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Socio-Economic Factors, Soil Fertility Management and Cropping Practices in Mixed Farming Systems of Sub-Saharan Africa: A Study in Kiambu, Central Highlands of Kenya

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Abstract: A study was carried out in Kiambu District, central highlands of Kenya to explore the effects of household socio-economic factors on farm nutrient balances and agro-economic performance and to determine nutrient depleting and conserving cropping practices in the crop-dairy (mixed) farming system. Data was collected from 30 smallholder farmers and processed using nutrient monitoring (NUTMON) tool. Family earnings (sum of net farm income and off-farm income) were low and off-farm income accounted for 61% of family earnings of the studied households. On-farm livestock density (TLU ha^{-1}) was the main determinant of farm N, P and K nutrient stocks and balances. The mean farm (total) nutrient balances were -2.6 kg N ha^{-1} half year^{-1}, 36.7 kg P ha^{-1} half year^{-1} and 16.9 kg K ha^{-1} half year^{-1}. In the analysis, purchased livestock feeds (and fertilizers) were the major determinants of farm N, P and K nutrient balances. The major loss pathway for P and K was erosion, accounting for 35 and 66% of total P and K outflows respectively. For N, it was leaching. Farmers adopted preferential soil fertility management strategies for cropping practices resulting in nitrogen, phosphorus and potassium nutrient mining under Napier (monocrop) and coffee (intercrop) fields and nutrient conservation under maize (intercrop) fields.

Key words: Crop-dairy, cropping practice, nutrient balance, soil degradation, soil fertility management, tropical farming

INTRODUCTION

Food production and soil fertility management in sub-Saharan Africa (SSA) is mainly done by smallholder farmers (85% of the population) living in rural areas and who therefore, are the main custodians of the soil production resource base (CGIAR, 2002; Omamo *et al*., 2002). The challenges of food production in the rural areas of SSA include socio-economic, policy and institutional and biophysical factors (Hilhorst and Muchena, 2002; Van Reuler and Prins, 1993; Hart and Voster, 2006). Among the biophysical factors, soil fertility decline remains an intransigent challenge and has been identified as the single most important biophysical constraint to food security in SSA (Sanchez *et al*.,1997).

Compared to other continents, a large proportion of soils in SSA has low inherent fertility and exhibits a variety of constraints, among them: low nutrient contents, low organic matter, moisture stress and high erodibility (Van Reuler and Prins, 1993). Evidence of soil fertility decline in SSA have been reported as declining yields of crops; reduced fallow periods; appearance of plant species which thrive only under low fertility, difference and changes in soil colour, texture, difficulties in soil

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workability and incidence of weeds such as *Striga hermonthica* and low soil index levels from laboratory determined soil indicators (Eyasu, 1998a; Nandwa and Bekunda, 1998). Macro-scale studies in SSA have reported that nutrients are commonly not replaced to the degree that they are removed in crop harvesting and in other loss pathways resulting in nutrient mining for N, P and K in the order of 22, 2.5 and 15 kg N ha^{-1} year^{-1}, respectively (Smaling *et al*., 1997). However, at the micro-scale level in SSA, the magnitude and direction of nutrient mining and concentrations vary across agro-ecological zones and land use types with positive nutrient balances occurring mainly in home gardens and concentric rings close to settlements where soil fertility is maintained by incorporation of plant and animal wastes while nutrient mining has been reported in outfields, under subsistence crops and in farming households with low resource endowments (Prudenctio, 1993; de Jager *et al*., 1998; Eyasu *et al*., 1998b; Vanlauwe and Giller, 2006).

In the phase of declining soil fertility, many farmers have taken the initiative to improve the situation (Mowo *et al*., 2006). Similarly, the scientific community has responded in diverse ways to reverse the declining soil fertility, with current debates focusing on soil nutrient imbalances, nutrient mining and sustainability of nutrient management practices; improving organic matter and managing soil biota; soil fertility recapitalisation; policy options in input-output markets and in integrating technical options with institutional elements; the roles of the public and private sectors, especially in privatised, liberalised input markets; determination of strategic choices that dictates investment in soils; and approaches for enhancing farmer-science knowledge linkages and learning among others (Farrington and Mundy, 2002). However, despite farmer initiatives and a diversity of technical-policy options and the investment of time and resources by a wide range of institutions, soil fertility management continues to be a challenge in SSA.

There is a perception that the soil fertility problem remains intractable because of the failure to deal with the issue in a sufficiently holistic way by integrating biophysical, socio-economic and institutional and policy factors (CGIAR, 2002). The efforts of smallholder farmers in improving soil fertility in SSA has been hampered by high input costs (inorganic fertilisers, improved germplasm, agrochemicals and machinery); inadequate knowledge on integrated soil fertility management practices and cropping system designs; exacerbation of pests and diseases; poverty-land degradation spiral, perverse national and global policies on input-output markets and institutional failures (van Reuler and Prins, 1993; Hart and Voster, 2006).

