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Organic material flows within a smallholder highland farming system of South West Uganda

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Abstract

It is now recognised that nutrient losses from the steeply sloping hillsides of the tropics and subtropics occur not only through soil erosion, but through the net transfer of annual crop residues to more profitable parts of the farming system. Studies of soil nutrient balances across Africa are showing evidence of widespread mining of the soil resource within the smallholder farming sector, as the organic matter and nutrient source is not replenished in annually cropped hillside fields. This paper presents information that is central to the understanding of the farming systems employed by smallholder farmers within the highlands of South West Uganda.

A time static model of organic resource flows was developed with a smallholder farming community, using visible flow data from farm surveys and semi-structured interviews, to describe this situation. The model explores the sources, whereabouts and current management strategies of organic resources and defines their flow around the farming system. Results confirm a net transfer of 24 Mg ha^{-1} yr^{-1} ($P < 0.01$) of organic material, mainly crop yields and residues, from the annually cropped hillsides (covering an area of 0.6 ha per farm ($P < 0.001$)) to other parts of the farming system. The stover from the annual crop is used almost exclusively as mulch in banana (*Musa* sp.) plantations. As a consequence, the soils on the hillsides are gradually becoming depleted of nutrients, as farmers' place little value on improving the nutrient status of hillside fields distant from homesteads. Households, as is the case with most African subsistence farmers, would rather concentrate their limited labour and organic residue resources in maintaining the fertility/productivity of the more profitable parts of the farming system, in this instance banana plantations and annual fields close to homesteads. Consequently, in the short term the perennial banana system maintains a balanced flux of organic resources at the expense of hillside soil fertility. Unfortunately, over the longer term the current system will inevitably lead to a severe reduction in mulch availability, which will mean perennial crop yields will eventually decline, leading potentially, towards an unsustainable farming system. Fortunately, however, there are under-exploited organic resources within the existing farming system, that if fully utilised and could help sustain and even improve the yields of both annual and perennial crops. The whereabouts, management and value of these organic resources need to be highlighted to farmers so that alternative management strategies for organic residues can be developed, that are both economically appropriate to the farmer and the resources available, at farm level.

Keywords: East Africa; Uganda; Highlands; Organic matter flows; Organic matter management; Participation; Soil and water conservation

1. Introduction

Studies of soil nutrient balances across Africa are showing evidence of widespread mining of the soil resource within the smallholder farming sector, as

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the organic matter/nutrient source is not replenished from one season to the next (Buresh et al., 1997). This continued and extensive depletion of soil nutrient status is (largely) caused by continued crop production on erosive soils with poor nutrient conservation practices and is one of the main constraints on subsistence farming in sub-Saharan Africa, leading to poor crop growth and reduced food production (Vlek et al., 1997). Rates of nutrient depletion are particularly high in areas with favourable climates for crop production and high population densities. The East African Highlands is such an area (Stoorvogel et al., 1993; Drechsel and Reck, 1998).

In the highland areas of South West Uganda, e.g., annual crops are grown in a zone of high rainfall intensity on steeply sloping (20–30%) hillsides, where the major forms of soil and water conservation (SWC) are achieved through the use of traditional systems. These have been identified by Critchley (1991), Critchley et al. (1994) and Miiro et al. (1995). Detailed studies of these indigenous systems (Briggs et al., 1998a,b,c; Critchley et al., 1999) showed that declining soil fertility on the steeply sloping hillsides was due not only to soil erosion and poor conservation. Nutrient losses also occurred through the removal of annual grain crops for household consumption and the net transfer of crop residues to more profitable parts of the farming system as mulch materials. This export of residues is leading to a decline in soil fertility and increasingly severe limitations to crop productivity on steeply sloping hillsides. Thus if no alternative sources of organic matter are found, perennial crop yields will inevitably suffer, leading towards a (potentially) unsustainable system.

The maintenance of soil organic matter (SOM) and thus soil nutrient status through the supply of organic residues, is an essential component in the management of tropical soils. Organic matter is the key to soil fertility and productivity in agricultural systems where there is no use of inorganic fertilisers (Greenland and Dart, 1972). Yet in many tropical cropping systems, little or no organic residues are returned to the soil. This leads to a decline in SOM (Lal, 1986; Bouwman, 1990; Post and Mann, 1990) which results in lower crop yields (Lal, 1986) or plant biomass productivity (Woomer and Ingram, 1990). Maintenance of productivity on smallholder farms through the improved use and management of organic resources within the farming system has become a priority for research in recent times (Critchley et al., 1999; Snapp et al., 1998). However, much of the experimental work to test hypotheses on soil improvement through organic residue management (Lal, 1989; Fernandes et al., 1993; Nill and Nill, 1993; Mafongoya and Nair, 1997), has been done on-station at plot level, without regard to the availability of organic resources or the socio-economic constraints at farm level (Nandwa and Bekunda, 1998; Scoones and Toulmin, 1999; Hilhorst and Muchena, 2000). Viable recommendations for improving soil fertility management practices, which are both economically suitable to the farmer and appropriate for resources available, can only be made if the current sources, whereabouts and uses of organic materials and nutrients within smallholder farming system have been identified (Nandwa and Bekunda, 1998).

This paper presents information that is central to the understanding of the farming systems employed by smallholder farmers within the highlands of South West Uganda. The current management strategies of organic resources are described, and other organic sources, as yet under utilised by the farmers are highlighted. Appropriate interventions that may be beneficial to the sustainability of the farming system are identified. For the purposes of this paper organic materials are defined as any vegetative material within the farming system, live or dead, including night soil, which might contribute to the SOM pool.

2. Methodology

2.1. Background

Information on the utilisation of organic resources was collected from the smallholder farming community of Kamwezi Sub-County, Kabale District, in the Highlands of South West Uganda (Fig. 1). The farmers in this area have been involved in a collaborative venture with Uganda's Ministry of Agriculture, Animal Industries and Fisheries (MAAIF), Makerere University and Silsoe Research Institute (SRI) since 1995, to look at ways of improving their crop production and soil conservation (Briggs et al., 1998d). The overall goal of the project was to identify and improve soil and water management techniques that could be spread amongst, and adopted by, small scale farmers in areas with unreliable rainfall and that gives rise to

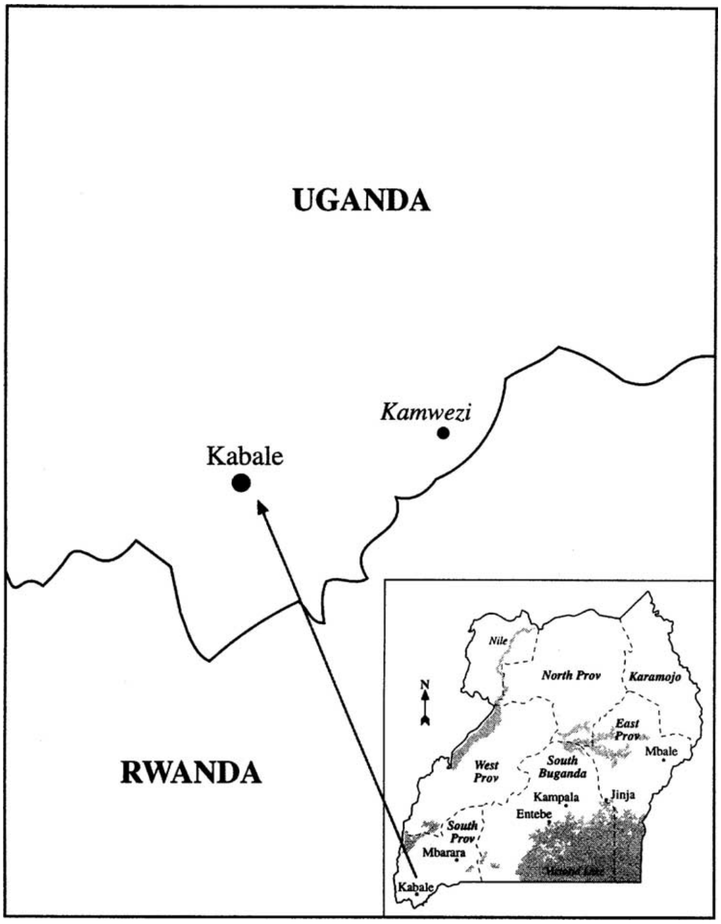

Fig. 1. Location of Kamwezi within Kabale District, South West Uganda (modified from FAO, 1997).

a high risk of water stress during the cropping season. To achieve this goal the project team developed a participatory research and development approach (Fig. 2), that used the farmers traditional SWC technologies as the project entry point, and involved the farmers in the entire research process; from the selection and development of improved land husbandry techniques, to monitoring and evaluation (Willcocks and Critchley, 1996). A detailed description of the approach and its strengths and weakness can be found in Critchley et al., 1999.

