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RESEARCH ARTICLE

Farm nitrogen flows of four farmer field schools in Kenya

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Abstract Re-use of nutrients within farming systems contributes to sustainable food production in nutrient limited production systems. Re-use is established when nutrients pass through several farm compartments before they leave the farm via marketable products. In this paper re-use of nitrogen is examined as an indicator for sustainable soil fertility management. Re-use (RU, kg farm^{-1}) was defined as the amount of nitrogen that was translocated within one farm divided by the sum of transitions between farm compartments within a farm. In 2002, a total of 101 farms belonging to 4 farmer field schools in Kenya were analysed using the NUTMON (now known as MonQI) toolbox. The farms were distributed over 4 farmer field schools located in two agro-ecological zones. RU was positively related to the net farm income and to crop yields. However, data were scattered and often local farm conditions veiled the relation between nitrogen management strategies and farm performances. The results of this paper demonstrate that different agro-ecological zones with diverse production constraints have developed different in-farm nitrogen management strategies that are best adapted to the local conditions, but may have different environmental impacts.

Keywords Kenya · Soil fertility · Nutrients · Nitrogen · Balances · Farm management · NUTMON · MonQI

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Introduction

The ongoing decline of soil fertility is considered East-Africa's major threat with regard to food production (Gachimbi et al. 2005) given that approximately 60%–80% of the farm income is based on soil depletion, i.e. through unreplenished nutrient uptake in marketable crops (de Jager et al. 2001). Sustainable soil management can not be visualized easily and therefore indicators are often used to facilitate discussions on soil fertility management. Smallholder farmers generally prefer visible criteria for soil quality, for instance crop yield, soil tilth and soil colour (Murage et al. 2000), but these criteria are hard to relate to current practices and therefore scientists generally refer to two kinds of indicators of soil fertility status viz. (i) input-output ratios and (ii) soil stocks.

Ratios of nutrient inputs and outputs are commonly used as indicators for soil fertility changes (de Jager et al. 1998a; Bekunda and Manzi 2003; van den Bosch et al. 1998b) and are based on the observation that a change in soil fertility is basically the result of mismatches between inputs and outputs of nutrients. In the concept of input-output ratios as indicators for soil fertility management the farm is considered as a black-box. Nutrients (and capital) enter and leave the farm, but one is unaware of the processes in the farm itself (Schlecht and Hiernaux 2004). This aspect of input-output ratios is in contrast to the well reported impact of on-farm management, i.e. manure management, livestock management and crop management on soil fertility (Ayuk 2001; Smith et al. 1997).

Another frequently used indicator for the soil fertility status is the soil C stock. Gbadegesin and Areola (1987) showed that 78% of the variance in maize yield in Nigeria could be explained by differences in soil C stocks. However, the quantification of soil C stocks demands for chemical soil tests which are commonly unavailable to smallholder farmers. And, additionally, soil C stocks are generally expressed in mass and/or volume units and to assess its potential as soil fertility indicator, nutrient stocks, rooting depth and bulk density should be known as well (Smaling and Dixon 2006).

Hence, both conventional indicators (input-output ratios and soil stocks) of (sustainable) soil management have their drawbacks and both fail in resolving the high spatial variation that is common to most soil fertility indicators (Smaling and Dixon 2006). In this paper we present re-use (RU, kg farm^{-1}) as a possible indicator for (sustainable) soil management for small-scale farming systems. Notably, through sound farm management practices, nutrients may be re-used several times, e.g. from herbage to manure to crop uptake to fodder, etc. By re-using nutrients the effectiveness of imported nutrients may multiply and nutrient re-use may be a valuable indicator of farm nutrient use efficiency and may help to identify best practices. The longer nutrients are captured within the farming system, the higher the possibility of plant-uptake and/or consumption by livestock. Therefore, high re-use of nutrients may result in increased productivity of the farm and consequently in increased farm incomes and decreased environmental losses. In-farm RU of nutrients can be analyzed using standardized data assessments ('nutrient monitoring'). However, high in-farm turn-over rates of nutrients do not necessarily indicate high re-use of nutrients. High in-farm turn-over rates may also point to soil depletion when these nutrients are extracted from soil in stead of being imported from off-farm compartments (i.e. market). Also, during every nutrient translocation losses occur. Hence, a proper indicator refers to high quantitative nutrient turn-over with a minimum of translocations. Consequently, RU was defined as the amount (kg) of in-farm nutrient turn-over divided by the number of in-farm nutrient translocations.