Given the above scenario, an understanding of the major factors underlying poor soil fertility management in SSA is indispensable in an attempt to revamp agricultural productivity and to raise food production. Relatively little is known about how smallholders' soil fertility management decisions are linked to other characteristics in their production systems and to external environments (Omamo *et al*., 2002). Many studies on soil fertility management have failed to account for the links between soil fertility management decisions and various farmer specific socio-economic factors that characterize subsistence oriented production systems found in many parts of sub-Saharan Africa (Omamo *et al*., 2002; Waithaka *et al*., 2006).

This study attempts to identify household socio-economic factors influencing farm nutrient balances and agro-economic performance of smallholder cropping practices in mixed farming systems (crop-dairy farming). It also explores the relation between household socio-economic factors and the magnitude of farm nutrient inflows and outflows as well as the profitability of cropping practices and their potentials in conserving soil nutrients under current management practices.

METRIALS AND METHODS

Site Description

The study was carried out in Kiambu District, central Kenya highlands (Latitude 0°75′ and 1°20′ S and Longitudes 36°54′ and 36°85′ E) with a population density of 562 persons km^{-2} (CBS 2001).

Table 1: Characteristics of farms studied (mean with standard deviation in parenthesis)

Characteristic	Average value (n = 30)
General	
Household size	6.3 (2.4)
Labour units (aeu)[1]	3.4 (1.4)
Area cultivated (ha)	0.8 (0.5)
Average slope (%)	13.9 (7.2)
Distance to the market (km)	6.1 (1.0)
TLU[2]	4.0 (5.1)
TLU person^{-1}	0.7 (0.8)
TLU ha^{-1}	6.1 (7.7)
Households below poverty level (%)[3]	80.0
Soil	
pH-H_2O (1:1.2.5 suspension)	5.2 (4.3, 6.1)
Organic C (g kg^{-1})	16.5 (13.0, 20.7)
Total N (g kg^{-1})	2.4 (1.8, 3.0)
Extractable P (mg kg^{-1})	22.5 (8.0, 76.0)
Exchangeable K (cmol kg^{-1})	1.3 (0.7, 2.3)

[1]aeu: Adult equivalent units; [2]TLU: Tropical Livestock Units (1 TLU = 250 kg live weight of an animal); [3]Poverty level: 1 US $ a day

The District has an altitude range of 1200-2550 metres above sea level and mean annual temperature range of 13.5°C to 21.9°C depending on altitude. Rainfall in the District is bimodal and annual rainfall ranges from 600 to 2000 mm with an average of 1200 mm in the study area.

The District has two main rainfall periods viz., Long rains (March-May) and short rains (October-November).

Mixed farming (crops and dairy cattle) practiced in the study site, takes place mainly under rain-fed conditions. Dairy cattle (Friesian, Ayrshire, Guernsey, Jersey and their crosses) are stocked at a rate of 4-6 Tropical Livestock Units per hectare (TLU ha^{-1}) and are managed under cut-and carry system (zero-grazing). Dairy production in the District is favoured by flourishing milk processing and packaging industries in the neighbouring urban area, Nairobi. Crops grown include maize, beans, Irish potatoes, vegetables, coffee, bananas and fodder crops. The land is intensively cultivated and is cropped 1.4-1.7 times per year (Jaetzold and Schimidt, 1983).

Farm Characteristics

Thirty farm households were selected from Kibichoi farmer field school (FFS) in a representative catchment of Kiambu District. Data on household socio-economic characteristics were collected using nutrient monitoring methodology (NUTMON), Table 1. Cultivated land was small, measuring 0.8 hectares, on average, while fallow land was estimated to be about 2.8% of total land owned. This implies that opportunities for use of fallow for soil fertility maintenance were limited. The stocking rate for livestock was high, averaging 6 TLU ha^{-1}.

The soils in the catchment with the 30 households were Humic Nitisols (FAO, 2001). Some properties of a representative profile are given in Table 2. Soils in the study site are well drained, deep to extremely deep, dusky red to dark reddish brown, friable clay in places with humic acid topsoil. In general, the erodibility of these soils is low due to high water uptake and retention capacity and stable aggregates partly attributed to high organic matter content.

NUTMON Methodology

Household socio-economic characteristics and farm nutrient flows and balances were quantified using Nutrient Monitoring (NUTMON), methodology (Vlaming *et al*., 2001a). NUTMON is an integrated, multi-disciplinary and multi-scale approach used for calculating nutrient (nitrogen, phosphorus and potassium) flows, stocks and balances and economic performance indicators at different scale levels (plots, farm, catchment, district, national etc.). NUTMON toolbox comprises

Table 2: Some soil profile properties of a representative Humic Nitisols in Kibichoi study catchment

Depth (cm)	0-10	10-53	53-100+
Sand %	18	22	12
Silt %	26	20	22
Clay %	56	58	66
Texture class	Clay	Clay	Clay
pH-H_20 1:2.5 suspension	5.5	5.5	5.9
Organic C (%)	1.9	2.01	0.86
CEC (cmol/kg)	32.4	31.5	26.2
Exchangeable Ca (cmol kg^{-1})	17.8	13.8	28.2*
Mg (cmol kg^{-1})	1.06	0.96	1.18
K (cmol kg^{-1})	1.06	0.62	0.10
Na (cmol kg^{-1})	3.25	1.70	0.65
Sum (cmol kg^{-1})	23.2	17.1	30.1
Base saturation (%)	72	54	> 100*

*High base saturation could be due to analytical error in exchangeable Ca; Source: Muya (2003)

a set of manuals and questionnaires that are used to collect required farm-specific information on management, the farm environment, the farm household, soils and climate; and computer software for data entry and processing.

