Nutrient flows and balances in intensive crop-dairy production systems in the Kenya highlands

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Summary
Sustainability of their agricultural systems is essential for many tropical countries where the majority of the people depend upon agriculture for their livelihoods. In the short term economic sustainability is the main factor influencing viability of an agricultural system and of the farms which form its production units. In the long-term, however, economic viability will depend upon the nutrient status of a system. In common with much of the eastern African highlands, Kiambu district in central Kenya has high and increasing pressure on its land and farmers are responding by steadily intensifying their farming systems. This paper addresses the hypothesis that where ruminant livestock are present in intensifying smallholder cropping systems, they make a positive contribution to the nutrient status of the smallholder system.
For 21 crop-dairy farms representative of the major smallholder-farming systems in the central highlands of Kenya, annual nutrient balances were determined in a longitudinal study. The farms were visited twice a week; data on all farm inputs and outputs were collected, based on farmer recall. Measures of livestock feed inputs were collected fortnightly. Estimates of nutrient gains and losses in the soil resulting from erosion, leaching, denitrification, volatilisation and N fixation were taken from the literature. Using these data, annual nutrient balances per hectare were estimated for N, P and K.
The majority of the sample farms had balanced nutrient flows or were in positive balance for N, P and K overall because of positive flows to the dairy sub-unit, which counterbalanced the outflows from the crop sub-unit. The dairy unit contributed significantly, principally through feed purchases, particularly concentrates for lactating cows. Napier grass and crop residues were also purchased, and large quantities of roadside grass were collected from outside the farms. On the majority of the farms the nutrients returned to the cropping land as manure (which consisted of faeces, bedding material and feed refusals) contributed more nutrients than inorganic fertilisers.
It is concluded that the dairy cattle played a major role in contributing nutrient in-flows into these intensive smallholder farms, as well as providing the household's regular source of income through milk sales.

Key words: Nutrient cycling, Nutrient balances, System analysis, Kenya, Dairy cattle

1 Introduction

In Kenya, in common with many tropical countries, more than 90% of all households depend for their livelihoods on agriculture (KCBS, 1999). The sustainability of the agricultural systems on which the majority of people depend is therefore essential for their wellbeing. In the short term economic sustainability is the main factor influencing the viability of a system and of the farms which form its production units. In the long-term, however, economic viability will depend upon its nutrient status. Sustainability does not mean that an agroecosystem, in our case the farm, is not subject to change. The system will be dynamic and fluctuations the norm, but overall a balanced system will be preferred for natural resource management reasons, and for profit. Sustainability has been defined as "the successful management of resources to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving resources" (CGIAR, 1988). Therefore, long-term sustainability of agricultural systems must rely, as much as possible, on the use and effective management of internal and external resources.
In Kiambu district in the Central Highlands of Kenya, pressure on land is increasing. Human population density in the district increased on average from 194 persons per km^2 in 1969 to 350 in 1989 (KCBS, 1971,1991) and the trend is continuing. Farmers have responded by intensifying their production systems. Between 1982 and 1998 the proportion of land used for cropping increased by 30 %, but fertiliser use did not (KCBS, 1999). How are farmers balancing their farms' nutrient flows, or are they "mining" their farms? For smallholdings in Western Kenya, Smaling (1993) calculated a negative annual balance of 112 kg N per hectare, and considered this typical of much of Africa.

In the central highlands of Kenya dairy cattle play an important role in the nutrient cycling on smallholder farms (Lekasi *et al*., 1998) as they speed up the rate of nutrient turn over. Rumen digestion slowly degrades fibres of crop residues and forages, which are then returned to cropping land in manure. The dairy cattle also act as a major conduit of nutrient inputs into the farm-system as farmers buy concentrate feeds and fodder to help meet the dairy unit's feed requirements for marketed milk production. This paper addresses the hypothesis that where ruminant livestock, and particularly dairy cattle, are present in intensifying smallholder cropping systems, they make a positive contribution to the nutrient status of the farm.

