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Monitoring nutrient flows and economic performance in African farming systems (NUTMON)
IV. Linking nutrient balances and economic performance in three districts in Kenya

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Abstract

At the national level, agricultural production in Kenya is characterized by a negative nutrient balance and a downward trend in food production per capita and can therefore be classified as unsustainable. However, little information is available concerning ecological and economic sustainability of the various production systems at farm level. A one year monthly monitoring activity was conducted in the season 1995/1996 in three districts with the participation of 26 farm households covering the major existing farming systems in these districts, in which data were collected on agronomic and economic aspects of the farm management. The average N-balance at farm level is -71 kg ha^{-1} yr^{-1} with large variations among farms ranging from -240 kg ha^{-1} yr^{-1} to $+135$ kg ha^{-1} yr^{-1}; the average K-balance is slightly negative, the P-balance slightly positive. Net farm income shows no relation with the nutrient balance. A high market orientation on the other hand correlates with a more negative N- and K-balance. The market-oriented farms located in the highly populated areas are characterized by intensive crop and livestock activities, import nutrients through fertilizers and/or animal feeds, but insufficient to compensate the outflow through marketed products, leaching and erosion. The average annual net farm income amounts to US$ 1490 per farm, with large variations among farms. Average returns to family labour (US$ 2.2 per day[1]) and returns to land (US$ 91 per ha[1]) are comparable or higher than unskilled wage rates and annual land rent respectively, but 50% of the farms perform below these rates. Market oriented farms have an economic performance that is similar to subsistence oriented farms. Off-farm income, however, is essential for large groups of small-scale farm households to achieve economic viability: without additional off-farm income, 54% of the farms in the sample are estimated to be below the poverty line. The replacement costs of mined nutrients amounts to 32% of the average net farm income.

At crop level the cash crops tea and coffee realise higher gross margins and considerably lower nutrient mining levels than the major food crops maize and maize-beans. It is concluded that a multi-disciplinary monitoring activity at farm level, contributes to targeting and prioritization of development options aimed at optimization of soil nutrient management. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Kenya; Nutrient balance; Economic performance; Ecological sustainability; Economic sustainability

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1. Introduction

In sub-Saharan Africa (SSA) it is increasingly difficult to satisfy short-term production needs and long-term sustainability demands at the same time. Forced by the need to produce more staple crops for a growing population and to grow cash crops to integrate in the monetary economy, farm households replaced once stable systems by more intensive systems relying heavily on external inputs, or moved into more ecological fragile areas. Implementation of Structural Adjustment Policies resulted in increased prices of external inputs, but price levels of agricultural products decreased and only a limited growth in productivity was realised. These developments have forced farm households to exploit soil nutrient resources, leading to negative nutrient balances and declining soil fertility in most countries in SSA. At national level, two indicators illustrate the unsustainability of agricultural production: nutrient outputs exceed inputs by 40 kg N, 3 kg P and 30 kg K ha^{-1} yr^{-1} (Stoorvogel and Smaling, 1990) and per capita food production has been declining over the past 7 years (Fig. 1; FAO, 1996). However, little information is available on ecological and economic sustainability of the production systems at farming system level. In order to turn the tide, a comprehensive and targeted approach for specific farming systems is required, involving appropriate technologies in the framework of Integrated Nutrient Management, farmers' knowledge and relevant policy instruments (Mokwunye et al., 1996). Such an approach requires detailed knowledge of the farm management at farm household level in the various agro-ecological zones and its impact on the nutrient balance and economic performance. An earlier developed model for nutrient monitoring (NUTMON) and a proposed framework for development (Smaling et al., 1996) have been applied to identify the level of ecological and economic sustainability in Kenyan farming systems.

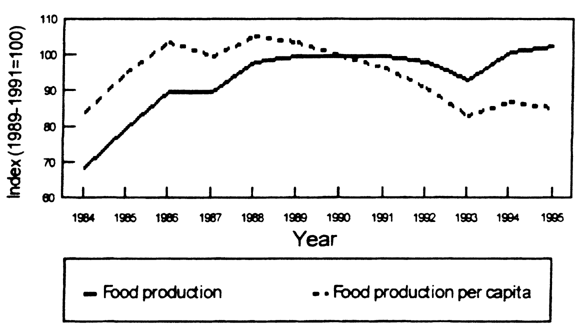

Fig. 1. Food production indices Kenya.