NUTMON distinguishes six sets of inflows, six outflows and internal flows for calculating nutrient balances and economic performance indicators at defined study scale (Table 3). Whether a flow qualifies as an input or an output or as an internal flow depends on system boundaries. At farm level, the quantified nutrient flows explain which activities within a farm result in nutrient depletion and which activities accumulate nutrients and how and when nutrients flow from one activity to another. The quantified economic flows reveal the profitability of farming activities (Vlaming *et al*., 2001b for economic calculations adopted in NUTMON). NUTMON calculates the nutrient balance of a study unit by subtracting the sum of all flows out of a unit from the sum of all flows into a unit (Table 3).

Quantification of Nutrient Stocks

In each of the 30 study farms, five soil sub-samples were taken at random to a depth of 30 cm, mixed together and a composite sample taken for analysis. Analysis was done for soil particle size distribution, pH, organic C, total N, total P, extractable P and exchangeable K. Soil particle size distribution was determined using a modified hydrometer method (Hinga *et al*., 1980). The pH was measured in 1:2.5 soil to water suspension using conventional glass electrode meter. Organic C was oxidised with a concentrated sulphuric acid and potassium dichromate solution and determined colorimetrically (Anderson and Ingram, 1993). A wet digestion method followed by colorimetric determinations was used to measure total N and total P (Okalebo *et al*., 2002). The exchangeable K was extracted with NH_4OAc solution followed by flame photometry. A Mehlic I solution was used to extract P for colorimetric determination (Mehlich *et al*., 1962).

Quantification of Household Socio-economic Characteristics, Nutrient Flows and Balances and Farm Economic Performance

Data on household characteristics, nutrient flows and farm economic performance were collected through one-time recall interviews using NUTMON Farm inventory (FIQ) and NUTMON farm monitoring questionnaires (FMQ). Farm inventory questionnaire was administered to farm household heads at the beginning of the growing season while FMQ was administered at the end of the agricultural season. Flows IN1, IN2, OUT1 and OUT2 (easy-to- quantify flows) were quantified by asking the farmer, carrying out measurements at farm level and collecting relevant data at farm level (Table 3). They were also converted into economic flows by using local market prices (input-output prices) and opportunity costs as appropriate. This resulted in the calculation of farm economic performance indicators. The other flows (IN3 to IN5 and OUT3 to OUT 6) are hard-to-quantify on a routine basis

Table 3: Flow types distinguished in NUTMON at farm level

IN flows	Out flows
IN 1: Inorganic fertilizers and feeds	OUT 1: Harvested products
IN 2a: Imported organic fertilizers and feeds	OUT 2a: Exported crop residues and manure
IN 2b: Imported manure from external grazing	OUT 2b: Excretion of manure outside the farm
IN 3: Wet and dry deposition	OUT 3a: Leaching from soils
IN 4a: Symbiotic nitrogen fixation	OUT 3b: Leaching from redistribution units
IN 4b: Non-symbiotic nitrogen-fixation	OUT 4a : Gaseous losses from soil
IN 5 : Irrigation and flooding	OUT 4b : Gaseous losses from redistribution units
IN 6: Sub-soil exploitation	OUT 5 : Erosion
	OUT 6 : Human excreta

[1]IN 6: Sub-soil exploitation excluded due to difficulties in quantification and limited availability of secondary data; Source: Vlaming *et al.* (2001)

and (pedo) transfer functions and relevant literature values were used in NUTMON model calculations as described in Vlaming *et al*. (2001b). The NUTMON model calculates total (full) nutrient balances based on all flows (both easy and hard to quantify flows) while partial nutrient balances are calculated based on easy-to-quantify flows only.

Data on household socio-economic characteristics collected by NUTMON questionnaires included education level of household members, number of household members, labour for farm and off-farm activities, total farm size and area cultivated, value of production capital (equipment, livestock and land), number of livestock, off-farm income and distance to the market.

Data Analysis

The collected data were processed using NUTMON computer software. Means of outputs were calculated for household characteristics, nutrient flows and balances and economic performance indicators at farm level. The processed data were exported and analysed using Statistical software, SPSS 12 for Windows (SPSS Inc., 2003). Correlation analysis procedure in SPSS was used to explore the relation between household socio-economic factors and modifiable soil attributes (soil N, P and K stocks) and nutrient management practices, as well as to determine cropping practices accumulating and or depleting nutrients under current management practices. The premise of this correlation analysis was that households with high resource endowments (favourable socio-economic characteristics) have high opportunities to modify soil attributes and to practice sound soil fertility management and cropping practices for increased soil productivity and food production.