In this paper we studied RU of nitrogen (N) for 101 smallholder farms in Kenya to determine whether high RU can be used as an easily applicable, low data demanding indicator for (sustainable) soil management and whether RU is related to crop productivity and farm net income.

Materials and methods

Site description

The farmers were organized in four farmer field schools (FFSs) that were distributed over two contrasting agro-ecological zones in Kenya: Kiambu and Mbeere. In general, Mbeere is considered a low-medium agricultural potential area and Kiambu a high agricultural potential area. In each zone two FFSs were established: Ngaita and Kibichoi in Kiambu, and Munyaka and Kamugi in Mbeere. In each district community workshops were organized to introduce the project and to assess interest and willingness of farmers to participate. The Kamugi and Munyaka FFSs were based on existing community groups, whereas the Ngaita and Kibichoi FFSs were newly formed. FFS meetings were held every two weeks and facilitated by a FFS trainer. All FFSs conducted simple experiments on a central learning plot. In the FFSs joined learning on integrated nutrient management, crop production, livestock management, farm management and home economics were promoted (de Jager et al. 2007). This study was performed simultaneous with de Jager et al. (2007) and the same dataset was used. However, de Jager et al. (2007) focused on rural empowerment and they concluded that strenghtening farmers' organisations and institutions contribute to general empowerment of rural people and stimulate the process of farmer-led innovations in smallholder agriculture in East-Africa. The focus of the current paper is on nutrient management strategies and indicators for proper soil fertility management.

Table 1 Some general features of the studied areas

	Mbeere	Kiambu
Location	Latitude 0°20″–0°50″ South Longitude 37°16″–37°56″ East	Latitude 0°75″–1°20″ South, Longitude 36°54″–36°85″ East
Farmer field schools (# of farms)	Munyaka, Kamugi	Kibichoi, Ngaita
Precipitation (mm year^{-1})	Bimodal 550–1,200 with most parts receiving <750 mm	Bimodal 600–2,000
Soils	Ferrasols, arenosols, acrisols and luvisols	Humic nitisols and humic andosols
Altitude (masl)	500–1,200	1,200–2,500
Temperature	20°–30°C	13°–22°C
Major crops	Maize, sorghum, beans, cowpeas, tobacco	Coffee, tea, maize, beans, vegetables
Population density (inhabitants/km^2)	82	562

The Kiambu FFSs were within the vicinity of Nairobi, which is reflected in the high population density and the production of cash crops as well as food crops for self-sufficiency. In Table 1 some general properties of the study areas are provided. The Mbeere soils were somewhat sandier than the Kiambu soils (61–89% vs 31–39% sand contents). Total N contents of the topsoils ranged from 0.3 g kg^{-1} for Mbeere to 2.5 g kg^{-1} for Kiambu (www.inmasp.nl). The soils in FFSs of Kiambu were classified as Humic Nitisols, as Luvic Arenosols in Munyaka and as Haplic Acrisols in Kamugi (Muya 2003). Table 2 shows some general FFS characteristics.

