance was most markedly negative in the *shoka* fields of rich and middle economic group farmers in the highlands, and for the poor and very poor farmers in the lowlands (annex 6).

In the highlands, differences between N depletion rates are explained by variations in the farm size, amounts of inputs applied and intensification of soil management practices (soil conservation, residue return, etc.) used by different groups of farmers. Richer highland farmers cultivate larger areas and although they purchase larger amounts of fertiliser, the rate of fertiliser application per unit area is low. Moreover, richer farmers do not invest so much labour in intensive soil conservation and fertility enrichment practices because they are more involved in off-farm activities. Differences in losses of N from erosion (OUT5) may partly explain the greater N deficiency in the *shoka* fields of richer farmers (S1 and S2 in Figure 2).

Overall, the poorer farmers in the highlands had lower N depletion rates. Their holdings are too small for their subsistence needs, but they have limited access to more profitable off-farm activities due to a lack of capital. Therefore, poorer farmers have to rely on agriculture which forces them to invest a large amount of labour in soil fertility management. They use a wide range of fertility inputs and conservation practices to improve yields, such as the careful use of all available manure, systematic management and recycling of crop residues, collection of leaf litter and intensive soil conservation. Since the fields of poorer farms are small and intensively managed, the effects of soil erosion on soil fertility is kept low. Moreover, their cropping patterns are largely dominated by subsistence crops so that loss of nutrients through crop sales are considerably lower than for richer farmers (annex 3). However, they still have a negative N balance due to their limited ownership of livestock, which affects access to manure and access to credit for obtaining fertiliser.

In the lowlands, however, the position is reversed as N balances are lower for poorer than for richer farmers. Poorer farmers in the lowlands are severely constrained by limited access to livestock. This is a major problem because lowland soils are hard to work while the labour force is weakened by malaria and malnutrition. Hiring oxen is only possible in exchange for labour as there exists no system of cash payment. Poorer farmers thus hire themselves out as labourers to the richer farmers, to gain access to draught oxen. Consequently, they have less time to invest in intensive soil fertility enrichment practices on their own farms. By contrast, richer farmers reap the benefits of poorer farmers' labour, which also creates more scope for spending time earning cash through off-farm activities. Moreover, they have more livestock and can apply larger volumes of manure as well as having access to credit for obtaining mineral fertiliser.

5 Concluding remarks

This study has shown the complexity of soil fertility issues in Kindo Koisha farms. Farmers' soil management practices are radically different across land use types with different niches receiving different levels of attention and management care, and generating diverse patterns of fertility. Soil fertility is being maintained, and even increased, in farm components such as the enset-garden, *darkua* and taro fields. Farmers are creating and enriching soil fertility in these sites to sustain subsistence production and food security. Soil nutrient loss is currently present in only one farm component, the *shoka* field; however, this component also occupies the largest area. Levels of nutrient depletion from the *shoka* field vary between socio-economic group, and it is particularly serious for richer farmers in the highlands and for poorer farmers in the lowlands[7]. Livestock ownership is the main factor determining soil fertility management in the lowlands, as it determines access to manure, draught power and credit for fertiliser. The resource-poor farmers in the densely populated highlands demonstrated a capacity to intensify soil fertility management which resembles cases reported in other parts of Africa such as the Machakos district of Kenya (Tiffen and Mortimore, 1992) and Sukumaland in Tanzania (Meertens et al, 1996; Budelman, 1996), where agricultural intensification and regeneration of soil fertility have occurred under conditions of high population pressure.

The results for N and P balances found in this study show the same tendencies as those calculated for other regions in sub-Saharan African. The pattern of nutrient balances observed for the highlands is comparable to the balances calculated by Smaling et al (1993) for Kisii District of Kenya. Both Kindo Koisha and Kisii are part of the densely populated, erosion-prone east African highlands, that are characterised by strongly negative N balances. On the other hand, the nutrient balances found in the farms of lowland Kindo Koisha are comparable to those for sub-humid zones in southern Mali (Van der Pol, 1992).