RESULTS AND DISCUSSION

Household Socio-economic Factors, Farm Nutrient Balances and Agro-economic Performance

The study investigated whether there were linkages between household socio-economic characteristics and soil nutrient balances (Table 4). A significant positive correlation was observed between farm N, P and K balances and total tropical livestock units (TLU), livestock density (expressed in TLU ha^{-1}) and value of livestock (US$). This shows that the presence of livestock in the studied farming systems could be an important factor determining nutrient balances.

Nutrient balances were negatively correlated with farm size and area under cultivation and also with majority of farm economic indicators. As the size of land increases, the magnitude of nutrient balances decreased. This could probably be due to the inability of farm households to provide regular and adequate soil fertility inputs in large pieces of cultivated land. Constraints to the use of soil fertility inputs such as organic soil amendments (e.g., livestock manure) have been reported to include high labour demand for transporting them and incorporating them into the soil, their availability and poor quality (Palm *et al*., 1997). The negative correlation observed between farm nutrient balances and major farm economic indicators point to the fact that the profitability of the farming system studied could partly be dependent on soil nutrient balances with soil nutrients decreasing as farm profitability increases.

Table 4: Main significant correlations (Pearson) of household socio-economic characteristics and nutrient balances

Characteristic	Positive correlation	Negative correlation
Farm N balance (kg ha^{-1})	Value of livestock (US$) (r = 0.390, p<0.05)	Total farm area (ha) (r = -0.458, p<0.05)
	Total tropical livestock units (r = 0.419, p<0.05)	Cultivated area (ha) (r = -0.479, p<0.05)
	Family cropping labour land ratio (days ha^{-1}) (r = 0.362, p<0.05)	Value of land (US$) (r = -0.488, p<0.01)
	Tropical livestock units ha^{-1} (r = 0.748, p<0.01)	Net farm income (US$) (r = -0.381, p<0.05)
		Farm net cash flow (US$) (r = -0.455, p<0.05)
Farm P balance (kg ha^{-1})	Value of livestock (US$) (r = 0.699, p<0.01)	Value of land (US$) (r = -0.382, p<0.05)
	Total tropical livestock units (r = 0.728, p<0.01)	Family earnings (US$) (r = -0.431, p<0.05)
	Tropical livestock units ha^{-1} (r = 0.874, p<0.01)	Net farm income (US$) (r = -0.525, p<0.01)
		Farm net cash flow (US$) (r = -0.673, p<0.01)
		Household net cash flow (US$) (r = -0.557, p<0.01)
		Return to labour (US$ day^{-1}) (r = -0.582, p<0.01)
		Family earnings person^{-1} (US$) (r = -0.382, p<0.05)
		Net farm income (US$) (r = -0.472, p<0.01)
Farm K balance (kg ha^{-1})	Value of livestock (US$) (r = 0.592, p<0.01)	Total farm area (ha) (r = -0.407, p<0.05)
	Total tropical livestock units (r = 0.603, p<0.01)	Cultivated area (ha) (r = -0.409, p<0.05)
	Tropical livestock units ha^{-1} (r = 0.825, p<0.01)	Value of land (US$) (r = -0.392, p<0.05)
		Family earnings (US$) (r = -0.527, p<0.01)
		Net farm income (US$) (r = -0.689, p<0.01)
		Farm net cash flow (US$) (r = -0.791, p<0.01)
		Household net cash flow r = -0.616, p<0.01)

r = Pearson correlation coefficient; Tropical livestock unit = 250 kg live weight of an animal

To understand agro-economic performance of the farming systems studied and soil nutrient management practices, we stratified the studied farms into three resource endowment classes according to livestock density (TLU ha^{-1}). The positive and significant correlations reported between livestock endowment (TLU ha^{-1}) and soil nutrient balances, presents a possibility of stratifying the study farms into classes, which distinguish themselves in nutrient management practices and farm economic performance (Table 5). Households with higher livestock density tended to have low performance of major economic indicators. This was partly because the profitability of animals in the study site was undermined by low product prices (e.g., milk) and high input costs during the study period. Previous studies carried out in the District reported fluctuating milk prices, high costs of inputs, livestock diseases and poor marketing infrastructure as major production risks impinging on dairy productivity and profitability (Kaguongo *et al*., 1996).

Family earnings, defined as the sum of net farm income and off-farm income, were low per farm and about 80% of the studied households were living below World Bank's defined poverty line of 1 US$ a day. Other authors have reported that poverty is a predisposing factor to land degradation as poor people depend heavily on natural resources for their basic needs and overuse them without good stewardship (Cleaver and Schreiber, 1994; Pinstrup-Andersen and Pandya-Lorch, 1995). The contribution of off-farm income to family earning was, on average 61%. The high contribution of off-farm income to family earnings has been corroborated by other studies elsewhere in Kenya, pointing to the fact that the current farming systems do not provide adequate earnings to the dependent farming households (De Jager *et al*., 2001).