Table 2 Selected farm characteristics of the studied FFSs (± standard deviation)

	Mbeere		Kiambu	
	Munyaka	Kamugi	Ngaita	Kibichoi
No. of farms	30	29	12	30
Livestock (TLU farm^{-1})	1.05 ± 1.65	1.81 ± 1.81	2.98 ± 4.52	3.97 ± 5.11
No. of plots (PPUs) (farm^{-1})	145	80	62	140
No. of plots per farm (farm^{-1})	4.7 ± 1.7	2.8 ± 0.8	3.9 ± 1.5	4.7 ± 1.4
Total farm area (ha farm^{-1})	1.5 ± 1.2	1.8 ± 3.3	0.1 ± 0.1	0.8 ± 0.5
Fallow area (ha farm^{-1})	1.3 ± 1.1	1.4 ± 2.8	0.0 ± 0.0	0.7 ± 0.4
Average slope (%)	18.5 ± 5.1	16.8 ± 8.2	14.7 ± 8.5	13.9 ± 7.2
Partial N balance[a] (kg ha^{-1} half year^{-1})	−3.1 ± 15.9	0.0 ± 19.1	24.9 ± 70.6	58.8 ± 83.1
Partial P balance[a] (kg ha^{-1} half year^{-1})	−1.0 ± 2.4	−1.5 ± 3.8	9.8 ± 32.0	39.3 ± 47.6
Partial K balance[a] (kg ha^{-1} half year^{-1})	6.6 ± 16.2	14.2 ± 21.9	6.1 ± 53.5	43.1 ± 71.6
Full N balance (kg ha^{-1} half year^{-1})	1.1 ± 12.0	2.5 ± 19.1	−50.0 ± 81.2	−2.6 ± 61.1
Full P balance (kg ha^{-1} half year^{-1})	−1.7 ± 2.4	−0.9 ± 3.8	5.9 ± 34.5	36.7 ± 48.8
Full K balance (kg ha^{-1} half year^{-1})	−5.4 ± 17.7	16.0 ± 21.4	−28.2 ± 87.5	16.9 ± 80.5
Total N stock[b] (kg ha^{-1})	1830 ± 568	2955 ± 749	8006 ± 717	7268 ± 811
Total P stock[b] (kg ha^{-1})	558 ± 217	695 ± 203	2229 ± 286	1978 ± 570
Total K stock[b] (kg ha^{-1})	4854 ± 2197	8299 ± 3397	14569 ± 8420	16068 ± 5777

[a] Partial balances include inputs via mineral and organic fertilizers and outputs via farm products

[b] Total nutrient stocks in the upper 30 cm of soil

Data collection

Detailed information on nutrient (N and P) flows between and within farms was collected using the NUTMON toolbox (now known as MonQI). NUTMON is a methodology for monitoring management and performance of small scale farming systems world-wide. Briefly, farmers were extensively interviewed about their farm management practices using standardized questionnaires. In total 101 farm households particpated in the project, ranging from 12 farm households in Ngainta to 30 households in Kamugi and Kibichoi (Table 2). Interviews were performed once by the FFS trainer in August 2002 and were considered representative for the previous 6 months considering the bimodal rain seasons (Table 1). The results of the questionnaires were entered in the NUTMON software and a wide range of data-output was generated, ranging from nutrient balances to economic flows between farm-compartments. Data-output was automatically formatted in individual user-defined farm reports to facilitate tailor-made feedback to the farmers. More information about the NUTMON/MonQI toolbox can be found on www.monqi.org, in the NUTMON manual (Vlaming et al. 2001) and in de Jager et al. (1998b), van den Bosch et al. (1998a) and van den Bosch et al. (1998b).

We distinguished four internal farm compartments: households, livestock, crops and stables/compost heaps, and two external farm compartments: market and environment. Nitrogen (and capital) flows between the compartments are shown in Fig. 1. Internal flows (IF) were defined as the quantity of N flowing from one compartment to another within the farm boundaries. External flows (EF) were defined as the amount of N flowing from internal farm compartments to external farm compartments, and vice versa. Typical examples of N flows between the different farm compartments are demonstrated in the matrix of Table 3. In Mbeere cattle was left grazing outside the farm boundaries. This so-called free-grazing regime is difficult to monitor, but an attempt was made based on the energy requirement of cattle and the on-farm feeding strategy (Vlaming et al. 2001), which results in output of nutrients because of deposition of cattle droppings outside the farm boundaries and input of nutrients because of uptake of nutrients through grazing outside the farm. Hence, the net effect of grazing depends on the nutrient content of off-farm roughage which is, however, generally unknown and consequently the N fluxes related to free grazing are highly uncertain.