2.2. Site characteristics

Kamwezi lies at an altitude of 1400–2000 m asl in the north-east of Kabale District with a generally mountainous relief (10–80% slopes) of flat topped hills and ridges, underlain by partly granitised and metamorphosed Precambrian rock formations of the Karagwe–Ankolean system (Harrop, 1960). The soils are predominantly Ferralitic sandy clay loams or skeletal sandy loams on the steeper slopes, classified as Ferralsols using the FAO classification system. During the initial project participatory rural appraisal (PRA) (Miiro et al., 1995), local soil classifications were determined with the community and subsequently matched (Briggs et al., 1998d) to the dominant soil types of the area described by Harrop (1960). Local and formal soil classifications for the Kamwezi soil catena are summarised in Table 1, and clearly show, as other participatory studies have shown elsewhere (Sillitoe, 1998; Briggs et al.,

Table 1
Local and corresponding soil classifications for a typical soil catena in Kamwezi

Catenary position	Local soil type (Miiro et al., 1995)	Local description (Briggs et al., 1998d)	Soil mapping unit (Harrop, 1960)	FAO classification
Mid to upper slopes	Enombe	Brown clay loam, sticky when wet, hard when dry. Varying depth with deeper more productive soils used for bananas	Kigara	Humic Ferralsol
	Orushenyi	Red brown sandy loam with stones. Dries very quickly and used for grazing	Bugangari	Mollic Ferralsol
Saddle of mid to upper slopes	Eririragura	Very dark, deep friable loam to clay loam soil, stable soil structure with good moisture holding capacity. Used for bananas	Kabale	Ferralsol
Mid slopes	Omufuna	Dark brown loamy soils of varying depth, shallower soils have more gravel and used for annual crops	Bugangari	Mollic Ferralsol
	Ekigugwe	Grey sandy loam, very shallow and dries very quickly, used for grazing	Bugangari	Mollic Ferralsol
Mid to lower slopes	Eryamabare	Dark brown shallow loam with many stones. Good for annual crops if destoned	Bugangari	Mollic Ferralsol
Valley bottoms	Eryorufunjo	Black clay loams with a good water holding capacity. Very productive and used for bananas	Ibanda	Humic Ferralsol
Low lying areas	Orucucu	Red brown sandy clay loam with a fine lose structures that easily absorbs water, but dries quickly. Homestead plots and bananas if much material available	Ibanda	Ferralsol

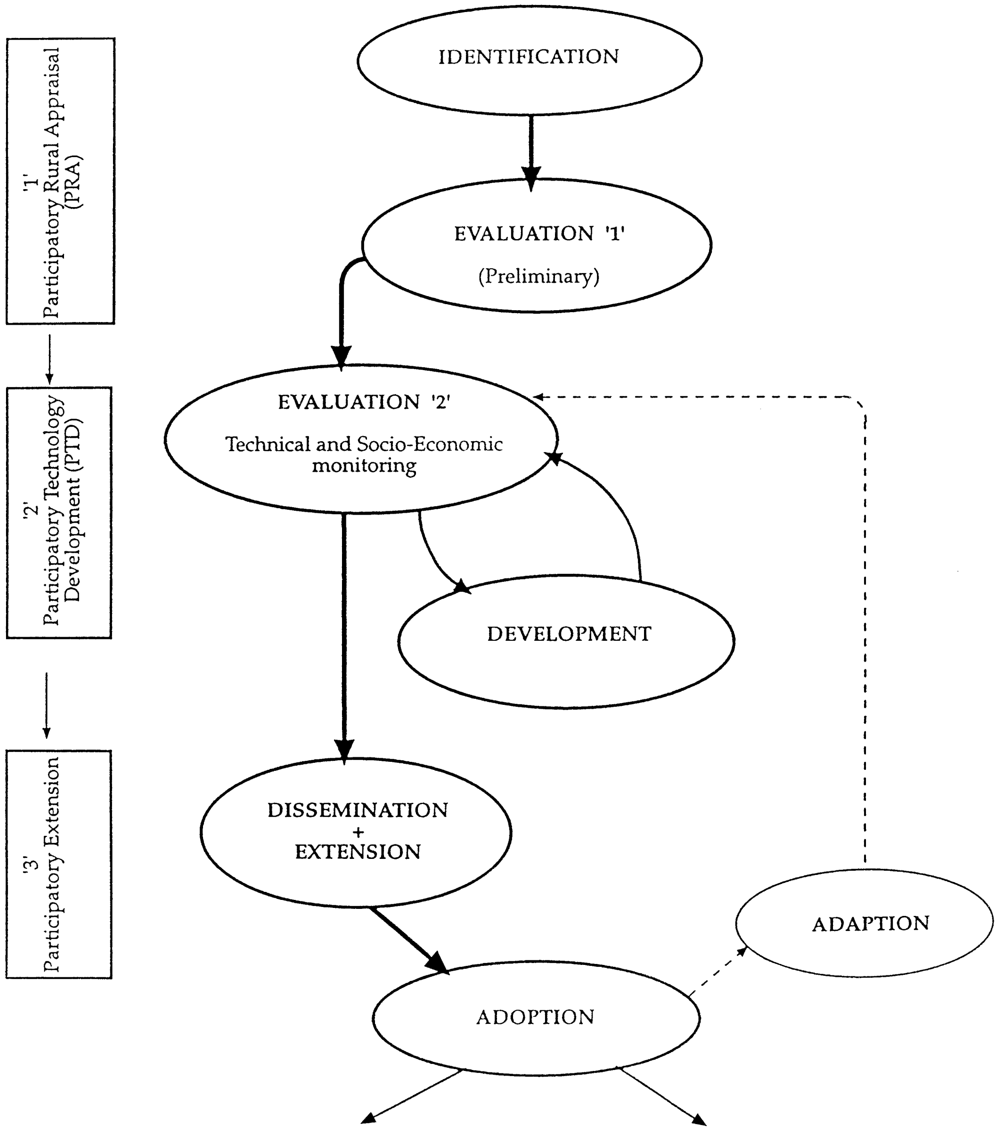

Fig. 2. The participatory research and development process followed in Kamwezi (after Willcocks and Critchley, 1996).

1998e), that farmers have a detailed knowledge of their agroecosystem.

Based on the 1991 Government census, the area is heavily populated with more than 193 people/km^2 (Government of Uganda, 1991). Rainfall is bimodal, with a 10% probability that annual rainfall will be between 500 and 750 mm, the first rains are from March to June and the second are from September to December. Farmers practise a mixed cropping system with a small livestock component. Two main cropping systems exist in the area, namely (a) the production of annual crops on the shallow hillside soils, and (b) the growth of perennial crops on the saddles and gentler slopes, and in the flat valley bottoms. The dominant and mostly widely grown perennial crop is the highland cooking banana (*Musa* sp.). The most popular annual crops grown are sorghum (*Sorghum bicolor* L.), beans (*Phaseolus vulgaris* L.), maize (*Zea mays* L.)

Table 2
The key components and tools used during the semi-structured interviews

Semi-structured interviews are guided conversations in which only the topics are predetermined and new questions or insights arise as a result of the discussion and visualised analyses (Pretty et al., 1995)
(1) *Preparation of check list*: Key project personal helped develop check list of questions (revised after farmer meetings)
(2) *Introductory community meeting*: Explain purpose of study and give farmers opportunity to pass comment and identify possible key informants
(3) *Cross check resource status of key informants*: Ensure key informants are a representative cross-section of community
(4) *Revision of check list*
(5) *Group and individual transect walks*: Initial identification of organic resources
(6) *Field visits with individual key informants*: Visual assessment of organic resources available and how used. Measurements made in field using a spring balance
(7) *Development of household land use maps*: Used to help visualise the movement of organic resources around household land holdings

and sweet potato (*Ipomoea batatas* L.), and to a lesser extent field peas (*Pisum sativum* L.), Irish potatoes (*Solanum tuberosim* L.) and tomatoes (*Solanum lycopersicum* L.). These are the crops that are focused upon in this study.

2.3. Data collection

To identify the source, whereabouts and use of organic residues within the Kamwezi farming system, a series of participatory semi-structured interviews (after Okali et al., 1994; Nabasa et al., 1995; Pretty et al., 1995) and farm surveys were conducted. The key components and tools used during the semi-structured interviews are summarised in Table 2. As pointed out by Defoer et al. (1998), before analysing nutrient/organic matter flows it is important to define the unit or system and its boundaries. In this study, the individual farm system was taken as the unit for analysis, with interviews conducted both at the farmers homestead and fields, so that the informants could clearly assess organic resources available, demonstrate their use, and carry out the measurements and some of the analysis themselves during field visits and transect walks. Defoer et al. (1998) defined flows as those that are visible to the human eye. As part of this approach, the participating farms developed land use maps to help visualise the location of their land holdings and associated organic resources in the locality, and thus analyse their own soil fertility management strategies. An example land use map, drawn by the farmer, is shown in Fig. 3. Resource constraints (financial, time and human) restricted the sample size to 20 farmers (10 female and 10 male) and limited the period of study to a 6 weeks in January and February 1997. The participating farmers were a representative cross-section of the different household resource categories defined during the initial project PRA (Miiro et al., 1995). Resource status (low, medium and high), as might be expected, varied with farm size, livestock ownership, area of bananas grown and off-farm income.