Table 5: Farm economic performance indicators, nutrient stocks and balances for studied farming system (mean values with standard deviation in parenthesis)[a]

	Resource endowment class			
Economic indicators	TLU ha^{-1} < 2 (n = 11)	2< TLU ha^{-1}<7 (n = 10)	TLU ha^{-1} > 7 (n = 9)	All (n = 30)
Net farm income (US$ half $year^{-1}$)	289 (348)	102 (192)	47 (821)	154 (501)
Net farm income (US$ ha^{-1} half $year^{-1}$)	279 (347)	185 (247)	18 (987)	169 (584)
Off-farm income (US$ half $year^{-1}$)	285 (418)	209 (358)	223 (291)	241 (353)
Family earnings (US$ half $year^{-1}$)	574 (521)	312 (402)	271 (764)	396 (569)
Family earnings (US$ aeq^{-1} half $year^{-1}$)	169 (171)	77 (89)	70 (153)	109 (146)
Family earnings (US$ $person^{-1}$ half $year^{-1}$)	113 (130)	48 (56)	46 (112)	71 (106)
Farm net cash flow (US$ half $year^{-1}$)	237 (355)	48 (232)	-200 (846)	43 (539)
Household net cash flow (US$ half $year^{-1}$)	523 (569)	257 (424)	24 (790)	285 (618)
Contribution of off-farm income to family earnings (%)	50.0	67.0	82.0	61.0
Soil N stock (kg ha^{-1})	7038 (821)	6916 (329)	7942 (827)*	7268 (812)
Soil P stock (kg ha^{-1})	1981 (628)	1823 (233)	2147 (750)	1978 (570)
Soil K stock (kg ha^{-1})	14359 (4768)	13817 (3827)	20658 (6485)*	16068 (5777)
Partial N balance (kg ha^{-1} half $year^{-1}$)	8.5 (25.9)	42.3 (38.5)	138.8 (107.1)*	58.8 (83.1)
Partial P balance (kg ha^{-1} half $year^{-1}$)	8.7 (15.4)	27.9 (26.7)	89.3 (53.6)*	39.3 (47.6)
Partial K balance (kg ha^{-1} half $year^{-1}$)	6.5 (27.2)	20.8 (32.6)	112.7 (92.5)*	43.1 (71.6)
Farm (total) N balance (kg ha^{-1} half $year^{-1}$)	-42.5 (36.9)	-7.0 (34.9)	51.0 (70.9)*	-2.6 (61.1)
Farm (total) P balance (kg ha^{-1} half $year^{-1}$)	5.6 (17.0)	25.6 (26.8)	87.0 (54.8)*	36.7 (48.4)
Farm (total) K balance (kg ha^{-1} half $year^{-1}$)	-19.2 (42.6)	-4.1 (26.4)	84.3 (113.9)*	16.9 (80.5)

[a]1 US $ = 75 Ksh; TLU = Tropical livestock unit; *Denotes significant differences ($p<0.05$) between means for a given nutrient stock and nutrient balance (ANOVA; Bonferroni test used in mean separation)

Nutrient stocks in soils are key components of farmers' natural capital and can serve as a state indicator of the system at a given point in space and time (Smaling and Dixon, 2006).

Soil nutrient stocks tended to increase with livestock resource endowments. Farming households with TLU ha^{-1}>7 had significantly high N and K nutrient stocks. Similarly, households with high livestock densities tended to have positive or less negative partial and total nutrient balances (Table 5). The contribution of livestock to maintaining nutrient balances could be through closing nutrient cycles. The cycling of biomass through animals into manure and urine that fertilise the soil is an important linkage between livestock and improvement of soil nutrient balances in crop-livestock farming systems (Lekasi and Kimani, 2003). Other studies have also indicated that the presence of livestock influences farm nutrient balances, especially N, positively due to the importation (purchase) of concentrates and forage for feeding livestock (Zemmelink *et al*., 1999).

The mean total N balance for the 30 farms was slightly negative (low magnitude of N mining) while total P and K balances were positive. The results of this micro-scale study contrasts results of national aggregate studies for Kenya, which reported nutrient mining of 42-46 kg N ha^{-1} $year^{-1}$, 1-3 kg P ha^{-1} $year^{-1}$ and 29-36 kg K ha^{-1} $year^{-1}$ (Stoorvogel and Smaling, 1990). Thus, although nutrient mining is taking place at national and sub-continental levels (SSA), there could be some bright spots at the micro-scale where soil nutrients are nearly balanced or are accumulating as attested by this study. In smallholder farms throughout SSA, it is a common pattern for some fields to receive substantial inputs of fertilisers and manure (resulting in positive nutrient balances), but others to receive nutrient inputs infrequently or never, resulting in nutrient mining (Rowe *et al*., 2006). While nutrient mining and declining soil fertility has been widely reported in SSA, the myth that nutrient balances are always negative everywhere in SSA may not be the case (Vanlauwe and Giller, 2006).