2. Methods

Three districts were selected for monitoring, covering the wide agro-ecological and socioeconomic variability of existing farming systems in the high- and medium potential areas of Kenya. Because methodology development is a major objective, the farm selection procedure was aimed at covering the wide variety of existing farming systems of major importance in the district, rather than obtaining a district representative sample. Based upon secondary data, satellite images and expert knowledge, different land use zones (LUZs) were defined and described. Thereafter a participatory rural appraisal (PRA) was organised to describe qualitatively the various LUZs, identify major problems and constraints and lay the foundation for the actual farm selection (De Jager et al., 1998). Per LUZ two or three farm households were selected based upon willingness to participate in the monitoring programme and a number of selection criteria for representativeness within the LUZ, such as cropping pattern, livestock activities, farm size, farm management practices, product marketing and off-farm income activities.

For analysis of the nutrient flows the NUTMON-model is applied which distinguishes between three types of units: crop activities (primary production units), livestock activities (secondary production units) and the homestead and a set of six inflows (mineral fertilizer, organic manure, wet and dry deposition, biological nitrogen fixation, sedimentation and subsoil exploitation), six outflows (crop products, crop residues, leaching, denitrification, water erosion and human faeces), and six internal flows (consumption of external feeds, reuse of household waste, reuse of crop residues, grazing, reuse of manure, and home consumption (Table 1; Van den Bosch et al., 1998a). In the ECMON-model basic economic performance indicators at the activity and farm household level as well as a number of general farm household charac-

Table 1
Distinguished types of nutrient flows at farm level in NUTMON

IN flows	Out flows	Internal flows
IN1 Mineral fertilizers	OUT1 Farm products sold	FL1 Feeds
IN2 Organic inputs	OUT2 Other organic products	FL2 Household waste
IN3 Atmospheric deposition	OUT3 Leaching	FL3 Crop residues
IN4 Biological nitrogen fixation	OUT4 Gaseous losses	FL4 Grazing of vegetation
IN5 Sedimentation	OUT5 Runoff and erosion	FL5 Animal anure
IN6 Subsoil exploitation	OUT6 Human faeces	FL6 Farm products to household

teristics are quantified. For both scale levels, cash flow measures and income and profitability measures are calculated. At activity level, the main indicators were gross margins (returns minus variable costs) and cash flows (cash income minus cash receipts) per unit area and at farm household level net farm income (total gross margins minus fixed costs), family earnings (net farm income plus off-farm income).

A structured questionnaire was used to collect data with a monthly recall period on quantity and prices of inputs and outputs of crop and livestock activities, growth of the herd, confinement of livestock, redistribution of manure, stock of household staple crops, labour input and off-farm income. Beside this monthly monitoring, a farm inventory was conducted, primary data collected (soil samples, nutrient contents of products, market prices, etc.) and secondary data gathered (soil maps, agro-climate data, relevant research results). For non-traded goods and family labour opportunity costs were estimated based on the average market rates.

The economic performance indicators were analysed using basic descriptive statistical techniques. Non-parametric correlation was used to investigate relations between the various economic and agronomic characteristics. In order to evaluate the economic sustainability of the farming system, the following indicator has been applied:

$$\mathrm{IMEQ} = \mathrm{FE/MFE}$$

in which IMEQ is the income minimum-expenditure quotient; FE is family earnings and MFE is the minimum family expenditures.

A variety of methods have been developed to internalise environmental issues in the traditional economic analyses (Harrington, 1992; Ehui and Spencer, 1993; van Pelt, 1993; Bojö, 1996). For nutrient mining, the replacement costs method and productivity method are most generally used. For application of the productivity method, estimations need to be made of the future loss of productivity from nutrient mining (Bishop and Allen, 1989). Application of this method, requires additional data such as simulation estimates of crop responses to different crop nutrient levels in the soil and effects on crop-livestock interactions (Shepherd and Soule, 1998). The replacement cost method on the other hand is relatively simple and can be applied with the current available data set. In this method, the costs to replace damaged productive assets, such as nutrients in this case, are estimated. The depleted nutrients are considered to have an economic value equal to the market value (at farm gate prices) of an equivalent amount of fertilizers. Different efficiency factors of fertilizers are not considered in this calculations. The sustainability of a farming system can then be estimated through relating the costs of replacement to the net farm income. The farmers income sustainability quotient (van der Pol, 1993) can then be defined as follows:

$$\mathrm{FISQ} = 1 - (\mathrm{NDV_{farm}/NFI}) \qquad (-\infty < \mathrm{FISQ} \leq 1)$$

in which FISQ is the farmers income sustainability quotient; $\mathrm{NDV_{farm}}$ is the nutrient deficient value at replacement costs at farm level and NFI is the net farm income. Also at activity level a similar indicator can be defined:

$$\mathrm{GMSQ} = 1 - (\mathrm{NDV_{act.}/GM}) \qquad (-\infty < \mathrm{GMSQ} \leq 1)$$

in which GMSQ is the gross margin sustainability quotient; $\mathrm{NDV_{act.}}$ is the nutrient deficient value at replacement costs at activity level and GM is the gross margin.

Table 2
Basic farm characteristics

	Districts						Total	
	Kissi		Kakamega		Embu			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Cultivated area (ha)	3.8	2.4	5.1	3.9	4.5	7.1	4.5	5.3
Crop diversity (No.)	9	2	9	2	8	2	9	2
Value implements (US$)	235	220	270	235	200	180	220	200
Parcels (No.)	3	1	2	1	2	1	2	1
Plots (No.)	18	6	15	7	10	3	14	6
TLU (units)	4	3	5	3	3	2	4	3
Livestock diversity (No.)	3	1	3	1	3	1	3	1
Household members (No.)	9	1	11	4	8	3	9	3

3. Results

3.1. Farm household level

Each district is characterized by a large variation in agro-ecological zones and corresponding farming systems and characteristics. The average cultivated area of the sample farms amounts to 4.5 ha (Table 2). The farms have a relatively high farm size compared with the estimated average holding size at provincial level which is: 1.4 ha, 1.7 ha and 2.2 ha in Nyanza, Western and Eastern province respectively (World Bank, 1995). The level of mechanisation is low with an average value of implements of US$ 220 per farm, of which wheel barrows, knapsack sprayers and chaff cutters are the major capital intensive implements.

The high pressure on land in Kisii, is illustrated by the high land fragmentation compared with the other districts. All the farms have a high degree of diversification, with an average of nine different crops or crop mixtures and three different types of livestock. The number of livestock expressed in Tropical livestock units (TLU) is slightly higher in Kisii and Kakamega district compared with Embu. The average farm household comprises nine persons, varying from 3–19.

Table 3 (derived from Van den Bosch et al., 1998b) shows that the farms in the sample are mining nitrogen (N) at an average level of 71 kg ha^{-1} yr^{-1} (Table 2), the potassium (K) balance is slightly negative (-9 kg ha^{-1} yr^{-1}), the phosphorus (P) balance slightly positive ($+3$ kg ha^{-1} yr^{-1}). The average partial N-balance, consisting of the nutrient flows in

Table 3
Nutrient flows at farm level

	Districts						Group total	
	Kissi		Kakamega		Embu			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
N-balance (kg ha^{-1} yr^{-1})	−102	29	−72	78	−55	79	−71	71
P-balance (kg ha^{-1} yr^{-1})	−2	9	−4	10	9	17	3	15
K-balance (kg ha^{-1} yr^{-1})	−34	21	18	53	−15	71	−9	53
Partial N-balance (kg ha^{-1} yr^{-1})	10	11	35	41	45	52	37	50
N-inflow fertilizers (kg ha^{-1} yr^{-1})	16	12	12	25	29	35	21	28
N-inflow organics (kg ha^{-1} yr^{-1})	14	7	42	52	32	37	31	43
N-outflow products (kg ha^{-1} yr^{-1})	18	8	20	25	16	17	17	18

direct farm inputs and product outputs and excluding, however is positive. Farmers apparently import more nutrients through inputs than are exported through sale of products, but factors as leaching, erosion and home consumption cause the total balance of N to be negative. No significant differences among districts are observed, although in Kisii district the mining levels of N and K appear slightly higher. On average 21 kg ha^{-1} yr^{-1} of N is imported through fertilizers, but 46% of the farms apply less than 5 kg ha^{-1} yr^{-1} of N in fertilizers. N-inflow through organics (organic feeds and outside grazing) contributes more to the N-balance than fertilizers (31 kg ha^{-1} yr^{-1} on average). Especially in Kakamega high levels are observed, mainly because of grazing outside the farm.