2.4. Data analysis

Of the 20 farmers interviewed, each related information regarding the sources, whereabouts and management of organic materials on the farm. Where possible the quantity of organic residues available was based on the farm households own estimates, supported by direct measurements in the field and/or cross referencing with quantities given in the literature. Values obtained from the 20 farms were subsequently averaged (standard errors calculated) to be representative of the farming system as a whole, rather than individual farm household practices.

2.4.1. Field sizes

The size of banana plantations, hillside and homestead plots, and areas of crop grown were based on the households own estimates and cross referenced with detailed measurements made in the area by Briggs et al. (1998d) and information supplied by the District Agricultural Office (DAO) (pers. commun.). This aided in the assessment of crop and stover yields on a farm basis for each crop, and allowed subsequent extrapolation to Mg ha^{-1} or Mg per farm per year.

2.4.2. Crop yields, stover production and use

Typical yields from both annual and plantation crops were described by each household on a field

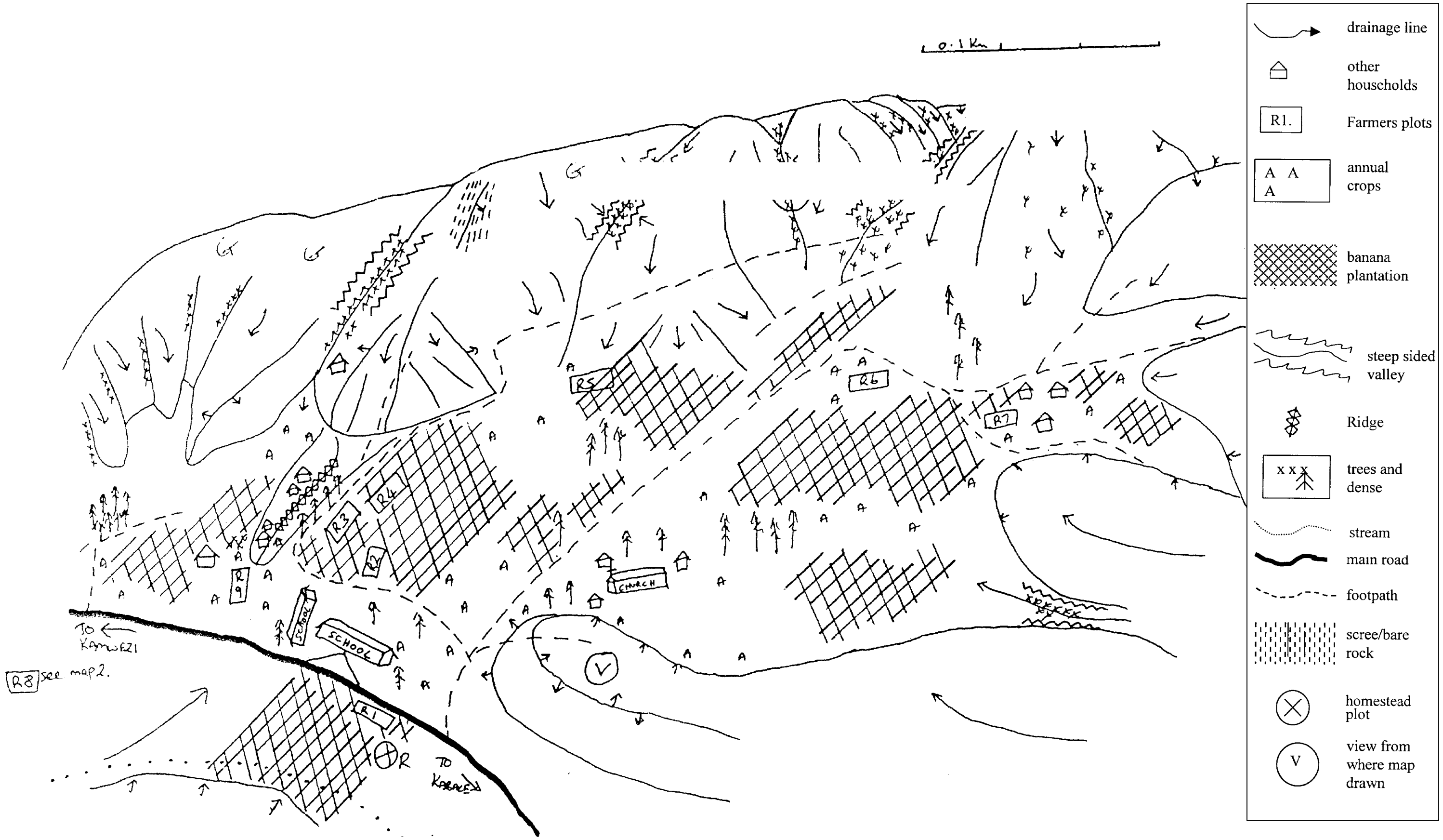

Fig. 3. An example land use map drawn by Richard Tibikweise, a smallholder farmer in Kamwezi.

by field basis over the farming year and their use, e.g., home consumption, off farm sales, mulching, thatching and losses, e.g., pests and disease indicated. Where possible these estimates were cross referenced with both quantitative (Briggs et al., 1998d) and qualitative (DAO Kabale, pers. commun.) data collected in the study area, or with data from the literature for similar agroecosystems (e.g., Godefroy, 1974; Dalzell et al., 1979; Wild, 1988; Landon, 1991).

2.4.3. Stubble, roots and trashlines in annually cropped fields

Households estimated the quantity of stubble remaining in their fields through direct measurement during a series of informal interviews and indicated its uses. The mass of roots returned to the annual soil was based on a root litter fraction of 0.2 of the total plant biomass (yield and stover), calculated for all plant types (after Shepherd et al., 1996). Quantities of material added to trashlines were determined through formal surveys (Briggs et al., 1998d) and summation of all the additions mentioned by the households.

2.4.4. Livestock and manure

Ownership patterns were established during the informal interviews, and included numbers, type, grazing management practised (free range or zero grazed), and composition and quantity of fodder. Where livestock were allowed free range, farmers estimated (in percentages or fractions) the quantity of stover and crop yield consumed or destroyed during the growing season and after harvest. Farmers also gave a qualitative description of their manure management and utilisation strategies, estimating the quantities of manure in terms basins collected over various periods of time. One basin of manure weighed approximately 15 kg. Where the livestock pens are cleared on a daily basis, the manure is typically stored in heaps with some crop residues added. Otherwise, the manure is removed from the pens just prior to spreading on the crop lands.

2.4.5. Household waste and composting

Household waste materials include waste from food preparation (peelings), beer brewing and sweeping from around the homestead compound, which includes hedgerow prunings. A typical household produces two basins of peelings (1 basin = 15 kg) and one basin of sweepings (1 basin = 10 kg) per day. A basin of sweepings was estimated to contain 35% peelings, 20% straw, 35% soil and 10% hedge prunings. A proportion of the household waste was incorporated into compost heaps or pits in the adjacent homestead or plantation plot.

2.4.6. Other organic sources

Other organic sources were identified, potential uses discussed during the field visits, and if possible quantities estimated and cross referenced with the literature. These included hedgerows (after Palm et al., undated), weeds, fallowed areas (after Bebwa and Lejoly, 1993), woodlots, ash residues, and crop residue purchased from other households.

2.4.7. Soil erosion

Soil loss due to erosion was estimated at 5.7 Mg $ha^{-1} yr^{-1}$ for annually cropped hillsides in the study area (after Tukahirwa, 1995; Zöbisch et al., 1995). This low rate is in contrast to conventional wisdom for much highland Africa, where figures in excess of 100 Mg $ha^{-1} yr^{-1}$ are quoted, and can be explained by the low rainfall intensity, highly permeable soils of south west Uganda and the mixed cropping system practised (Tukahirwa, 1995).

3. Results

3.1. General farm data

All farms included in this study, and those visited by the parent project (Briggs et al., 1998d), were divided into small scattered land parcels of 0.1–0.4 ha in size, with fields spread from hilltops to valley bottoms. For the 20 farmers interviewed, farm sizes ranged between 0.2 and 4 ha, scattered over 2–15 plots. An example farm land use map, drawn by Richard Tibikweise, is shown in Fig. 3, and illustrates the fragmentation of land and distances from the homestead, which makes individual plot management difficult. The average farm size (excluding woodlots) was 2.2 ha (S.E. 0.3), with most farmers growing bananas and a range of annual crops. The typical area of bananas was 1.20 ha (S.E. 0.3), grown on three separate plots with an average plot size of 0.4 ha (S.E. 0.1). Typical field sizes for annual crops (sorghum, beans, maize, sweet potato, Irish potato, field pea), grown on the hillsides are 0.15 ha (S.E. 0.01), with three to four annual crops grown per year, giving a total annual cropped area of 0.6 ha per farm, with a further 0.2 ha of land being left fallow. An additional 0.2 ha (S.E. 0.04) of annual crops (Irish potatoes and tomatoes) are grown on land adjacent to the homestead, in the homestead plot. It should be stressed, however, that the area of land devoted to each annual crop and the subsequent management, does vary considerable with the resources status of the household and the distance the field is from the homestead (Elliot, 1997; Briggs et al., 1998d), as is the case with many other smallholder farming systems in Africa (e.g., Briggs et al., 1998e; Drechsel and Reck, 1998; Tenberg et al., 1998). Of the livestock present, all households possess a small number of free range chickens, 18 households owned goats, with an average of 15 per household (S.E. 2.9), whilst only five households owned cattle, typically 17 (S.E. 7.2).