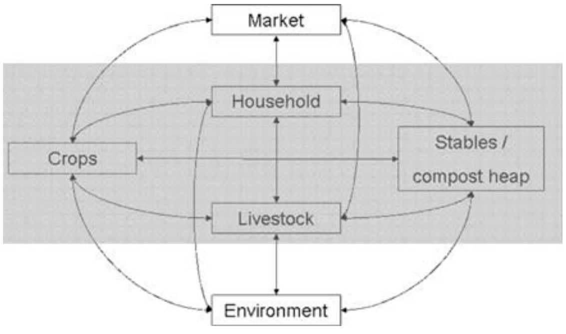

Fig. 1 Flows of nutrients (and capital) between internal (grey) and external farm compartments. All flows are bi-directional

Data analysis

Partial N balances were defined as the differences between of inputs via mineral fertilizers and organic inputs and outputs via farm products. Additionally, full N balances included atmospheric deposition, biological N fixation, sedimentation, subsoil exploitation, leaching, gaseous losses, erosion and human excreta (Vlaming et al. 2001). RU was defined as the amount of IF (kg) divided by the number of IF per farm, thus being a quantitative measure of the average IF at farm level. Subsequently, IF's, EF's and RU's were related to crop production and net farm income (NFI) to test the applicability of RU as indicator for crop production and farm performance, respectively. The NFI equals the sum of gross margins obtained with the production of crops and livestock minus fixed costs. Also, RU was related to the number of tropical livestock units (TLU, 1 TLU = 250 kg live weight) to find a possible explaining factor for differences in RU's. It was not possible to relate RU to soil characteristics like soil nutrient stocks because of differences in topographical positions (e.g. slope versus up-hill farms) and because of differences in historical soil management. RU was considered an appropriate indicator when it could be related to farm management practices. Farm areas were much smaller in Kiambu compared to Mbeere (Table 2) and expressing flows on basis of area may scatter differences between farm management strategies. Therefore, flows (e.g. IFs and Efs)

Table 3 Typical nitrogen flows between farm compartments

From	To: Market	Household	Crops	Compost heaps and stables	Livestock	Environment
Market	–	–	Import of seeds and fertilizers	Import of composting materials	Import of roughage and concentrates	–
Household	Removal of latrines	–	*Application of household waste as organic fertilizer*	*Composting materials (household waste)*	*Fodder (household waste)*	Wastes
Crops	Harvested products sold at (local) market	*Consumption of harvested products*	*Application of crop residues as organic fertilizer*	*Crop residues and Napier grass for composting*	*Fodder (crop residues)*	NH_3 volatilization, denitrification, leaching
Compost heaps and stables	–	–	*Compost*	*Farm yard manure*	–	NH_3 volatilization, denitrification, leaching
Livestock	Sale of animal products	*Consumption of animal products*	*Application of manure*	*Farm yard manure*	–	NH_3 volatilization, denitrification, leaching

Empty cells indicate absence of flow in dataset. Flows in italic refer to internal farm flows (IFs)

were expressed per farm. Relations were visually evaluated and, whenever appropriate, by simple linear regression using standard criteria for significant relations (*P* values and R^2 between data points)

Results and discussion

Farm management in four FFSs in Kenya

Partial N, P and K balances included manageable flows and the surplus of the partial nutrient balance is an indicator for net changes in farm nutrient stocks. For Kiambu FFSs the partial balances were positive, indicating that more nutrients were applied than withdrawn, whereas for Mbeere FFSs partial balances were slightly negative for N and P (Table 2). However, when estimates of losses via denitrification, erosion, volatilization and leaching were included the Kiambu FFSs showed negative N balances indicating depletion of soil resources, whereas the Mbeere FFSs showed minor or no depletion (Table 2). Hence, relatively high nutrient inputs (i.e. positive partial nutrient balance) like in Kiambu resulted in relatively high hard to manage nutrient losses (i.e. negative full balance) which was caused by the more than proportional positive relationship between nutrient inputs and hard to manage -and hard to estimate- N losses like denitrification and erosion.