This study applied a nutrient input and output balance model for the first time in Ethiopia. It was found to be a useful tool for monitoring nutrient depletion in agricultural land use. When calculating nutrient balances, a high level of accuracy is not possible. It is more important to understand variability in the size of flows which constitute the balance than to measure these with great accuracy. Nutrient balances can be discussed easily

[7] Similar patterns have been observed in other parts of SSA such the Mossi farming system in Burkina Faso (Prudencio, 1993).

with farmers by focusing on the more visible, managed flows such as application of fertiliser (IN1) and manure (IN2), removal of nutrients in crops (OUT1), and residues (OUT2) and losses from erosion (OUT5). These are flows that farmers can easily observe and interpret. Visualisation of these flows on farm maps helps to identify opportunities to improve nutrient management.

The extent of the soil fertility problem in Kindo Koisha differs between highland and lowland areas, between farms and between fields within a farm. Care should thus be taken when aggregating nutrient balances at higher scales (farm, district, nation). They can be misleading when they fail to capture spatial scale issues and the exposition of diversity that are vital in farmers' soil fertility management strategies.

The results of this study also underline the importance of a targeted intervention approach to improve soil fertility. Policies should specify where (which agro-ecological zone or farm component), and for whom (resource-poor farmers or resource-rich farmers) the intervention is planned.

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Annexes

Annex 1. Nutrient composition (% dry weight) of animal manure and leaf litter in the highland and lowland case study farms (average calculated for two samples)

	Nutrient content (%)	
Material	*N*	*P*
Animal manure (highland)	1.68	0.23
Animal manure (lowland)	1.39	0.21
Leaf litter (highland)	3.3	0.22
Leaf litter (lowland)	2.28	0.15
Manure (literature data)	1.1 - 1.7	0.13 - 0.26

Annex 2. Nutrient composition (% dry weight) of harvested products and residues of crops in the case study farms. Figures for maize (highland and lowland) and enset are means of four samples. Figures in parentheses refer to ranges

	Harvested product (%)		Crop residue (%)		Source
Crop	*N*	*P*	*N*	*P*	
Maize (highland)	1.25 (1.13 - 135)	0.18 (0.16 - 0.19)	0.35 (0.32 - 0.47)	0.03 (0.02 - 0.04)	Analysed
Maize (lowland)	1.14 (0.81 - 1.47)	0.17 (0.14 - 0.18)	0.39 (0.37 - 0.43)	0.03 (0.02 - 0.04)	Analysed
Maize	0.93 - 1.3	0.15 - 0.27	0.35 - 1.39	0.11 - 0.39	(Stoorvogel and Smaling 1990)[8]
Enset	0.87 (0.8 - 0.94)	0.1 (0.04 - 0.15)	1.89 (0.53 - 3.25)	0.15 (0.08 - 0.21)	Analysed
Haricot bean	3.47	0.26	0.65	0.03	Analysed
Teff	1.76	0.45	0.60	0.10	Analysed
Sweet potato	0.26	0.04	0.64	0.09	FAO data
Taro root	0.35	0.07	1.68	0.18	FAO data
Sorghum	1.30	0.35	0.42	0.09	FAO data

Source: FAO, 1994

[8] The mean values of the lowest and highest quartiles of data from several countries. These ranges have been used in the estimation of optimistic and pessimistic values for maize.

Annex 3. Nitrogen flows (kg/field) for different fields and socio-economic groups in the highland zone (N fixation (IN4) was zero for all fields)