Nutrient Inflows and Outflows and Household Socio-economic Factors

Imported manure from external grazing was not a major nutrient flow into the farming system as livestock were predominantly kept under cut and carry system (confined in zero grazing units). The major source of N and P inflows were purchased inorganic fertilisers and livestock feeds accounting

Table 6: Sources of nutrient inflows and outflows in crop-livestock systems, Kiambu, Kenya (standard deviation in parenthesis)

	Nitrogen		Phosphorus		Potassium	
Flow description	Mean (kg ha^{-1})	Percentage of sub-total	Mean (kg ha^{-1})	Percentage of sub-total	Mean (kg ha^{-1})	Percentage of sub-total
Inflows[1]						
IN1: Inorganic fertilizers and Feeds	64.2 (70.6)	63.6	26.6 (25)	55.8	24.2 (26.1)	38.4
IN2a: Imported organic fertilizers And feeds	25.2 (42.6)	25.0	19.8 (35.6)	41.5	33.6 (60.1)	53.3
IN2b: Imported manure from external grazing	0.0 (0)	0.0	0.0 (0)	0.0	0.0 (0)	0.0
IN3: Wet and dry atmospheric Deposition	8.0 (0)	7.9	1.3 (0)	2.7	5.2 (0)	8.3
IN4: Biological nitrogen fixation	3.6 (2.2)	3.6	0.0 (0)	0.0	0.0 (0)	0.0
Sub-total (inflows)	101.0	100.0	47.7	100.0	63.0	100.0
Outflows						
OUT1: Harvested crop products	19.1 (20.9)	18.5	2.3 (2.2)	20.9	8.9 (9.8)	19.3
OUT2a: Crop residues and manure	2.3 (6.9)	2.2	2.4 (8.2)	21.8	4.1 (12.3)	8.9
OUT2b: Excreted manure outside Farm	0.0 (0)	0.0	0.0 (0)	0.0	0.0 (0)	0.0
OUT3: Leaching	33.7 (21.6)	32.6	0.0 (0)	0.0	1.0 (0.8)	2.2
OUT4: Gaseous losses	20.8 (12.7)	20.1	0.0 (0)	0.0	0.0 (0)	0.0
OUT5: Erosion	18.5 (14.8)	17.9	3.8 (3.3)	34.5	30.5 (29.3)	66.0
OUT6: Human excreta	9.1 (6.5)	8.8	2.5 (1.8)	22.7	1.7 (1.2)	3.7
Sub-total (outflows)	103.5	100.0	11.0	100.0	46.2	100.0

[1]In 5: Irrigation and flooding-irrigation is not practiced in the study site; [1]IN 6: Sub-soil exploitation excluded due to difficulties in quantification and limited availability of secondary data

for about 64 and 56% of total N and P inflows respectively (Table 6). Similarly, imported organic fertilisers and feeds were the major source of K inflow, accounting for about 53% of total K inflows into the farming system studied. However, variation among farms was high (standard deviations higher than the means, Table 6), reflecting differences in management (mainly the amount of concentrate and fertilisers bought).

The major outflow pathways for nitrogen were leaching, gaseous losses, erosion and harvested crop products, human excreta and crop residues and manure in that order. Leaching and gaseous losses accounted for about 33 and 20% of total N outflows in the farming system while outflows attributed to the removal of harvested crop products and erosion were nearly equal in proportion (Table 6). The major loss pathway for P and K was through erosion. Erosion accounted for 35 and 66% of total P and K outflows respectively. The second major loss pathway for P was in the form of crop residues and manure and harvested crop products in nearly equal proportions while the second loss pathway for K was mainly through harvested crop products.

It is observed from this study that the major outflow pathways for N, P and K were the difficult-to-quantify flows. Minimising nutrient losses in the study farming system will depend, among others, the adoption of strategies to reduce uneconomic nutrient outflow pathways (OUT3-OUT6) and to increase nutrient inflows into the farming system. The major nutrient outflows observed in this study cannot be addressed through single application of technologies. Integrated nutrient management approaches are required that add nutrients to the farm, reduce nutrient losses from the farm, maximize nutrient recycling within the farms and increase efficiency of nutrient uptake (Nandwa and Bekunda, 1998). Technologies required include, inorganic inputs (inorganic fertilisers, rock phosphates etc.), crop residues and agroforestry, deep soil nutrient capture, manures, biomass transfer, use of agro-industrial by-products and wastes, crop rotations, improved fallows and nitrogen fixing legumes, soil and water conservation technologies and improved livestock feeding technologies (e.g., using concentrates) among others (Buresh *et al*., 1997; Nyathi *et al*., 2003).

Table 7: Pearson correlation between socio-economic factors and partial nutrient flows