3.2. *The organic matter resource model*

From the field data collected and additional socio-economic and farm data obtained from other sources in the study area and the literature, a detailed static time–mass balance model was generated (Briggs et al., 1998d). A simplified version that highlights the major organic matter flows within the system is shown in Fig. 4. The main calculations in the model are based on farmers' numerical estimates (with facilitation from researchers) of the location, use and quantity (fresh weight basis) of existing organic resources with additional information taken from the literature for conversion to a dry weight basis. All values presented are arithmetic means of the data collected from the farmer group and therefore representative of the farming system as a whole and not of individual farmer practice. A consequence of limiting the analysis to visible flows is that the resulting

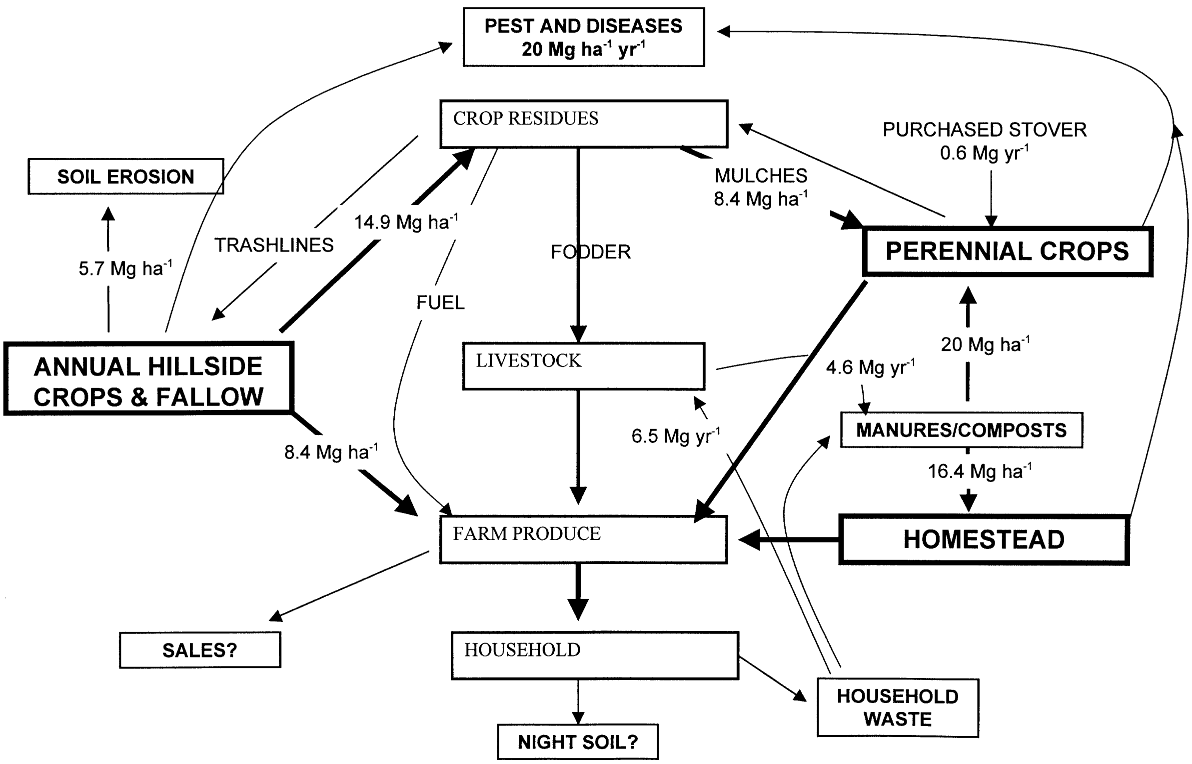

Fig. 4. A simplified time static model of equivalent ($Mg\,ha^{-1}\,yr^{-1}$) organic material flows around a typical smallholder farming system in Kamwezi. Unknown quantities are represented by ?

organic matter balance is only a partial balance and may overestimate nutrient inputs, as losses due to volatilisation, oxidation and leaching at all stages of organic residue decomposition have not been accounted for.

Results indicate that there are many sources of organic material within the farming system. Their uses are varied, some organic materials are used to their full potential, whilst other are not utilised at all. The model depicts the sources, movement and use of organic residues available within an average smallholder farming system on an annual basis and highlights the three major components of the farming system (Fig. 4). These are the perennial and the annual cropping systems and the homestead plot which, after data analysis, was found to be of equal importance in terms of organic resource as both the annually cropped hillside plots and the banana plantations.

With many types of annual crops grown, it was not possible to depict all the sources of crop stover and yields in the model. Intercropping is a common practice in southern Uganda (Linblade et al., 1998) and due to the two cropping seasons, farmers may grow four different annual crop types in a single year in one field. Thus only the most regularly grown crops of beans, sorghum, maize and sweet potato were used. Data presented in Fig. 4 for annual hillside crops (therefore excluding the homestead plot), is depicted on the basis that an average field covers an area of 0.15 ha, with a total of four such plots generally being owned by one farmer. Using the four most dominant crops, an assumption was made (following farmer discussion) that farmers would intercrop beans, maize and sorghum in one season, followed by a monocrop of sweet potato in the next. The model over-simplifies the farming system by this assumption and by assuming all farmers will grow the same four crops on all four hillside fields in any one year. The model therefore is not wholly representative of the farming system, although every attempt was been made to depict typical farming practices, while simultaneously accommodating the limitations imposed by a static model framework.

The rates of application of some residues to the perennial crop e.g., manure, compost, etc., are given on a $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ basis (i.e., approx. 3×0.4 ha plots) in the model (Fig. 4). This allows for improved representation of the farming system, as large quantities of such residues are generally applied to a single plantation (of 0.4 ha) in one season and a different plantation the following season. Thus the residues are not evenly distributed throughout all perennial plots (of 1.2 ha total) but are heavily concentrated on one preferred plot per season, reflecting the individual farmers' assessment of the plots fertility status (Miiro et al., 1995; Briggs et al., 1998d).

Farmers grow a proportionately smaller area of annual crop than perennial crop, at a ratio of 1:2. If stover production is calculated for one field of 0.15 ha growing the four crops (sorghum, beans, maize, sweet potato), in 1 year such a plot could provide 0.84 Mg of stover. As stated earlier, farmers generally grow four such annual plots thus they have the potential to provide 3.4 Mg of annual stover from 0.6 ha, as mulch for the preferred plantation of the season (0.4 ha). Thus the stover from annual crop production can provide mulch to one plantation at a rate equivalent to $8.4\,\mathrm{Mg\,ha^{-1}\,yr^{1}}$. Project participatory rural appraisal work carried out in the project area estimates that a typical banana growing household will purchase an additional $0.64\,\mathrm{Mg\,yr^{-1}}$ of stover to use as a mulch. When the purchased stover is added to the stover produced from the annual hillside crops this equates to an equivalent rate of $9.0\,\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ (Miiro et al., 1995; Elliot, 1997; Briggs et al., 1998c). However, it should be noted that this rate of $9\,\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ does not include mulch provided from banana pseudostems and leaves ($27\,\mathrm{Mg\,ha^{-1}\,yr^{-1}}$), it applies only to the amount of annual crop stover applied to the plantation.

For farmers to be self sufficient in providing adequate mulch from their own annual crop stover, to mulch all 1.2 ha of bananas at an equal rate of $9\,\mathrm{Mg\,ha^{-1}\,yr^{-1}}$, they would currently have to grow 2.15 ha of annual crops, thereby almost quadrupling their current growth output (whether through increased growth of cropped area or improved production per current cropped area). This input assumes that all annual crop stover is used as banana mulch, which, as Fig. 4 indicates, is not the case.

Despite the limitations of the data collected, Elliot (1997) did attempt a partial nutrient balance for the system using the data presented in this paper. Although such balances are of interest to the scientific community and quantify the amounts of nitrogen, phosphorus and potassium within the system, for a farming community that deals solely in organic biomass transfers, it is of questionable relevance. The development of simple models that track visible flows of organic biomass resources, as in Fig. 4, help farming communities understand the organic matter pools within their agroecosystem and identify under utilized resources that may be beneficial if properly managed.