The average net farm income amounts to US$ 1490 per farm per year (Table 4), again with large variations among farms. Between the districts no statistically significant differences are observed. Crop and livestock activities contribute equally to the net farm income, although in Kakamega the share of livestock activities is significantly higher compared with the other districts. The average economic performance of the farm activities is satisfactory, when looking at the realised returns to land and to family labour, which are above the districts average land rent (US$ 55 ha^{-1} yr^{-1}) and wages for unskilled labour (US$ 1.5 day^{-1}) respectively. However, there is a large variation among the farms and 46% of the farms in the sample realise lower returns than these district averages.

The average annual farm net cash flow amounts US$ 675, with no statistically significant differences among districts. Crop and livestock activities contribute equally to the total farm cash income, but only in Kakamega is a significantly higher contribution of livestock observed. The average market orientation of the farms, expressed in the percentage of the total revenues of crop and livestock outputs sold, is 45% varying from complete subsistence (0%) to almost fully market oriented (95%). The selected farms in Kakamega district appear more subsistence oriented, although the difference is not statistically significant. On average 773 labour days are used for farm activities, equivalent to two full-time persons. Around 16% of this labour is hired, again with a large variation between farms. The labour intensity of crop activities in Kisii and Embu is considerably higher than in the more extensive farming systems in Kakamega. Labour intensity in livestock between the districts is comparable.

The net farm income shows no relation to the nutrient balance, only a logical positive correlation with the number of livestock and cultivated area (Table 5). Market orientation correlates positively with net cash flow, N-inflow through fertilizers (IN1), N-outflow through products (OUT1), internal manure applied, labour intensity for crop activities,

Table 4
Economic performance indicators

	District						Total	
	Kisii		Kakamega		Embu			
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Net farm income (US$ $farm^{-1}$)	1435	1235	1655	1180	1420	1200	1490	1165
Farm net cash flow (US$ $farm^{-1}$)	490	475	525	635	855	1200	675	910
Returns to land (US$ ha^{-1})	−200	580	110	475	235	980	90	765
Returns to family labour (US$ day^{-1})	1.4	1.4	2.4	2.1	2.5	2.7	2.2	2.3
Share crops in gross margin (%)	49	27	19	20	68	23	49	31
Share crops in cash income (%)	51	34	18	19	73	39	50	39
Market orientation (%)	48	15	30	15	55	33	45	27
Total labour input (days $farm^{-1}$)	1059	308	767	434	634	173	773	337
Share hired labour (%)	20	13	15	16	15	21	16	17
Labour intensity crops (days ha^{-1})	258	181	176	194	281	212	244	198
Labour intensity livestock (days TLU^{-1})	65	33	63	49	68	75	66	58

Table 5
Main significant correlations of net farm income, market orientation, Farm size and N-balance with major farm and farm management characteristics

Characteristic	Positive correlation*	Negative correlation*
Net farm income (US$ $farm^{-1}$)	Cultivated area (ha)	
	TLU	
Market orientation (% sold of gross returns)	Share crops in cash income and total gross margin (%)	Cultivated area (ha)
	Farm net cash flow (US$ $farm^{-1}$)	N- and K-balance (kg ha^{-1} yr^{-1})
	N-inflow through fertilizers (kg ha^{-1} yr^{-1})	TLU
	Internal manure applied (kg ha^{-1} yr^{-1})	
	Labour days per ha crops (days ha^{-1})	
	N-outflow through products (kg ha^{-1} yr^{-1})	
	Zero-grazing unit (yes/no)	
Cultivated area (ha)	Implement value (US$ $farm^{-1}$)	Internal manure applied (kg ha^{-1} yr^{-1})
	Net farm income (US$ $farm^{-1}$)	Labour days crops (days ha^{-1})
	TLU	Market orientation (%)
		N-outflow through products (kg ha^{-1} yr^{-1})

*(P=0.05)

share of crops in net farm and cash income and occurrence of zero-grazing units. On the other hand, a higher market orientation corresponds with a lower cultivated area, a more negative N and K balance and a lower number of livestock. The cultivated area is positively related to the value for implements and the number of livestock and negatively to the application levels of on-farm produced manure, labour intensity, market orientation and the level of nutrients leaving the farm through agricultural products sold.