Characteristic	Positive correlation	Negative correlation
N inflows		
Mineral fertilisers and feeds (kg ha^{-1})	TLU ha^{-1} (r = 0.65, p<0.01)	Value of land US$ (r = -0.39, p<0.05)
Organic fertilisers and feeds (kg ha^{-1})	Value of livestock US$ (r = 0.56, p<0.01)	Net farm income US$ (r = -0.37, p<0.05)
	TLU (r = 0.58, p<0.01)	Farm net cash flow US$ (r = -0.47, p<0.01)
	TLU ha^{-1} (r = 0.68, p<0.01)	Household net cash flow US$ (r = -0.41, p<0.05)
		Return to labour US$ day^{-1}(r = -0.47, p<0.01)
N outflows		
Crop products (kg ha^{-1})		TLU ha^{-1} (r = -0.376, p<0.05)
Crop residues (kg ha^{-1})	Distance to market (km) (r = 0.40, p<0.05)	
P inflows		
Mineral fertilisers and feeds (kg ha^{-1})	TLU (r = 0.38, p<0.01) TLU ha^{-1} (r = 0.63, p<0.01)	Value of land US$ (r = -0.40, p<0.05)
Organic fertilisers and feeds (kg ha^{-1})	TLU (r = 0.73, p<0.01) TLU ha^{-1} (r = 0.74, p<0.01)	Family earnings US$ (r = -0.55, p<0.01) Net farm income US$ (r = -0.60 p<0.01) Farm net cash flow US$ (r = -0.68, p<0.01) Household net cash flow US$ (r = -0.61, p<0.01)
P outflows		
Crop products (kg ha^{-1})		TLU (r = -0.63, p<0.01) TLU ha^{-1} (r = -0.59, p<0.01)
Crop residues (kg ha^{-1})	Distance to market (km) (r = 0.45, p<0.05)	
K inflows		
Mineral fertilisers and feeds (kg ha^{-1})	TLU (r = 0.38, p<0.05) TLU ha^{-1} (r = 0.63, p<0.01)	Value of land US$ (r = -0.40, p<0.05)
Organic fertilisers and feeds (kg ha^{-1})	TLU (r = 0.73, p<0.01) TLU ha^{-1} (r = 0.74, p<0.01)	Family earnings US$ (r = -0.55, p<0.01) Net farm income US$ (r = -0.60 p<0.01) Farm net cash flow US$ (r = -0.68, p<0.01) Household net cash flow US$ (r = -0.61, p<0.01)
K outflows		
Crop products (kg ha^{-1})		TLU (r = -0.63, p<0.01) TLU ha^{-1} (r = 0.59, p<0.01)
Crop residues (kg ha^{-1})	Distance to market (km) (r = 0.45, p<0.05)	

r = Pearson correlation coefficient; Tropical livestock unit = 250 kg live weight of an animal

Livestock density (TLU ha^{-1}) was significantly correlated to N, P and K inflows in form of imported inorganic and organic fertilisers and livestock feeds (Table 7). The dairy cattle kept in the study site act as a major conduit of nutrient inputs into the farm-system as farmers buy concentrate feeds and fodder (imported feeds) to help meet the dairy cattle feed requirements for marketed milk production (Utiger *et al*., 2000). Nitrogen, phosphorus and potassium inflows were, however, negatively correlated with major economic indicators during the study period. The low product prices (e.g., for milk) and thus the poor economic performance of the dairy animals did not deter farmers from importing or purchasing organic and mineral feeds to maintain the animals in anticipation of better product prices in the future. Furthermore, the animals are also kept for other non-market benefits not valued in this study. Ouma *et al*. (2004) have reported that the benefits of smallholder livestock production systems in Kenya outweigh costs when non-market parameters are considered in the cost-benefit analyses.

Nitrogen, phosphorus and potassium outflows inform of crop residues were positively correlated with distance to the market. With increasing distance, crop residues such as fodder and maize stovers fetch better prices, encouraging more outflows. However, farms with high livestock density (TLU ha^{-1}) tended to have low crop product and residue outflows.

Table 8: The impacts of cropping practices on productivity, profitability and nutrient balances in Kibichoi, Kiambu Cropping practice

	Cropping practice			
Data	Napier sole crop (n = 19)	Maize intercrop (n =29)	Coffee sole crop (n = 17)	Coffee intercrop (n =8)
Yield (kg ha^{-1})	5920 (3401)	119 (84)	1089 (1064)	2644 (2313)
Gross value (US$ ha^{-1})	6690 (10255)	595 (481)	515 (520)	1854 (1287)
Variable costs (US ha^{-1})	22 (45)	84 (120)	69 (93)	142 (169)
Gross margin (US ha^{-1})	6449 (10340)	65 (681)	194 (546)	1263 (994)
N balance (kg ha^{-1})	-436 (761)	70 (156)	-32 (85)	-80 (102)
P balance (kg ha^{-1})	-650 (1057)	69 (92)	13 (36)	-6 (65)
K balance (kg ha^{-1})	-1022 (1702)	86 (170)	4 (94)	-54 (116)
Detailed N inflows				
IN1 Inorganic fertilizers (kg ha^{-1})	3.8 (11)	29.8 (42)	11.9 (28)	69.9 (93)
IN 2 Organic inputs (kg ha^{-1}))	97.4 (170)	155.9 (219)	44.3 (106)	51.1 (65)
IN 3 Atmospheric deposition (kg ha^{-1})	8.0 (0)	8.0 (0)	8.0 (0)	8.0 (0.0)
IN 4 Biological fixation (kg ha^{-1})	1.3 (0)	9.5 (9)	1.3 (0)	1.3 (0.0)
Detailed N outflows				
OUT 1 Crop products (kg ha^{-1})	0.0 (0)	-24.3 (18)	-36.0 (36)	-95.3 (91)
OUT 2 Other organics (kg ha^{-1})	-477.7 (732)	-8.0 (10)	-2.8 (8)	-30.4 (32)
OUT 3 Leaching (kg ha^{-1})	-37.6 (36)	-54.7 (51)	-26.0 (22)	-39.3 (34)
OUT 4 Gaseous losses (kg ha^{-1})	-22.0 (21)	-32.1 (30)	-15.0 (13)	-23.0 (20)
OUT 5 Erosion (kg ha^{-1})	-8.9 (7)	-14.6 (14)	-17.9 (9)	-22.5 (24)