3.3. Organic matter pools

3.3.1. Crop yield and stover

Organic material flows within the farming system indicate a net loss of 14 Mg yr^{-1} (23.3 Mg ha^{-1} yr^{-1}) fresh weight of organic matter from the annually cropped hillsides (Fig. 4). These losses comprise the edible portion of the crop, typically 5.04 Mg per farm per year (8.4 Mg ha^{-1} yr^{-1}), which is either consumed by the household or exported out of the farming system (sold) and the removal and use of stover (Fig. 5). Annual and perennial crop yields and stover production are summarised in Table 3 after losses, based on farmers best estimates, due to pests, disease and

Table 3
Descriptive statistics for annual crop yield and stover production (Mg ha^{-1} yr^{-1})

Crop ($N = 20$)	Yield (Mg ha^{-1} yr^{-1})		Stover (Mg ha^{-1} yr^{-1})	
	Mean	S.E.	Mean	S.E.
Banana	7.7	1.93	27.0	6.75
Bean	0.7	0.14	0.7	0.16
Sorghum	1.5	0.30	4.0	0.80
Maize	2.0	0.71	6.0	2.10
Sweet potato	7.0	0.091	2.0	0.03

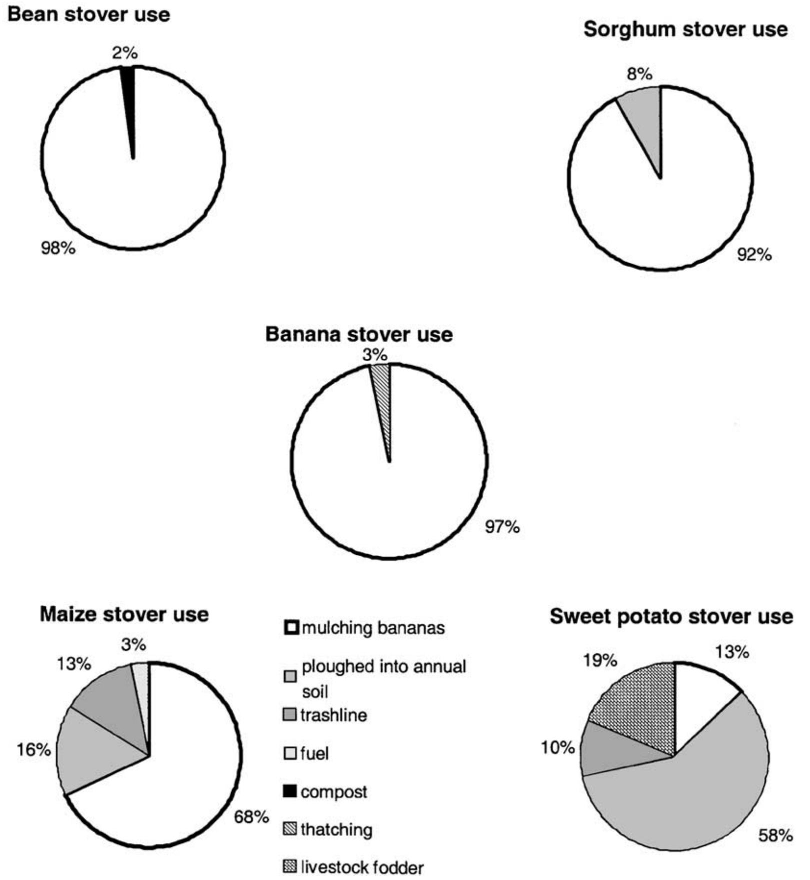

Fig. 5. Average household utilisation of stover from the five major crops; beans, sorghum, banana, maize and sweet potato, in the Kamwezi farming system (based on best estimates from 20 households).

livestock damage have been accounted for (Fig. 6). A further major source of loss from the annual hillside cropping system is due to soil erosion, which is estimated at 3.4 Mg per farm per year (5.7 $Mg\,ha^{-1}\,yr^{-1}$) of soil, from the cultivated hillside (Zöbisch et al., 1995). Little or no soil losses have been reported for the heavily mulched plantation crops.

Stover from the annual crops is the main source of organic residue input to the perennial system, providing 1.88 Mg per farm per year (3.4 $Mg\,ha^{-1}\,yr^{-1}$) of mulch material. Additional banana mulch is supplied from purchased annual crop stover from outside the farming unit, providing a further 0.6 Mg per farm per year. However, the major source of mulch within the perennial banana crop is the cut leaves and pseudostems of the crop itself, 32.4 Mg per farm per year (27 Mg per farm per year) (Fig. 5).

In addition to the mulch residues, 8 $Mg\,yr^{-1}$ of alternative organic material, derived from manure, compost or household waste, is also applied to a preferred banana plot each season. This is equivalent to a rate of 20 $Mg\,ha^{-1}\,yr^{-1}$. The perennial system, therefore maintains a near balance of organic residue losses and gains, with the majority of losses from yield being replenished by manure, compost and annual crop stover residue inputs.

Organic residue inputs to annual cropping system include a proportion of the crops' own stover (1.6 $Mg\,ha^{-1}\,yr^{-1}$) and roots (excluding root crops), which are incorporated into the soil before the next crop is planted. It was estimated that four annual crops per year grown on 0.6 ha, would produce the equivalent of 2.8 $Mg\,ha^{-1}\,yr^{-1}$ of roots (after Shepherd et al., 1996). Additional organic inputs come from trashlines, a traditional hillside SWC technique, not only in Kamwezi (Briggs et al., 1998f), but in the whole of the East African Highlands (e.g., Farley, 1993; Hudson, 1995; Linblade et al., 1998). Trashlines are an important source of organic matter to the annual hillside crops (Fig. 4) and comprise the stubble of grain crops, some of the stover from harvested crops such as sweet potato and maize, and a small addition from hedgerow prunings. Weeds are also added to the trashline throughout the year as the weedings take place. Such additions allow trashlines to potentially provide 2.8 $Mg\,ha^{-1}\,yr^{-1}$ of organic

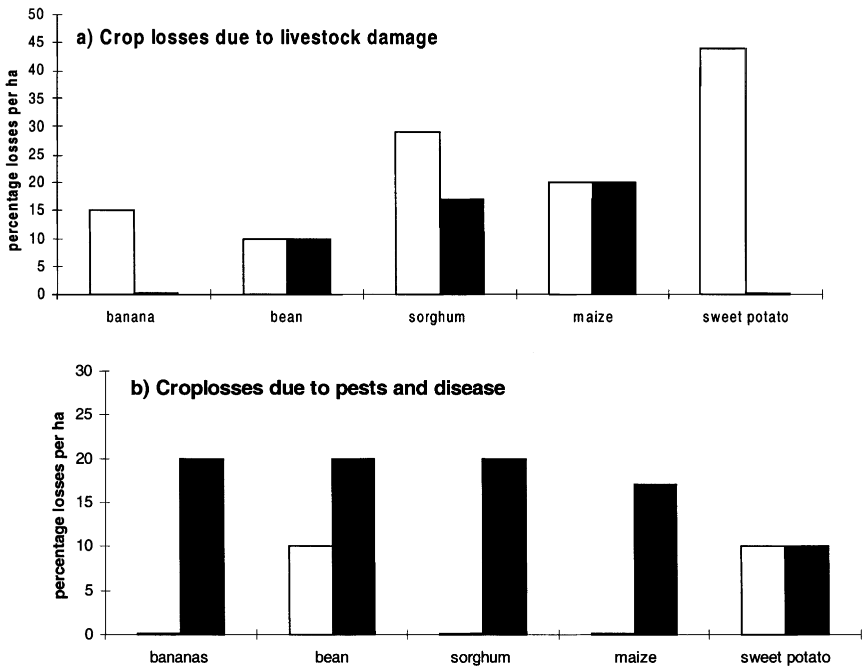

Fig. 6. Percentage of crop (per ha basis) lost each year due to (a) livestock damage and (b) pests, diseases (based on best estimates from 20 households).

residue to the soil (0.4 Mg/0.15 ha field). All such additions total 7.2 $\text{Mg}^{-1}\,\text{yr}^{-1}$ (12.0 $\text{Mg ha}^{-1}\,\text{yr}^{-1}$) of organic material to the annually cropped hillside plots.

The greatest losses of crop yield and stover for both the annual and perennial cropping systems occur through the incidence of pest/disease problems and livestock damage/consumption. The main pest and disease problems highlighted by farmers on annual crops include rats, moles, birds, aphids (*Aphis fabae*), various caterpillars (e.g., American bollworm (*Heliothis armigera*)), stalk borers (e.g., *Chilo partellus*), and fungal diseases, in particular, potato blight (*Pseudomonas solanacearum*), smutt (*Sphacelotheca sorghi*), and cassava mosaic virus spread by white flies (*Bemisia* spp.). In the perennials, damage is mainly caused by weevils (*Cosmopolites sordidus*), nematodes (e.g., *Meloidogyne* spp.) and Panama wilt (*Fusarium* wilt), creating a yield loss of 20 $\text{Mg ha}^{-1}\,\text{yr}^{-1}$ (Fig. 6).

Perennial crops can lose up to 4.8 Mg yr^{-1} of stover from livestock consumption alone, this coupled with the minor use of leaves for thatching, allows 22.2 $\text{Mg ha}^{-1}\,\text{yr}^{-1}$ of fresh banana pseudostems and leaves to be available as a mulch to the crop. Between 10 and 20% of potential annual crop yields are lost through livestock trampling and consumption and up to 40% of crop stover (this includes stover used for animal bedding).