2 Material and Methods

2.1 Case study area

Kiambu, a district in the central Kenya highlands, has predominately deep, fertile humic Nitosol soils (FAO-UNESCO, 1977). The district is covered by steep sided, narrow valleys, which limit mechanised farming and require substantial soil erosion control. Rainfall is bimodal with the long rain season from March to June and the short rain season from October to December. The dry season from December to March is hot, while that from June to September is cold. Annual rainfall ranges from 800 to 1,500 mm depending on elevation, exposure, and aspect. The central highlands are divided into three main zones (Upper Highland (UH), Lower Highland (LH) and Upper Midland (UM)) based on rainfall, altitude, temperature, soil type and the length of growing season (Jaetzold and Schmidt, 1983). Two study sites were selected: Limuru Division with 10 study farms, and Githunguri Division with 11 farms. Limuru lies in the Lower Highland zone, which is suitable for tea and vegetables. In 1989 its human population density was 688 persons per km^2 (KCBS, 1990). Coffee production is the main cash crop in the Upper Midlands, the site of Githunguri, which in 1989 had a population density of 646 persons per km^2. Associated with these cash crops is dairying, which is second only to the cash crops in economic importance (Staal *et al*., 1998).

2.2 Selection of the farm and data collection

To characterise the current farming systems, a cross-sectional survey using a structured questionnaire was carried out on a random sample of 340 agricultural households (Staal *et al*., 1998). Based upon the results of the survey, 21 representative crop-dairy farms were selected for a longitudinal study to characterise the seasonal crop and livestock activities, to capture the major inputs and outputs and to estimate nutrient flows and balances. Over the 12 month study period, the farms were visited twice weekly to collect farmer recall data. Livestock feed inputs were collected and measured fortnightly. Weights of the different measures used by farmers (e.g. wheelbarrow, bucket) were determined by taking sample measurements. The data were entered using the Access data management software and verified. Estimates of nutrient gains and losses in the soil resulting from erosion, leaching, denitrification, volatilisation and N fixation were taken from the literature (Shepherd *et al.*, 1995). Using the field data and literature estimates, nutrient balances per hectare were estimated for N, P and K. Balances per hectare were also estimated for dry matter (DM) to quantify the inflows and outflows of organic matter.

The nutrient budgets were calculated for land utilised for agriculture. Land with, for example, rental houses was excluded. Further, the poultry units of the four farmers who kept poultry on a commercial basis were regarded as a separate enterprise and poultry inputs and outputs were not included in the nutrient flow calculations. Poultry manure going either to cropping land (as org. fertiliser) or to the dairy animals (as concentrate feed) was considered as coming from outside the farm. Inputs to the farm system were concentrates, fodder from outside the farm, inorganic fertiliser, manure from outside the farm and natural inputs such as biological N-fixation and deposition. Milk and meat extracted for home consumption or for sale, and ruminant liveweight gain together with the crop production (home consumed or sold), fodder sold and soil nutrient leaching and erosion were the outputs. In aggregating the nutrient flows, the farms were considered to consist of two sub-units, the livestock (mainly dairy) sub-unit, which included the small ruminants and any donkeys, and the crop sub-unit, including cash, food and fodder crops.

3 Results

3.1 Farm system

The study farms had an average size of 1.5 ha (range 0.4 – 2.9 ha) of which 1.1 ha (0.4 – 2.2 ha) was cultivated. Cattle for dairy production were the main source of agricultural income for more than half of the farmers. On average 3.6 TLU ha^{-1} (0.3 – 8.7 TLU ha^{-1}) dairy cattle were kept, as well as some goats and sheep; three farmers had a donkey. All households had local scavenging chickens and four farmers had a commercial poultry sub-unit. The staple food in Kiambu is Irio, a mixture of Maize, Beans and Potatoes. Therefore all farmers plant Maize (mean 0.2 ha), Beans (0.1 ha) and Potatoes (0.1 ha). Coffee (0.35 ha) was produced as the main cash crop on all the study farms in the coffee-zone. Vegetables, mainly kales (*Brassica oleracea*) and cabbages, were produced for home consumption on all coffee-zone study farms and in the non coffee-zone for home consumption and as cash crops. To feed their dairy animals all farmers also planted Napier grass (*Pennisetum purpureum*) (0.2 ha).