Field & group	Input functions (IN)				Output functions (OUT)						Balance
	1	*2*	*3*	*Total*	*1*	*2*	*3*	*4*	*5*	*Total*	
E1	0.0	21.6	1.0	22.6	0.4	3.8	6.8	7.5	0.00	18.5	+ 4.2
E2	0.0	16.0	1.0	17.0	0.9	5.2	5.0	5.7	0.00	16.8	+ 0.2
E3	0.0	6.6	0.5	7.1	1.9	2.5	1.7	2.1	0.00	8.4	-1.2
E4	0.0	3.7	0.2	3.9	1.6	1.2	0.7	0.8	0.00	4.3	- 0.4
D1	0.0	37.1	1.5	38.6	12.6	7.8	8.9	9.9	0.00	39.2	- 0.6
D2	0.0	27.6	1.0	33.6	10.4	8.6	7.1	7.8	0.00	34.1	- 0.5
D3	0.0	17.5	1.0	18.5	6.1	4.9	3.8	4.5	0.00	19.3	- 0.8
D4	0.0	11.7	0.5	12.2	4.5	2.6	2.6	3.0	0.00	12.9	- 0.6
T1	0.0	2.0	0.1	2.1	0.4	0.2	0.6	0.7	0.00	2.0	+ 0.1
T2	0.0	3.3	0.2	3.5	0.7	0.4	1.0	1.2	0.00	3.3	+ 0.2
T3	0.0	1.7	0.5	2.2	0.2	0.5	0.9	1.2	0.00	2.7	- 0.5
T4	0.0	1.3	0.1	1.44	0.6	0.1	0.3	0.4	0.00	1.4	+ 0.04
S1	13.5	0.00	2.5	16.0	20.0	23.9	5.2	6.9	10.8	67.0	- 51
S2	9.0	0.00	3.0	12.0	19.7	19.8	4.0	6.4	13.0	62.9	- 51
S3	4.1	0.00	1.5	5.6	5.7	7.8	2.0	3.0	3.7	22.4	- 17
S4	0.7	1.4	0.5	2.6	2.8	2.0	0.8	1.2	0.9	7.7	- 5
F1	13.5	60.7	5.1	79.3	33.4	35.7	21.5	25.0	10.8	126.4	- 47
F2	9.0	46.9	5.2	66.1	31.7	34.0	17.1	21.1	13.0	116.9	- 51
F3	4.1	25.8	3.5	33.4	13.9	15.7	8.4	10.8	3.7	52.5	-19
F4	0.7	18.1	1.3	20.1	9.4	5.9	4.4	5.4	0.9	26.2	- 6

Note: E = enset-garden, D = *darkua*, T = taro, S = *shoka*, F = farm level
1 = resource rich farmer; 2 = medium resource farmer; 3 = resource poor farmer; 4 = very poor farmer

Annex 4. Phosphorus flows (kg/field) for fields and socio-economic groups in the highland zone (IN4, OUT3 and OUT4 were zero for P)

Field & group	Input functions (IN)				Output functions (OUT)				Balance
	1	*2*	*3*	*Total*	*1*	*2*	*5*	*Total*	
E1	0.00	2.9	0.2	3.1	0.00	0.3	0.00	0.3	+ 2.8
E2	0.00	2.2	0.2	2.4	0.1	0.4	0.00	0.5	+ 1.9
E3	0.00	0.9	0.1	1.0	0.2	0.2	0.00	0.4	+ 0.6
E4	0.00	0.5	0.00	0.5	0.2	0.1	0.00	0.3	+ 0.2
D1	0.00	5.0	0.3	5.3	1.8	0.8	0.00	2.6	+ 2.7
D2	0.00	3.7	0.2	3.9	1.5	0.8	0.00	2.3	+ 1.6
D3	0.00	2.0	0.2	2.2	0.9	0.4	0.00	1.3	+ 0.8
D4	0.00	1.4	0.1	1.5	0.6	0.2	0.00	0.8	+ 0.7
T1	0.00	0.3	0.00	0.3	0.07	0.00	0.00	0.1	+ 0.1
T2	0.00	0.5	0.00	0.5	0.1	0.00	0.1	0.2	+ 0.3
T3	0.00	0.2	0.1	0.3	0.00	0.1	0.00	0.1	+ 0.2
T4	0.00	0.18	0.00	0.18	0.12	0.00	0.00	0.12	+ 0.06
S1	15.0	0.00	0.5	15.5	3.1	3.0	3.4	9.4	+ 6.0
S2	10.0	0.00	0.5	10.5	3.2	2.4	4.1	9.8	+ 0.7
S3	4.6	0.00	0.3	4.9	1.0	0.8	1.2	3.0	+ 2
S4	0.8	0.2	0.00	1.0	0.4	0.2	0.3	0.9	+ 0.1
F1	15.0	8.2	1.0	24.2	5.0	4.1	3.4	12.5	+ 11.7
F2	10.0	6.4	1.0	17.4	4.9	3.6	4.1	12.6	+ 4.8
F3	4.6	3.1	0.7	8.4	2.1	1.5	1.2	4.8	+ 3.6
F4	0.8	2.1	0.1	3.2	1.3	0.5	0.3	2.1	+ 1.1

Annex 5. Nitrogen flows (kg/field) for fields and socio-economic groups in the lowland zone (erosion (OUT5) was zero in the lowlands).