3.3.2. Livestock and manure

Up to 88% of farmers possess livestock, mainly goats, with cow, sheep and pig ownership being more restricted (Elliot, 1997; Briggs et al., 1998d). Goats are the main source of manure, which is generally collected from animals tethered near the homestead at night. Manure is rarely collected from animals during the day, other than from zero-grazing pens, which is practiced by only 2% of farmers living in the region (Briggs et al., 1998d). Free range animals are predominantly grazed on the communal land, with some grazing of fallow land (either deliberate or not). From these source up to 4.6 Mg (S.E. 0.7) of manure are produced annually on an average size farm (of 2.2 ha). Of the farmers interviewed, 90% stated that they considered the closest homestead plot, 2.5 Mg yr^{-1} (12.5 Mg ha^{-1}), and the preferred banana plantation, 0.8 Mg yr^{-1} (2 Mg ha^{-1}) to be the most important fields on which to apply their manure. On the homestead plot manure is generally stored in an uncovered heap until the field is ready to be hand cultivated, at which time it is spread in the field and incorporated into the soil. The 1.3 Mg yr^{-1} of manure that remains is used to make compost and is mixed with household waste/sweepings, and a small quantity of bean stover.

3.3.3. Household waste and composting

Farmers estimate that a typical household produces 9.2 Mg yr^{-1} (S.E. 1.1) of waste (banana peelings and maize cobs), plus 4.4 Mg (S.E. 0.7) of household sweepings (Fig. 4). The majority of the waste peelings, 6.5 Mg yr^{-1} are fed to livestock (either zero grazed or tethered at the homestead) with the remainder being either added to compost (2.3 Mg yr^{-1}) or spread directly on the homestead plot, 0.36 $\text{Mg}^{-1}\,\text{yr}^{-1}$ (1.8 $\text{Mg}^{-1}\,\text{yr}^{-1}$). Most household sweepings are added to compost (2.1 Mg yr^{-1}), with the remainder (0.9 Mg yr^{-1}), added to manure heaps in both the annual and perennial fields.

Other than providing waste peelings and additional mulch to the bananas through banana beer brewing, the food crops have no other uses after human consumption. Brewing typically takes place at a rate of two per month. The residues produced include banana peelings and grass cuttings used to strain the juice, all of which are spread in the plantation where the brewing is taking place. The remaining crop yield is consumed and the waste from this human consumption is left in 'long-drop' toilets constructed close to the homestead. When full, the long-drops are covered with soil and a new one constructed. Human faeces and urine have no use or value to farmers within the Kamwezi cropping system (Fig. 4 'night soil').

Seventy five percent of all farmers interviewed within this study, and by the parent project (Briggs et al., 1998d), make compost either in pits (50%) or in piles (50%), none of which are covered. Farmers who do not make compost came from the poorest resourced group and gave the reasons for not making compost as insufficient time or labour, and a lack of correct tools, e.g., wheelbarrows. However, it must be stressed that compost production is limited, with only 1.7 Mg per farm per year per farm per year (S.E. 0.6), which is split equally between the preferred banana plantation or the homestead plot at a rate of 2.1 Mg ha^{-1}.

3.3.4. Other organic sources

During the field visits it became apparent that a range of organic sources existed within the farming system, that were either not recognised as contributing to the households fertility management practices, or were completely under utilized. These include hedgerows, weeds, fallowed areas and ash residues (Fig. 4).

The dominant hedgerow species in Kamwezi were found to be *Euphorbia* sp., *Acanthus pubescens* (L.) with some *Lantana camara* (L.). Currently farmers only prune the hedgerows in order to reduce competition with the crop and to maintain the appearance of the homestead. Based on survey results and available reports (Palm et al., undated) it has been estimated that 30% (0.4 Mg yr^{-1}) of prunings taken from hedgerows contribute to organic material flows, the rest as is shown in Fig. 7 is either not utilised, used as fencing materials or burnt.

Fallow biomass provides a major addition to the SOM pool of the hillside plots. Vegetation was found to be of local unimproved species and consisted of *Digitaria abscinica* (L.), *Tagetes minuta* (L.), and shrubs of *A. pubescens* (L.) and *Bidens* sp. This 3-year fallow period can potentially provide 5.6 Mg per farm of vegetative biomass, the majority of which is either incorporated back into the soil or placed on the trashline as well as being consumed by livestock (Fig. 7). However, fallow vegetation was not included in the relevant model pools, as this source of organic residue provides an input only 1 year out of 7, due to the 4-year cropping period followed by a 3-year fallow growth on average, and thus is not representative of the annual cycle.

Unfortunately, burning of organic residues, particularly the pea stover and fallow materials is still very common amongst many of the farmers in Kamwezi, and for that matter throughout the East African Highlands (e.g., Briggs et al., 1998f; Drechsel and Reck, 1998; Tenberg et al., 1998). The ash from burnt residues has no use to the farmers and remains where the burning occurred. Frequently this is at the homestead, where the material has been transported, or it remains in the field and is incorporated at the next ploughing, it is rarely distributed evenly throughout the plot. Other fallow material is simply thrown away as waste, with up to 0.34 Mg yr^{-1} being lost after the fallow is cut (Fig. 7). Farmers place no value on this waste material which is frequently thrown onto someone else's land.

The main fuel sources for the homestead are provided from within the farming system unit, either from a woodlot, fallow material or hedgerow cuttings (Fig. 7). Seventy five percent of farmers interviewed possess a woodlot, on which *Eucalyptus* sp. alone is grown. The input from woodlots (i.e., as an ash end product) is annual, but the amount of trees used per year is small; it was estimated that on average 36 trees are harvested per year to provide fuel. The leaves from these trees have no value to the farmer and are

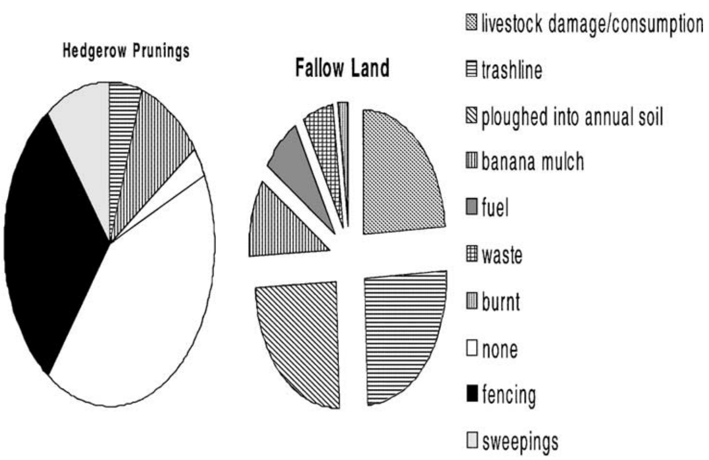

Fig. 7. Household utilisation of biomass from (a) hedgerow pruning and (b) fallow vegetation (based on best estimates from 20 households).

considered a waste product to be disposed of, resulting in an organic residue loss of 0.6 Mg per farm per year. The ash from cooking fires also appears to have little organic value within the farming system other than a limited addition to the perennial crop, where it is applied to the base of fallen stems as pest and disease control agent. The remainder is used in the brewing of sorghum porridge or is thrown away as waste.

4. Limitations and opportunities to improve organic matter management

4.1. Current system

Fragmentation of the land in Kamweiz has a major impact on SWC management strategies used by farmers (Briggs et al., 1998a,b,c,d), as is the case for much of the East African Highlands (Drechsel and Reck, 1998; Tenberg et al., 1998). The non-contiguous nature of field ownership on a hillside makes it unattractive for a farmer to invest in any form of intensive SWC strategies if the farmers who own land parcels up-slope, down slope, or in adjacent fields do not wish to invest in SWC. Without some collective investments an individual's efforts in SWC will be largely wasted. This fragmentation of a homestead's land holding makes land preparation and harvesting difficult, as some plots are located far away from the homestead (e.g., see Fig. 2). Due to the large distances between plots, poorer resourced farmers find it difficult to give maximum care and management to distant plots. For example, in the study area, farmers find it difficult to move crop residues from distant plots to banana plantations, and will spread manure and compost only on the plots closest to the homestead. Consequently, the availability of organic matter residue to a family does not always ensure its use on their banana plantations, but may be sold to better resourced households, or households that are closest to the annual fields, as the model suggests (Fig. 4).

It is clear, however, that the perennial cropping system, as depicted in the model (Fig. 4) is gaining organic residues and thus nutrients, to the detriment of the hillside crops. This emphasises the high priority most farmers' place on banana plantations, reflecting the dependence upon bananas as both the main cash and food crop of the region. Therefore, the current farming system is sustaining the perennial cropping system with a considerable organic matter gain per annum to the detriment and thus potential unsustainability of the annual cropping system. Hillside crops are being grown primarily to provide food for the family, and mulch for the perennial crop. As hillside soils become further depleted and unproductive, a point may be reached when the hillside soil cannot provide sufficient food to meet the needs of a family, or a sufficient stover yield to maintain the banana mulch requirement, rendering the perennial system unproductive also. In such a circumstance the whole farming system could become unsustainable.