3.2 Nutrient balances

There were two major internal flows, the transfer of nutrients from the livestock (dairy) sub-unit to the crop sub-unit as manure and from the crops to livestock as fodder. Flows from one sub-unit to another were considered as farm-internal nutrient flows or the recycling of nutrients. The results in Table 1 show that in the study year the farms were, on average, in positive DM balance (3,022 kg ha^{-1} year^{-1}), had positive N (31 kg ha^{-1} year^{-1}) and P (38 kg ha^{-1} year^{-1}) balances and had a small negative K balance (- 3 kg ha^{-1} year^{-1}). Whereas the nutrient balances for the dairy sub-unit were on average positive, those for the crop sub-unit (except for P) were negative (Table 1). Variation amongst farms was high (SDs close to or higher than the means, Table 1), reflecting differences in management (mainly the amount of concentrate bought) as well as natural conditions.

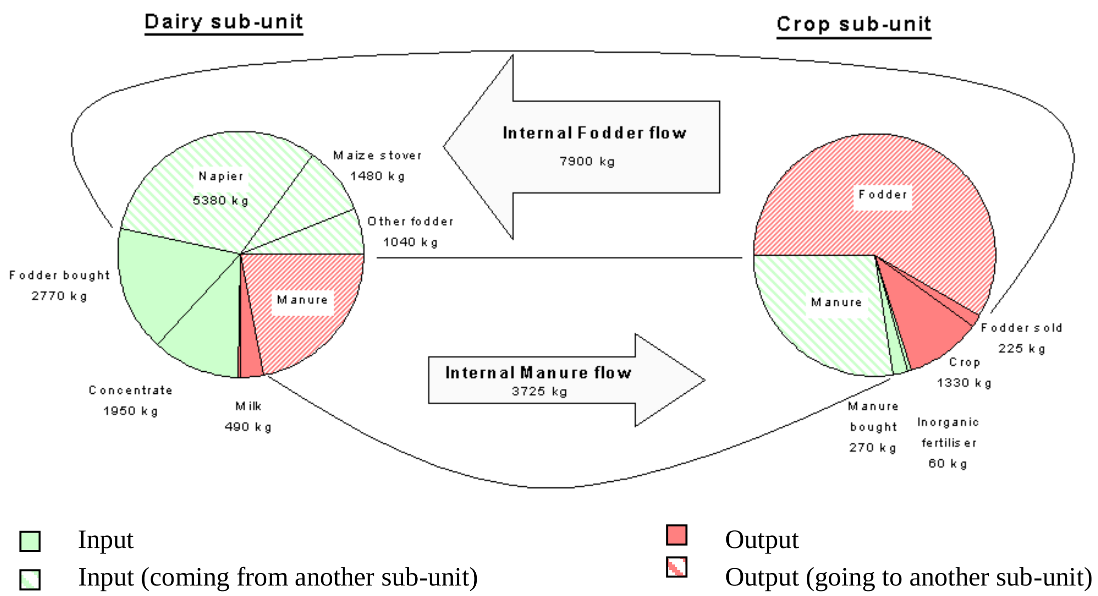
Table 1 Average Nutrient balances (kg ha^{-1} year^{-1}) for the farms level and sub-units.