Field & group	**Input functions (IN)**					**Output functions (OUT)**					**Balance**
	1	*2*	*3*	*4*	*Total*	*1*	*2*	*3*	*4*	*Total*	
D1	1.9	42.4	2.0	8.0	54.4	17.9	8.8	13.6	14.9	55.2	- 1.0
D2	0.00	38.4	2.0	0.00	40.4	9.8	8.8	11.9	13.2	43.7	- 3.0
D3	0.00	15	1.6	0.00	16.6	5.8	13.4	3.3	4.4	27.2	- 10.6
D4	0.00	7.9	0.4	0.00	8.3	3.8	1.8	2.1	2.4	10.1	- 2
T1	0.00	9.4	0.4	0.00	9.8	1.5	3.5	2.8	3.0	10.7	- 1.0
T2	0.00	19	1.0	0.00	20.0	2.9	5.4	5.8	6.5	20.6	- 1
T3	0.00	4.8	0.5	0.00	5.3	1.6	2.8	1.6	1.9	8.1	- 2.8
T4	0.00	2.5	0.5	0.00	3.0	1.7	1.6	0.7	1.0	5.0	- 2
S1	27	0.00	9.6	8.0	44.6	28.0	37.2	10.2	16.5	92.0	- 47
S2	15.6	0.00	7.6	4.0	27	20.6	26.1	6.5	11.4	64.8	- 37
S3	8.4	0.00	7.0	4.0	19.4	17.2	31.9	3.9	8.5	61.5	- 42
S4	0.5	0.00	1.2	4.0	5.7	12.7	7.5	0.4	1.2	21.8	- 16
F1	28.9	61.4	12	16.0	108.8	47.4	49.5	26.5	34.4	158	- 49
F2	15.6	57.4	10.6	4.0	87.4	33.3	40.3	24.2	31.1	129	- 41
F3	8.4	19.8	9.1	4.0	41.3	24.6	48.1	8.8	14.8	96.8	- 55
F4	0.5	10.4	2.1	4.0	17.0	18.2	11.0	3.2	4.6	37.0	- 20

Annex 6. Phosphorus flows (kg/field) for fields and socio-economic groups in the lowland zone (IN4, OUT3 and OUT4 were zero for P)

Field & group	**Input functions (IN)**				**Output functions (OUT)**			**Balance**
	1	*2*	*3*	*Total*	*1*	*2*	*Total*	
D1	2.2	6.4	0.5	9.1	2.0	0.5	2.5	+ 6.6
D2	0.00	5.8	0.5	6.3	1.5	0.8	2.3	+ 4
D3	0.00	1.5	0.4	1.9	0.8	1.5	2.3	- 0.4
D4	0.00	1.1	0.1	1.2	0.3	0.2	0.5	+ 0.7
T1	0.00	1.4	0.1	1.5	0.3	0.3	0.6	+ 0.8
T2	0.00	2.8	0.3	3.1	0.5	0.5	1.0	+ 2.1
T3	0.00	0.7	0.1	0.8	0.3	0.3	0.6	+ 0.2
T4	0.00	0.3	0.1	0.4	0.8	0.4	1.2	- 0.8
S1	30	0.00	2.4	32.4	4.9	4.5	9.4	+ 23
S2	17	0.00	1.9	18.9	4.3	3.4	7.7	+ 7.9
S3	9.4	0.00	1.7	11.1	3.3	3.8	7.1	+ 4.0
S4	0.6	0.00	0.3	0.9	1.6	0.8	2.4	- 1.5
F1	32.2	7.8	3.0	43.0	7.2	5.3	12.5	+ 30.5
F2	17.0	8.6	2.7	28.3	6.3	4.7	11.0	+ 17.3
F3	9.4	2.2	2.2	13.8	4.4	5.6	10.0	+ 3.8
F4	0.6	1.4	0.5	2.5	2.7	1.4	4.1	-1.6

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