Better resourced farmers, about 25% of households, currently rely on the purchase of additional stover from others as mulch for the perennial crop. However farmers, who have previously sold their annual stover, are beginning to appreciate its value as mulch and are becoming increasingly reluctant to sell. Non-availability of residues for purchase would mean that farmers would have to rely solely on their own annual crop stover production—which is declining.

Unfortunately, farmers currently appear to place little value on the improvement of the annual hillside plots. They recognise that these plots are declining in fertility and that incorporating residues into the soil and adding manure, compost, etc., maintains fertility, but constraints of time and labour restrict these inputs to the closest homestead plot which receives considerable nutrient gains from organic inputs, similar to the preferred perennial crop. At present a household concentrates its efforts and resources on one perennial plot per season due to the constraints imposed by lack of time, labour and organic resources. Households cannot carry compost or manure to more distant plots without incurring considerable costs of hired transport and labour. The efforts concentrated on the nearest annual homestead plots are therefore used to produce additional cash crops, such as tomatoes or potatoes. The stover of which is incorporated into the soil.

The model therefore highlights a need for improving the organic resource base to farmers, as existing, known resources are already used to meet the requirements of the current farming system, i.e., to maintain the productivity and thus fertility of the perennial crop and the closest homestead plot.

The organic resource base of the current farming system can be improved either through increased awareness of existing resources, or by growing additional organic matter resources, that specifically require little or no extra labour.

4.2. Improving the organic/nutrient resource pool

It has been reported that many soils in the densely populated humid and sub-humid highlands of East Africa are depleted in soil nutrients (Smaling, 1993; Buresh et al., 1997; Drechsel and Reck, 1998; Mango, 1999). This has been observed for the annual hillside crops of Kamwezi, which exhibit visual deficiency symptoms for nitrogen (N) and phosphorus (P) in particular (Briggs et al., 1998b). An essential factor for maintaining or even increasing the productivity of the hillside system is to increase the supply of plant-available soil P and N. The current literature for both only East Africa (Buresh et al., 1997) and Southern Africa (e.g., Snapp et al., 1998) abounds with organically based strategies that aim to increase farm soil fertility. One strategy with considerable biomass transfer potential is the harvesting of plant materials from the farm boundary (Drechsel and Reck, 1998).

4.2.1. Hedgerows

Recent research has indicated that certain shrubs have the potential to provide a valuable source of plant-available N and P, within smallholder farming systems. The current composition of *hedgerows* in Kamwezi include many species which are not beneficial to soil fertility, e.g., *Euphorbia* sp. Such species could be replaced by vegetation of more value as soil fertility improvers. Experiments have shown that the application of 5 Mg ha^{-1} on a dry matter basis (DM) of *Tithonia diversifolia* (L.) and *L. camara* prunings can improve crops (Niang et al., 1997).

T. diversifolia is a common shrub of the region, which at present grows only along the road verges and is currently not valued by farmers. The high N and P content (35 and 3 g kg^{-1}, respectively (TSBF Organic Input Database, 2001)), together with the low N:P ratio of this shrub, provides a readily available source of these nutrients to growing crops, when the shrubs' vegetation is incorporated into the soil, as it readily degrades.

The shrub *L. camara* is currently grown to some extent as hedgerows in the study area but again, its use is limited, as it has always been regarded as a toxic weed. Persuading farmers to improve hedgerow composition with these two shrubs could boost soil fertility, with little additional labour. However, this would only be of value if farmers are prepared to prune the shrubs regularly, and incorporate the material upon ploughing, or mulch the soil surface. At present farmer's prune only to trim the hedgerow, thus the average farm size of 2.2 ha provides 0.4 Mg of prunings per year. If farmers were to prune regularly (i.e., twice as often as present practice), then improved hedges of *Tithonia* and *Lantana* could provide 1.2 Mg of prunings which could mulch one and a half annual plots, at the application rate of 5 Mg ha^{-1}, the minimum required to boost crop yields (Niang et al., 1997). Unfortunately, this may only be a short term solution, as the increased removal of prunings is a nutrient depleting process itself.

A further benefit of improved hedgerows was highlighted inadvertently by farmers during interviews, in that the production of compost is too labour intensive and time consuming. Recent studies have shown that the quality of compost produced by smallholder farmers in the East African Highlands is lower than *T. diversifolia* prunings (Palm et al., undated) and would not make additional demands on household resources. Switching land and labour resources to hedge improvement and management may result in enhanced soil fertility of arable fields.

4.2.2. Fallow

The present farming system relies almost entirely on the natural re-growth of fallow shrubs for nutrient regeneration of the annual hillside crop soil. The current fallow vegetation, consists of unimproved varieties which do not fix N, and are not deep-rooting, e.g., *A. pubescens*. Trees and shrubs producing high quantities of leafy biomass with high N and P concentrations, and low N:P/C:N ratios, are the most successful at supplying plant available N and P (Buresh et al., 1997; Cadisch and Giller, 1997; Young, 1997). The value of the shrub *T. diversifolia* has already been discussed, and its use as improved hedgerows explained. This shrub could also be adopted to improve the current fallow species, together with other improved shrubs and fallow vegetation. Research has shown that the shrub *Sesbania sesban* (L.) is very effective in taking up accumulated subsoil nitrate (Buresh et al., 1996) and as a legume has the potential to provide plant available N. The vegetation of *Sesbania* is high in N at 31.4 g kg^{-1} (Palm et al., undated) and so would be most beneficial to N deficient soil upon incorporation. *Sesbania* is also more effective than natural grass fallows in extracting subsoil water, which suggests that the potential for leaching losses of nutrients is less under *Sesbania* fallow, than natural fallows (Buresh et al., 1996). Other similarly suitable shrubs for fallow improvement include *Tephrosia interrupta* (L.), *Calliandra calothyrsus* (L.), *Leucaena leucocephala* (L.) (Young, 1997). Numerous workers have demonstrated the advantages of managed fallows, rather than allowing natural re-growth over the last few years (e.g., Kirchhof and Salako, 2001). Unfortunately, none have accepted the challenge of carrying out a rigorous socio-economic analysis of these cover crops from the farming families perspective (Young, 1997; Tian et al., 1999).

The sowing of leguminous species such as *Trifolium* sp. or *Crotalaria* sp. on fallow ground could provide a considerable boost to plant available nitrogen contents within the soil. Such improvements may not prove too problematic, economically or socially for the farmers of Kamwezi to adopt. Thus there is considerable potential to improve fallow species and so increase the nutrient status of the soil, through deep uptake (the subsoil is thin, but overlies a soft, friable mica schist) on the lower slopes and through N-fixation, as well as through the incorporation of improved (e.g., *L. camara*) vegetation, providing additional organic matter for the soil leading to improved soil structure, enhanced water holding capacity and thus nutrient supply.

Valuable nutrients are lost through the burning of fallow vegetation, as they are throughout sub-Saharan Africa. Such practices are being widely discouraged, but are difficult to control. When burning does occur in the field, the piles of remaining ash are not distributed around the plot, or well incorporated into the soil. Many farmers are aware of the losses of nutrients incurred by burning, but the justification is the eradication of weeds, which without adequate herbicides, are a major problem. Again this issue is not easily solved, but it is hoped that through improved fallow management, the incidence of weeds will be reduced, and so farmers will have less cause to burn such a valuable source of organic residue.

4.2.3. Livestock interactions

The damage caused by livestock to both cropping systems is considerable, with on average 20% both of stover and yield being destroyed, particularly in the annual crops. It is difficult for farmers with inadequately fenced fields, to prevent such damage. During the interviews, it was observed that the more prosperous farmers could alleviate such damage through more employees, who could herd the livestock away from plots before they caused damage. The destruction of field bunds was highlighted as the other major livestock problem. All farmers recognised this destruction as a way of increasing soil erosion, and thus causing losses of soil fertility. A solution may only be found in the increased construction of hedgerows and barriers to control the movement of livestock, but this is too time consuming and labour intensive for farmers to adopt at present. The promotion of zero-grazing would go some way to alleviating this problem, and is on the increase within the Kamwezi farming system (Briggs et al., 1998d) and would also benefit from hedgerow and fallow improvement, as many of the species mentioned above could be cut and used for fodder, in particular, *C. calothyrsus* and *L. leucocephala*.

Unfortunately, with the current livestock management practice, the majority of manure from extensively grazed animals is wasted on paths or grazing land and is washed away with the rains. Consequently, the quantities of manure that can be easily collected from pens and night shelters is relatively small, based on the farmers best estimates about 4.6 Mg per farm per year. The situation is further compounded by the poor manure storage and handling practices that result in major losses of nutrients, particularly nitrogen due to volatilisation, oxidation and leaching. Information on the impact of such nutrient losses is limited (Probert et al., 1992), but work in other parts of Africa is being undertaken to redress this situation through farmer education on the contribution manure can make to their cropping system, correct manure management and application practices (Nzuma et al., 1998).