Nutrient balance	DM		N		P		K	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Farm	3022	5073	30.6	67	37.5	45	- 3.2	63
- Dairy sub-unit	8400	7533	92.9	91	15.9	23	103.8	96
- Crop sub-unit	- 5380	5262	- 62.2	61	21.6	40	- 107.0	73

3.2.1 Dry Matter Balance

The mean DM balance was positive (Table 1). On average two-thirds of the fodder for cattle was grown on the farm. Fodder from outside the farm (“external”), either bought or collected free of charge, was used on 85 % of the farms. The “external” fodder consisted on average of 45 % Napier, 35% Maize stover and 20 % other fodder (weeds, roadside grass, Banana pseudo-stems). In times of surplus two farmers sold a small amount of Napier. All farmers bought concentrate. Commercial Dairy meal (43 %), Wheat bran (23 %), and Maize germ (15 %) were those most commonly purchased. All home-produced manure was applied to crops. And, in addition, a third of the farms purchased poultry and cattle manure. Half of the farmers applied manure on their Napier plots. The amounts of inorganic fertiliser used were to 73 % Di-ammonium Phosphate (DAP), 23 % NPK-fertiliser (20:20:10) and top-dressing (CAN, Urea). Some fertiliser was purchased by all but two farmers. The rate of application varied between 6 and 300 kg ha^{-1} year^{-1}.

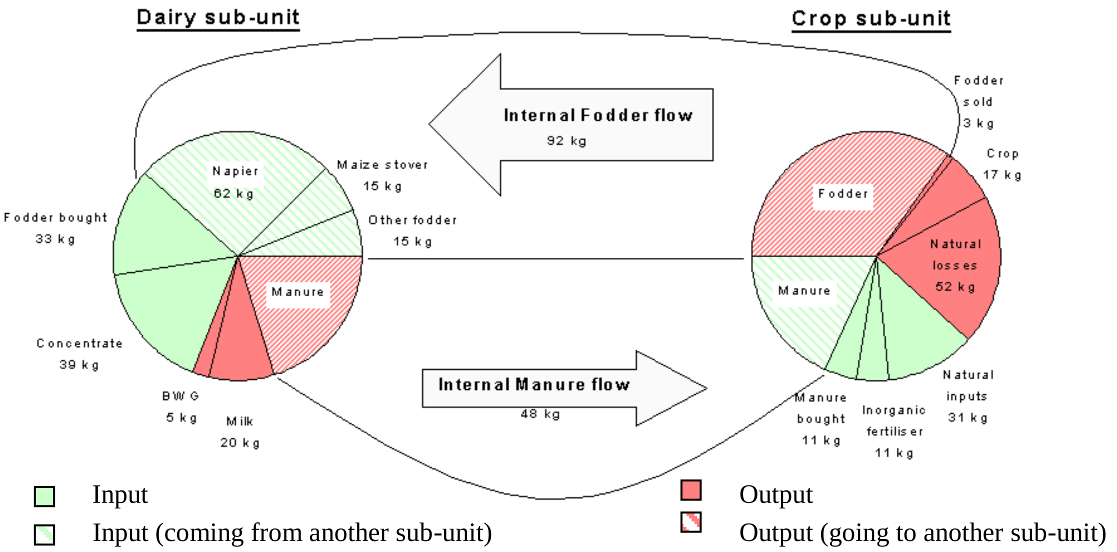
Figure 3.1 Average annual DM flows (kg ha^{-1} year^{-1}) on the study farms in Kiambu



3.2.2 Nitrogen Balance

More than 50 % of the N-inputs to the farm-system came through the dairy sub-unit. Purchased concentrate feed was the main source followed by fodder (Napier, Maize stover and other crop residues). Inorganic fertilisers contributed only 9 % to the total farm-system N-inputs. Under the assumptions made for losses and gains through natural processes, soil erosion and other natural losses from soil (leaching, volatilisation) were the major contributors to the nutrient losses of the system.