In order to target technical and policy interventions to specific farming systems it is necessary to investigate whether groupings can be made, which distinguish themselves in farm management practices, level of nutrient mining, economic performance and farm household characteristics. From the above analysis it appears that market orientation can be used as discriminating factor for nutrient balances and management aspects. Three groups of market orientation are distinguished: <33%, 33–66% and >66% of the gross revenues sold. The number of farms in the 3 groups are 9, 11 and 6 respectively; in Embu district the share of market oriented farms (>66%) is highest and in Kakamega district the lowest.

Table 6 presents the averages of the most relevant farm characteristics. Subsistence oriented farms (<33%) have a significantly less negative nutrient balance for N and K than market oriented farms (>66%). The partial balance for N is positive in all three groups, but the inflow through fertilizers increases with the market orientation. Inflow through organic sources on the other hand decreases with the market orientation because of higher occurrence of zero grazing management (less outside grazing and feeding from on-farm produced napier grass) and lower total number of livestock. It should be realised that on the subsistence-oriented farms, the nutrient balance is relatively positive through concentration of nutrients from grazing land to the cultivated area for arable crops. The sustainability of the system is therefore related to the grazing to arable land ratio and increasing land pressure may lead to a decline of this ratio. The market orientation is related to intensification of the farming system: capital and labour intensive production on relatively small cultivated areas. No significant differences are observed between the groups in economic performance, although the farm net cash flow is considerably higher on the market oriented farms.

3.2. Activity level

Analysis of the most frequently occurring crops or crop mixtures is done for plots with a minimum area of 0.1 ha and where a harvest has been recorded. To facilitate comparison of gross margins between crops

Table 6
Farm management, nutrient balances and economic performance according to market orientation of farms expressed in % of gross returns sold

	Market orientation		
	<33%	33–66%	>66%
N-balance (kg ha^{-1} yr^{-1})	−26[a]	−89	−106[b]
P-balance (kg ha^{-1} yr^{-1})	−2	5	6
K-balance (kg ha^{-1} yr^{-1})	32[b]	−12[b]	−68[a]
Partial N-balance (kg ha^{-1} yr^{-1})	46	25	33
Net farm income (US$ $farm^{-1}$)	1380	1620	1455
Returns to family labour (US$ day^{-1})	2.0	1.9	3.0
Farm net cash flow (US$ $farm^{-1}$)	180[a]	765	1235[b]
Cultivated area (ha)	6.7	4.3	1.7
TLU	4.4[b]	4.2[b]	1.5[a]
Zero grazing unit (1=yes/2=no)	2.0[a]	1.5[b]	1.4[b]
Share livestock in total gross margin (%)	61[a]	63[a]	16[b]
N-inflow fertilizers (IN1 in kg ha^{-1} yr^{-1})	9[a]	18[a]	45[b]
N-inflow organics (IN2 in kg ha^{-1} yr^{-1})	54	21	14
N-outflow products (OUT1 in (kg ha^{-1} yr^{-1})	17	13	25
Application on-farm produced manure (kg ha^{-1} yr^{-1})	6000	4500	9000
Labour intensity crops (days ha^{-1})	179	226	373
Labour intensity livestock (days ha^{-1})	71	48	91

[a,b] the mean difference is significant at P=0.05 level.

on different farms irrespective of source of labour inputs, the costs of hired labour is excluded in the calculations of the variable costs. The returns, gross margins and variable costs of the major cash crops coffee and tea are considerably higher than of the major food crops maize and mixed crop of maize and beans (Table 7). In cash crops, fertilization (manure in coffee and fertilizers in tea) is the major cost component, and for food crops, fertilization, and seeds are equally important cost components. Harvesting of tea, led to relatively high costs of hired labour compared with the other activities. Although not statistically significant, food crops tend to have more negative nutrient balances than cash crops. The fodder crop