Cropping Practices and Soil Nutrient Conservation

Analysis for productivity, profitability and nutrient conservation was done for crop and crop combinations grown by majority of the farmers. The dominant crop included maize (*Zea mays* under intercropping by 97% of study farms), Napier (*Pennisetum purpureum*, under sole cropping) and coffee (*Coffea arabicum*). The yields of crops during study period were low (Table 8). The dry matter yields of Napier was lower than 25-40 tonnes ha^{-1} expected under favourable fertilisation regimes, but within on-farm range of 4-29 tonnes ha^{-1} (Wouters, 1987). Similarly, maize yields were lower than 2-4.5 tonnes ha^{-1} reported for some parts of Kiambu District with improved soil management practices (Okalebo *et al*., 2004; Mwangi *et al*., 2001). Although coffee cherry yields of 1089-2644 kg ha^{-1} (equivalent to 150-368 kg ha^{-1} clean coffee) were within national averages of 194-486 kg ha^{-1} (clean coffee) for smallholders (cooperative sector for the period 1997/1998 to 2003/2004), they were lower than 438-917 kg ha^{-1} (clean coffee) for better managed coffee (estate sector) in the same period (Kinoti, 2005).

Napier was the most economically viable crop (high gross margins) followed by coffee intercrops. However, the production and profitability of these crops were dependent on nutrient mining (N, P and K) with nutrient inputs being inadequate to compensate for nutrient outflows. This has been corroborated by other studies done elsewhere for Napier and coffee in Kenya (De Jager *et al*., 1998). Napier sole cropping was the least nutrient conserving practice while maize intercropping was the most nutrient conserving production practice in the study site. The major nutrient outflow pathway, partly, responsive for nutrient mining under current cropping practices were harvests of crop residues and products and hard to quantify flows such as leaching.

The magnitude of nutrient flows and balances were dependent on the different soil fertility management practices adopted for different crops and crop combinations. Although the farmers combined organic inputs with inorganic fertilisers for crop production, there was preferential use of organic inputs. This can be attributed to their low cost and on-farm availability as well as the fact that smallholder farmers, partly, consider organic and inorganic inputs as substitutes rather than synergistic when household socioeconomic characteristics are taken into account (Omamo *et al*., 2002). The latter may not auger well for integrated soil fertility management. At present many small scale farmers do not apply the recommended quantities of inorganic fertilisers due to various reasons such as high costs and inadequate credit facilities. Inorganic fertilisers in Africa cost, at the farm gate, two to six times as much as in Europe, North America, or Asia (Sanchez, 2002). Organic inputs were preferentially applied to maize intercrops, Napier and coffee intercop in that order. The preferential application of inorganic fertilisers to coffee intercrops was because of the various crops intercropped with coffee such as Irish potatoes (*Solanum tuberosum*) and maize among others, rather than to coffee (specifically), which had poor prices during the study period.

CONCLUSIONS

Household socio-economic characteristics were inventoried and their relation to farm nutrient management (nitrogen, phosphorus and potassium) explored using nutrient monitoring methodology and correlation analysis. The study has shown that the presence of livestock in smallholder crop-livestock production systems is a major determinant of nutrient stocks, flows and balances with households having high livestock density experiencing less nutrient mining or having positive nutrient balances. Livestock in the studied farming system acted as conduits of nutrients imports into the farm as farmers purchase livestock feeds (concentrates, grasses including roadside grasses and crop residues) as well as inorganic fertilisers for fodder-crop production. It is envisaged that improving the accessibility to purchased livestock feeds through, for example, adopting policy measures that reduce costs of feeds would contribute to improving farm nutrient balances.

The study showed that the economic profitability of the farming system was in disrepute as indicated by a negative correlation between farm nutrient balances and major farm economic indicators, poor performance of economic indicators and the high dependency of the studied household's on off-farm income. Increasing the economic sustainability of these farming systems will require, *inter alia*, an enabling policy environment for smallholder livestock input-output markets and adopting sound strategies for adding nutrients to the farm, reducing nutrient losses from the farm and maximizing nutrient recycling.

Farmers adopted preferential soil fertility management strategies for cropping practices resulting in nitrogen, phosphorus and potassium nutrient mining under Napier (monocrop) and coffee (intercrop) fields and nutrient conservation under maize (intercrop) fields. Sustainable improvement of soil fertility under this farming system will require a better understanding of the rationale behind this farmers' preferential use of inputs, nutrient use efficiencies of such farmer strategies and the derived benefits in the short and in the long term within wider socio-economic and policy contexts.

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