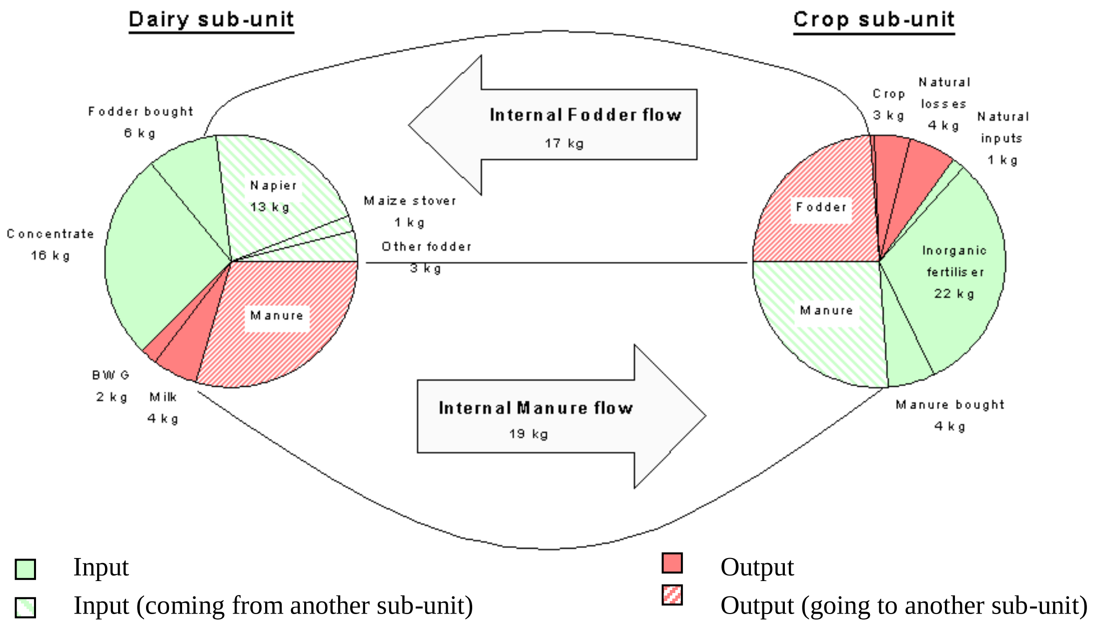
Figure 3.2 Average annual Nitrogen nutrient flows (kg ha^{-1} year^{-1}) on the study farms in Kiambu



3.2.3 Phosphorus Balance

Of the different inorganic fertilizers used, more than 70 % of the total was Di-ammonium Phosphate, which has a very high P content (48%). It was the main source of P (44 %) entering the farm-system, followed by mineral licks and minerals in concentrate feeds (purchased for livestock) which contributed 33 %. Phosphorus was the only nutrient for which the internal nutrient flow was balanced (Table 1). It was also the only one for which the crop sub-unit was balanced.

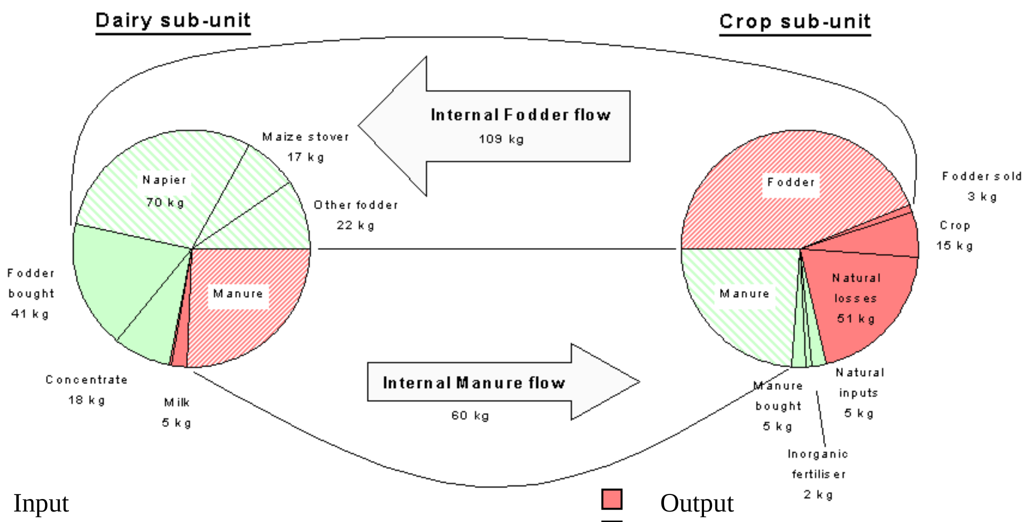
Figure 3.3 Average annual Phosphorus flow (kg ha^{-1} year^{-1}) on the study farms in Kiambu