4.2.4. Compost management

The present rate of composting is low and the quality dubious, due to the poor construction methods of compost heaps/pits. The majority of pits are constructed close to the homestead for ease of transport of material to be composted. Some, more affluent farmers construct pits by the field, which is to receive the compost, as they can afford to hire labour to carry materials. Howard (1943) has estimated that between 22 and 26 Mg of compost can be produced annually with one cow, using crop residues and dung from the stable floor mixed with soil. Thus, the increase of zero-grazing within the farming system could benefit compost production considerably. Unfortunately, the majority of farmers at present do not possess surplus residues for compost production, as any excess vegetation is used for mulching bananas. One of the main restrictions highlighted by farmers who did not compost was the high additional labour requirement for compost pit construction. However, the labour need not be so great if some of the existing residues (Fig. 4), regarded as waste are composted. These could also include alternative organic sources, such as *T. diversifolia* cuttings, which can be either incorporated into soil, or added to the compost (Drechsel and Reck, 1998). Farmers can therefore decide for themselves which practice they prefer, with those who already compost being trained in appropriate composting techniques, so that their labour is not wasted, and the full benefits of a good quality compost realised.

4.2.5. *Household waste management*

Large quantities of organic residues are produced through household waste, which is recycled to the best of the farmers' ability. However, some is lost through livestock fodder, the manure by-product of which is subsequently not fully utilised, either in the collection or storage processes of manure management. Household waste applied to the surface of fields, would potentially have more benefit as a compost ingredient, as large quantities of nutrients, particularly nitrogen, are lost from the decomposing residue, which may be left exposed on the soil surface for 2–3 months before incorporation (Dalzell et al., 1979).

4.2.6. *Pest and disease*

Pest and disease problems appear to cause major losses to both annual and perennial crops. Farmers are reporting rising losses, particularly in bananas with the spread of weevils (*C. sordidus*) and Panama (*Fusarium oxysporum* Schlecht. F. *cubense*) wilt disease. The solutions to such problems are complex, as many pesticides and fungicides that are available for perennial and annual crops are both expensive and frequently unavailable to the subsistence farmer. The present extension system is promoting the use of improved crop husbandry practices to decrease the spread of disease in bananas, e.g., through in-line suckering, or improved rotations of the annual crops. Such cultural methods will continue to marginally offset problems, but without external inputs of pesticides/fungicides, it appears likely that the losses of yield and stover due to pests and disease damage, will increase, given the limited land holdings and labour available to each household.

4.2.7. *Agro-forestry*

Trees have long been recognised as major elements in soil fertility regeneration and conservation (Atta-Krah and Kang, 1993). The dominant tree species grown by farmers at present are *Eucalyptus* sp., the leaves of which have no value to the farmers due to their toxic nature and are simply burnt, thus a loss of 0.6 Mg yr^{-1} of an organic resource is lost from the farming system unit. *Eucalyptus* is grown for its rapid biomass production rates and its high timber value, however there are many other tree species which have equal growth rates and timber quality, e.g., *Alnus* sp. *Melia volkensii* (L.), *Cassuarina cunninghamiana* (L.), *Grevillea robusta* (L.) to name but a few (ICRAF, 1992). The majority of these trees have the additional benefits of being able to provide N and P to the soil and thus crops, through N fixation, capturing leached N and recovering N and P from the subsoil (Palm et al., undated).

However, it should be recognised that such measures of nutrient replenishment are only temporary, particularly of P, as the availability of subsoil P is not unlimited, and the capture of P from the subsoil by deep rooted trees is small (Buresh et al., 1996). Trees essentially utilise and recycle recalcitrant soil P pools that are not utilised by crops (Palm et al., 1991). The leafy biomass of trees frequently has a higher N:P ratio than the ratio of N:P required by crops. Therefore quantities of biomass that supply sufficient N to a crop may not supply sufficient P. Jama et al. (1998) concluded that it is economically better to integrate an inorganic P source with the organic material, whereby the organic material provides all the required N for the crop and the inorganic P source meets the additional requirement of P. This view is supported by TSBF/ICRAF research which also suggests that integration of inorganic materials such as *T. diversifolia* with inorganic P sources (e.g., rock phosphate) can reduce the sorption of P on soil surfaces (Nziguheba et al., 1998). However, the use of inorganic P fertilisers does not help farmers, who cannot afford and do not have access to such a resource. Their only alternative at present is to persevere with the organic resources they have at their disposal, and to be assisted in the correct management and use of these resources, in order for them to be used to their full potential.

The leaves of such improved trees could provide an organic resource to be used either in compost, as a mulch material or as livestock fodder. If farmers could be persuaded to grow at least some other tree species, and to move their woodlots periodically, i.e., every 10–20 years, then the farming system, in particular, the annual crops, would benefit considerably (Kirchhof and Salako, 2001). Although destumping operations on reclamation are both labour intensive and time consuming, this is not foreseen as a problem in Kamwezi, as farmers are currently having to reclaim woodlots/woods for cropping due to land shortages and already perform this labour intensive task. Rotating with their own woodlots would save land and improve existing hillside fields.

4.2.8. Indigenous soil water conservation/fertility management interactions

Vegetation grown on bunds between plots has no use to farmers at present, and consists of species which have no value within the farming system, e.g., *Bidens pilosa*, *A. pubescens*. The improvement of bund vegetation would benefit farmers and following the recommendations of the parent project (Miiro et al., 1995) some are beginning to grow fodder grasses such as *Setaria splendida* (L.) and *Pennisetum purpureum* (L.), and legumes such as *Mucuna pruriens* (L.) on bunds. The continuation and extension of improved bund vegetation management would provide an additional nutrient source to soil, especially if the vegetation were cut and incorporated, or mulched. Lal (1975) found that mulching maize could suppress weed growth by almost 75%. Such a suppressant would be of considerable benefit to the farming system, where weed control on hillsides is problematic and leads to reduced yields. However, such improvements are time consuming and labour intensive, and so may not be readily adopted by farmers. Indeed attempts in other highland areas to persuade farmers to adopt techniques of improved use and management of bund vegetation have met with limited success (e.g., CARE Kabale, pers. commun.; Buresh et al., 1997; Young, 1997).

However, laying trashlines across the contour of the fields is widely practised by many farmers, not only in Uganda but throughout East Africa (Critchley et al., 1994). Associated field studies have shown that the trashlines are effective conservation measures, trapping soil and causing an accumulation of associated soil nutrients, immediately up and down slope of the trash barrier (Briggs et al., 1998b). In general, farmers in Kamwezi break trashlines every two seasons, thus the ‘trash’ is incorporated into the soil annually, although it is not yet known whether the nutrient gains provided by soil entrapment, are enough to fulfil the nutrient requirement of the growing crop.

5. Conclusion and recommendation

A widespread constraint to crop growth at the subsistence level in Africa is poor soil nutrient availability, due largely to the low inherent fertility of highly weathered soils (Sanchez et al., 1996). This problem is further exacerbated by the internal and external movement of plant material within the farming system, both of which are important causes of nutrient loss. Both qualitative and quantitative information was collected from the farmers in Kamwezi to develop a time static model of organic resource flows that described the current situation. Model development helped highlight the sources, whereabouts and current management strategies of organic resources and define the flow patterns around the farming system. Results confirmed a net transfer of 24 Mg ha^{-1} yr^{-1} ($P < 0.01$) of fresh organic material, mainly crop yields and residues, from the annually cropped hillsides (covering an area of 0.6 ha per farm ($P < 0.001$)) to other parts of the farming system. The stover from the annual crop is used almost exclusively as mulch in banana plantations. The participating farmers recognised that the hillside soils have gradually become depleted of nutrients, as annual crop yields have declined. Unfortunately, farmers place little value on improving the nutrient status of hillside fields distant from homesteads. Households, as is the case with most African subsistence farmers, would rather concentrate their

Table 4
Key recommendations to improve organic matter flows

Make farmer aware of under-utilised and alternative organic matter resources
Improve hedge row species composition
Improved fallow management
Improved management of field boundaries/earth bunds through tree establishment and planting fodder grasses
Improved management of ash, manure and compost
Discourage the burning of dry season pasture on the hillsides

limited labour and organic residue resources in maintaining the fertility/productivity of the more profitable parts of the farming system, in this instance banana plantations and annual fields close to homesteads. Consequently, in the short term, the perennial banana system maintains a balanced flux of organic resources at the expense of hillside soil fertility.

Unfortunately, over the longer term, the current farming system will inevitably lead to a severe reduction in mulch availability, which will mean perennial crop yields will eventually decline, leading towards a potentially unsustainable farming system. Fortunately, however, there are organic resources within the existing farming system, that are currently under utilized and could help sustain and even improve the yields of both annual and perennial crops. The whereabouts, management and value of these organic resources was highlighted during the model development and can be used to develop alternative management strategies for organic residues, that are both economically appropriate to the farmer and logical to the resources available, at farm level (Table 4).

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