Table 7
Economic characteristics and nutrient balances of major crops

	Crops				
	Coffee (n=9)	Tea (n=11)	Napier grass (n=11)	Maize (n=11)	Maize-Beans (n=30)
Yield (kg ha^{-1})	2900	3300	35 000	1800	11 00[d]
Returns (US$ ha^{-1})	1355[a]	620[b]	645[b]	85[b]	205[b]
Gross margin (US$ ha^{-1})	1115[a]	470	435	50[b]	170[b]
Variable costs (US$ ha^{-1})[c]	240[a]	150	210[a]	35[bc]	35[bc]
Fertilizers (US$ ha^{-1})	50	135[a]	60	20[b]	15[b]
Manure (US$ ha^{-1})	180[a]	10[b]	140[a]	1[b]	4[b]
Hired labour (US$ ha^{-1})	60	130[a]	55	25	30[b]
N-balance (kg ha^{-1})	−36[a]	−46	−154[b]	−68	−74
P-balance (kg ha^{-1})	6	17[a]	−10[b]	−1	−2[b]
K-balance (kg ha^{-1})	−4[a]	−26[a]	−153[b]	-44	−37[a]

[a,b] the mean difference is significant at P=0.05 level.
[c] excluding costs of hired labour.
[d] maize and beans yield added.

Table 8
Added value, actual and needed expenditures costs and gross margin sustainability quotient for major crops and crop mixtures

	Crops				
	Coffee	Tea	Napier grass	Maize	Maize-Beans
Gross returns (US$ ha^{-1})	1355	620	645	85	205
Fertilization costs (US$ ha^{-1})	235	145	200	20	15
Added value (US$ ha^{-1})	1120	475	445	65	190
Replacement costs (US$ ha^{-1})	40	50	340	125	130
In % of returns					
Actual fertilization expenditures	17	23	31	23	8
Needed expenditure	20	31	84	173	70

napier grass realises high gross margins, but is in most cases an intermediate product for the livestock activities. Average nutrient balances are highly negative, but with high variations between plots and farms. The monitoring of incomplete production cycles of napier may lead to this negative balances. Manure, for example, is sometimes applied before the monitoring period whereas intensive harvesting takes place during the monitoring period.

When relating gross returns to costs of fertilizers or manure, it appears that a significant and positive relation is found only for tea. This implies that higher application levels of fertilizers lead to higher gross returns per hectare. The observed value-cost ratio of application of fertilizers on tea amounts to 2.5. For the other crops no significant relations were found.

On coffee, tea and napier grass considerably higher levels of fertilizers are applied than on food crops and also the added values realised differs considerably (Table 8). Economic studies of the Fertilizer use recommendation project (FURP) show that application of fertilizers to food crops is not economical in the short term, and the data show this is consistent with actual farm practices. However, low fertilizer use in food crops results in high replacement cost levels. The cash crops coffee and tea needed expenditures to replace the mined nutrients amounting to 20–30% of the gross returns, and for napier grass and food crops this at least amounts to 70–80% of the returns.

Contrary to crop activities, livestock, just like the remaining identified nutrient storage places in the farm (manure stock, food stock, farm family and garbage heaps) show on average positive nutrient balances (Van den Bosch et al., 1998b). No significant differences between the gross margins and nutrient balances of the three distinguished cattle management systems are found, but the more intensive zero-grazing system tends to realise higher gross margins and more positive nutrient balances than the more extensive systems (Table 9). A more detailed analysis of nutrient flows in livestock systems and between livestock, dunghill and napier grass is presented in Van den Bosch et al. (1998b).

3.3. Sustainability indicators

For 1992 the poverty line in rural areas was estimated at Ksh 5820 per adult equivalent unit (aeu) per

Table 9
Average nutrient balances and gross margin per head of different livestock activities

	Livestock			
	Cattle zero-grazing	Cattle semi-grazing	Cattle external- grazing	Poultry
Gross margin (US$ head^{-1})	300	175	200	3.5
N-balance (kg head^{-1})	11	7	3	0.2
P-balance (kg head^{-1})	1	1	0	0
K-balance (kg head^{-1})	12	10	5	0.2

year (World Bank, 1995). Assuming an annual inflation rate of 20%, for 1995 this poverty line is estimated to be Ksh 10057 or US$ 182 per aeu. Applying this poverty line to the farm sample, it appears that on 54% of the farms, farming activities alone are not sufficient to meet basic needs of food and non-food items. The collected data for off-farm activities appeared to be highly unreliable concerning the total amount of income generated and labour days involved. Farm households were very reluctant to provide exact data on these sources of income. The monitoring data show that on 58% of the farms, any form of off-farm income is generated with an average time involvement of 106 days per farm. Assuming an income generated of Ksh 100/day (US$ 1.8) this amounts to only 7% of the average net farm income. Other sources (World Bank, 1995), which also observe high unreliability of the data, however estimate considerable higher shares: 50% of the total rural income comes from non-farm and off-farm income.