3.2.4 Potassium Balance

Potassium is found mainly in green material. Hence fodder on the study farms played an important role in its cycling. More than half of all K-inputs were imported through fodder. The internal nutrient flow was not balanced (Table 1), as more K was transferred as fodder from the crop sub-unit to the dairy sub-unit than returned through manure.

Figure 3.4 Average annual Potassium flow (kg ha^{-1} year^{-1}) on the study farms in Kiambu



Input
Input (coming from another sub-unit)
Output
Output (going to another sub-unit)

4 Discussion and Conclusions

During this one-year study, representative intensive maize-dairy small-scale farms in the central highlands of Kenya had net positive nutrient flows for N and P and were close to a balance for K. Whereas depletion of N and K was occurring from the cropland (reflected by the negative balances for the crop sub-unit), the dairy sub-unit was in surplus for N, P and K. The calculated surplus may be an over-estimate as nutrient losses through volatilisation, leaching and transport will occur from the time faeces and urine are excreted until their application as manure on the fields. The imports of nutrients to the dairy sub-unit were principally through feed purchases, particularly concentrates but also through grasses (including roadside grass) and crop residues. These inputs to the dairy sub-unit were required to enhance marketed milk production to generate cash income.

In common with the results presented here, studies of smallholder farming systems at the crop sub-unit level by Smaling (1993), Shepherd & Soule (1999) and IFDC (1999) estimated negative nutrient balances for N and K. However, the P surplus (Table 1) estimated for our maize-dairy farms contrasts with those findings. This might be as a result of the applications of the dairy manure from cattle supplemented with minerals, directly or through concentrate feeds, as well as the use of DAP fertiliser to the field.

The results from the whole farm studies by Gitari *et al*. (1999) and in Tanzania (MAC, 1999) show, in contrast to our study, negative nutrient balances at the farm level. This may be explained in part by farmers in the Gitari *et al* and Tanzania study areas (Embu and Arusha) purchasing less feed (particularly purchased concentrates) for their cattle, and relying more on fodder produced on their farms. Therefore keeping a dairy cow on the farm does not mean that the farm's nutrient status will improve *per se*, because without a secure market for the sale of milk the farmer may not invest in increased production, even if feeds, including concentrates, are available.

The generality of our estimates also need to be qualified because the study year included rainfall well above average, as a result of the El Niño phenomena. The unusually high rainfall damaged food crops resulting in lower than long-term average yields but relatively higher yields of fodder crops and weeds. In an "average" year therefore, it could be expected that more nutrients from crops would be exported and fewer nutrients from fodder would come from the farm, resulting in the need for more purchased fodder. Consequently in an "average" year (i.e. over the medium and long-term) the importance of the dairy sub-unit as a nutrient importer would be expected to be greater than estimated in this particular study year, although the overall balance would probably remain the same.

Finally it should be noted that the nutrient budgets and flow diagrams presented in this paper are useful as advisory tools for farm management. For example, it can be concluded in this intensifying maize crop-dairy system improved feeding and manure management practises would help increase the efficiency of nutrient utilisation and transfer. In the same way, rigorous soil erosion control measures and improved cropping practises will help to control natural losses from the crop sub-unit.

As indicated by Smaling *et al*. (1997) nutrient balances should also be treated as awareness raisers for policy-makers, with emphasis on the nutrient deficits in the crop sub-unit and the beneficial surpluses in the dairy sub unit. These beneficial surpluses in smallholder crop-dairy systems contrast with the negative impacts resulting from many intensive dairy production systems in industrialised countries.

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6 References

CGIAR (1988). Sustainable agricultural production: Implications for International Agricultural Research. FAO Research and Technology Paper No. 4, FAO, Rome.

FAO (1988). Soils map of the world: revised legend. Food and Agriculture Organization of the United Nations, Rome. 119 p.

Gitari J.N., Matiri F.M., Kariuki I.W., Muriithi C.W. and Gachanja S.P. (1999). Nutrient and Cash Flow monitoring in Farming Systems on the Eastern Slopes of Mount Kenya; In Nutrient disequilibria in Agroecosystems concept and case studies; 1999; ed. by E.M.A. Smaling, O.Oenema and L.O.Fresco; CABI Publishing; UK

IFDC (1999). Estimating rates of nutrient depletion in soils of Agricultural Lands of Africa. International Fertilizer Development Center, Muscle Shoals, AL, USA

Jaetzold R. and Schmidt H., (1983). Farm Management Handbook of Kenya. Vol. II/B. Central Kenya. Ministry of Agriculture, Nairobi, Kenya

K.C.B.S. (1998): Kenyan Central Bureau of Statistics; Ministry of finance and planning; Nairobi; Kenya. 1998

Lekasi, J.K., Tanner, J.C., Kimani, S.K. and Harris, P.J.C. (1998). Manure management in the Kenya Highlands: Practices and Potential; HDRA publications, 1998

MAC (Ministry of Agriculture and Co-operatives, Tanzania) (1999). Integrated plant nutrient management in the small-scale mechanised mixed farming system of Northern Tanzania; Arusha, Tanzania

Shepherd, K.D., Ohlsson E., Okalebo J.R., Ndufa J.K., and David S. (1995); A static model on nutrient flow on mixed farms in the highlands of western Kenya to explore the possible impact of improved management; In Powell J.M., Fernández-Rivera S., Williams T.O., Renard C. (eds.), Livestock and sustainable nutrient cycling in mixed farming systems in sub-Saharan Africa. Proceedings of an international conference, 22 - 26 November 1993; International Livestock Centre for Africa (ILCA), Publications Section, Addis Ababa, Ethiopia; Vol.2, pp 227 - 246.

Shepherd, K.D. and Soule, M.J. (1998). Soil fertility management in west Kenya. Agriculture, Ecosystems and Environment. 71: 133-147. Smaling E.M.A. (1993). Soil nutrient depletion in sub-Saharan Africa. In: H.Van Reuler and W.Prins (eds.), The role of plant nutrients for sustainable food crop production in SSA. VKP, Leidschendam, The Netherlands.

Smaling, E.M.A., Nandwa, S.M. and Janssen, B.H. (1997). Soil fertility in Africa is at stake. In: Buresh, R.J., Sanchez, P.A., Calhoun, F.G. (Eds.), Replenishing Soil Fertility in Africa. Soil -Science Society of America and American Society of Agronomy, Madison, WI, pp. 47-79.

Staal, S.B.; Chege, L.; Kenyanjui, M.; Kimari, A.; Lukuyu, B.; Njubi, D.; Owango, M.; Tanner, J.; Thorpe,W. and Wambugu, M., (1998). Characterisation of dairy systems supplying the Nairobi milk market: A pilot survey in Kiambu district for the identification of target groups of producers. KARI-ILRI-MoA. Nairobi, Kenya