The IMEQ relates the realised total family income to the estimated minimum needed family expenditures. When the IMEQ <1, the total family income is insufficient to meet minimum family expenditures. The average IMEQ for the farm households in the sample is 1.3, with 50% of the farms realising an IMEQ <1. When applying the results of the World-bank study that farm income is on average 50% of the total rural income, the IMEQ amounts to 2.4 with 19% of the farms realising an IMEQ <1.

Over all the farms, an average Farm income sustainability quotient (FISQ) of 0.68 is found, indicating that 32% of the net farm income is based upon nutrient mining. When differentiating according to district for Kisii, Kakamega and Embu respective FISQ values of 0.53, 0.60 and 0.80 are found, with the differences not statistically different. Table 10 presents the two sustainability indicators according to market orientation. No statistically significant differences were found, although the FISQ appears to go down with increased market orientation.

Table 10
Sustainability indicators at farm level according to market orientation

	Market orientation		
	<33%	33–66%	>66%
Farm income sustainability quotient	0.92	0.58	0.54
Income minimum expenditure quotient	1.2	1.3	1.4

At activity level the Gross margin sustainability quotients for the cash crops coffee (0.97) and tea (0.90) were significantly higher than for napier grass (0.22) and the food crops maize (−1.46) and maize-beans intercrop (0.24). This was caused by the observed differences in responses to fertilizers and the differences in input/output price ratios between cash crops and food crops.

4. Discussion

The above results prove that a detailed multi-disciplinary monitoring, provides essential information on the actually practised farm management in different farming systems and their performance in terms of nutrient mining, economic viability and cash generation. Gathering this information on current farming practices and indigenous knowledge on soil nutrient management is a vital step in initiating the participative development of technologies and policy instruments addressing the problem of soil nutrient depletion.

However, it is observed that the approach needs refining to generate more accurate data on the one hand and simplification in order to facilitate easy implementation on the other. Refinements are required in the estimation of ‘difficult-to-measure’ nutrient flows, and in the determination of opportunity costs, prices, labour and off-farm income. Simplification can be achieved through reduction of collection of field data through increased use of secondary data, priority setting of primary data collection according to sensitivity of these data to the nutrient balance and economic performance, training of farm households in basic record keeping and reduction of frequency of visits.

A large variation between farms has been observed in nutrient balances and economic performance. Therefore there is a need to increase the sample size of farms to facilitate a more profound analysis at the LUZ and district level. In addition seasonal and annual variation has so far not been captured. Because both yields and prices of inputs and outputs may vary considerably over time, a more reliable analysis can be made when data covering a number of seasons are available. In the long run determination of trends over time is essential to analyse the sustainability of a system.

The monitoring approach emphasises collection of quantitative data on sustainability of farming systems. Participation of farm households has been limited to assisting in the data collection and discussions on primary results. Increased participation of farm households in the analysis of the current farming systems is required to obtain a more comprehensive picture of the functioning of the farming systems, including qualitative assessments, social acceptability, farm household and community strategies (Defoer et al., 1998; Deugd et al., 1998). This will facilitate the analysis of social sustainability and covering aspects as equity, gender, community planning, farmers' organizations etc.

There is a need to capture ecological, economic and social sustainability in 'easy-to-measure' indicators at different scale levels. Such indicators should have an established relation to well defined sustainability factors. Analysis of these indicators must take place in connection with other indicators and have to include a time or dynamic factor to facilitate indication of trends over time. Research and development has so far resulted in an array of proposed sustainability indicators (Izac and Swift, 1994; Dalsgaard et al., 1995; ILEIA, 1996; Pearce et al., 1996). NGOs focus on identification of sustainability indicators used by farm households. Also in this paper some ecological and economic indicators are applied at farm and plot level like IMEQ, FISQ and GMSQ. The production sustainability indicators applied are based upon replacement costs and, for instance, Bojö (1996) argues that because of various limitations replacement cost can only be a proxy for deriving the real costs to society. It is also argued that this approach does not account for the fact that simply supplying this amount of fertilizers does not restore the nutrient content of the soil to the original state, as losses, for example because of leaching, always occur (Jansen et al., 1995). Development of simple methods to estimate future productivity losses and economic impacts because of long-term soil degradation processes are therefore required. So far, rather complicated and data demanding agronomic-economic models are available for such estimations (Schipper et al., 1995), some of them including dynamic aspects (Shepherd and Soule, 1998). It is also observed, that the currently applied nutrient mining indicators need to be related to available nutrient stocks (Van den Bosch et al., 1998a). An overall assessment of available indicators on different sustainability issues and scale levels on relevance to the target group, operational value, links to sustainability issues is required and will facilitate targeting of future monitoring activities.

Including higher scale-levels in the monitoring activities is necessary to assess instruments affecting farming systems sustainability like community decision structures and policy makers at district levels and higher. Establishing links between nutrient mining and economic viability at a higher scale level may for instance induce a change in priorities at policy level.

5. Conclusions

The indications of unsustainability of agricultural production at national level correspond with the observations at farm household level. On average 71 kg N $ha^{-1}yr^{-1}$ and 9 kg K $ha^{-1}yr^{-1}$ are mined which implies that 32% of the net farm income is based upon nutrient mining. In addition, currently, already 54% farms in the sample realise income levels from farm activities which are below the estimated poverty line. This leads to the conclusion that in the current socio-economic environment, a large portion of the farm households are producing in an economically unsustainable situation and that off-farm income is essential for large groups of small-scale farm households to achieve economic viability.

The average partial nutrient balances, consisting of nutrient flows in direct inputs and outputs are positive. This indicates that farmers apply more nutrients through inputs than are exported through sale of products, but processes such as leaching, erosion and the consumption of food grown on the farm cause the N and K balance to be negative. Much heterogeneity between farms and farming systems is observed. For instance, the market orientation of a farm appears to be a major discriminating factor for nutrient balances and farm management aspects. A high market orientation of a farming system is related to a capital and labour intensive production on a relatively small cultivated area and results in a more negative nutrient balance for N and K compared to a subsistence oriented farming system. Surprisingly the market oriented farms realise a comparable economic performance as the subsistence oriented farms. Therefore the farm income sustainability quotient tends to go down with increasing market orientation, but not statistically significant.

Cash crops including coffee and tea realise higher gross margins and considerably lower nutrient mining levels than the food crops maize and maize-beans intercrop. Apparently for farm households application of nutrients to cash crops is economically more attractive than to food crops. Unfavourable input/output price ratios apparently lead to low level nutrient application in food crops. Given the declining food production per capita and the threat of declining productivity from the observed nutrient mining, drastic changes in the economic environment are required to change this trend.

The results at crop level appear to contradict with the farm level results, where subsistence oriented farms realise less negative nutrient balances. However, the differences in livestock management on these farming systems play a crucial role: at subsistence oriented farms outside grazing results in high level of nutrient imports and at market oriented farms high losses in the cattle-dunghill-napier grass cycle occur (Van den Bosch et al., 1998b). But also other factors like higher levels of erosion and leaching occurring in the locations of market-oriented farms contribute to these differences.

The multi-disciplinary monitoring approach, although still in development, has proved to contribute to understanding the current farm management systems and to target and prioritize different development options. The observed heterogeneity, caused by differences in physical and socioeconomic environment, farm management strategies and objectives, technical knowledge etc., can be used as a starting point for inducing changes towards an increased sustainability. It is obvious from the results that market-oriented farming systems will have to follow a different strategy towards more sustainable practices than the subsistence oriented systems.

Incorporating environmental issues in the economic analysis is an appropriate way to link agronomic and economic analysis. It contributes to quantification of the financial impact of environmental degradation, provides the economic boundaries for development options and plays an essential role in policy advise. For instance, the results showing that on average 32% of the realised net farm income is based upon nutrient mining and assuming this level of mining will continue, is a clear indication for policy makers that in the long run soil fertility is declining and agricultural production is developing in an unsustainable way and that this issue needs to be addressed with the highest priority.

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