Tables 4 and 5 show matrix tables of summed N flows between compartments in the four FFSs, similarly to Table 3 with the exception that the environmental part is left out, because these fluxes are hard to quantify (and are –thus- unreliable) at field level. In general fluxes were small, which was caused by the small plot sizes. Major N fluxes were found between households and crops. The majority of these fluxes consisted of consumption of harvested products (i.e. fluxes from crops to households), application of household waste as organic fertilizer (i.e. fluxes from households to crops) and market related fluxes. Flows of N from the redistribution and livestock compartments to crops were lower in Mbeere FFSs compared to Kiambu FFSs, which was caused by grazing of livestock (and the associated deposition of manure) outside the farm boundaries in the FFSs in Mbeere. Consequently, the balances are valid at farm level, with its demarcation at the farm gate, and could not be up scaled to higher spatial scales. Sometimes differences between summed columns versus summed rows occurred, which were caused by mismatches in data. Notably, farmers were asked to estimate their yields (e.g. in wheelbarrows) that were subsequently calibrated to SI units, but it is not unlikely that the quantity of a wheelbarrow varied among farmers and districts, which occasionally yielded high differences (Tables 4 and 5).

Differences in farm management, socio-economical and environmental conditions caused large ranges in the flow indicators as presented in Table 6. Also, occasionally outliers were part of the average, for instance when a farmer had off-farm employment and/or when large cash transfers were made within the monitoring period of 6 months. These outliers were not omitted from the dataset because they represent common, though rare, practices but explain the high ranges observed in farm indicators.

In general, internal flows were higher for Kiambu compared to Mbeere (Table 6) and despite the high standard deviations the differences between the two areas were highly significant ($P < 0.0001$). Half yearly total N flows equalled 67 kg farm^{-1} for Kamugi, 44 farm^{-1} for Munyaka, 130 kg farm^{-1} for Kibichoi and 95 kg farm^{-1} for Ngaita (sums of flows

Table 4 Average *N* flows between farm compartments in Mbeere for Kamugi (A) and for Munyaka (B)

From	To: Market	Household	Crops	Redistribution	Livestock
A					
Market			2.13	1.04	25.44
Household	6.95		*2.56*	*4.35*	*0.89*
Crops	1.91	*6.40*	*0.09*	*0.47*	*1.64*
Redistribution			*3.76*	*0.14*	
Livestock	4.73	*0.24*	*0.51*	*4.01*	
B					
Market			1.57	0.00	11.33
Household	0.00		*2.38*	*6.78*	*1.49*
Crops	3.80	*5.21*	*0.06*		*1.94*
Redistribution	0.75		*0.43*	*0.04*	
Livestock	4.53	*0.17*	*1.11*	2.59	*0.03*

Italic numbers refer to internal flows (kg farm^{-1} half year^{-1})

Table 5 Average *N* flows between farm compartments in Kiambu for Kibichoi (A) and for Ngaita (B)

From	To: Market	Household	Crops	Redistribution	Livestock
A					
Market			17.29	0.11	40.27
Household			*1.43*	*6.40*	*1.63*
Crops	7.20	*2.58*	*0.29*		*4.42*
Redistribution	2.70		*18.88*		
Livestock	7.62	*2.15*	*1.08*	*15.72*	*0.05*
B					
Market			9.42	0.77	22.26
Household	6.99		*1.45*	*6.16*	*0.67*
Crops	3.64	*1.57*	*0.74*	*0.09*	*2.40*
Redistribution	0.24		*13.52*	*0.02*	
Livestock	15.10	*1.04*	*1.99*	*6.53*	

Italic numbers refer to internal flows (kg farm^{-1}half year^{-1})

Table 6 Flow indicators of nutrient management and profitability of farms (± standard deviation)

	Mbeere		*Kiambu*	
	Kamugi	Munyaka	Kibichoi	Ngaita
IF (kg N farm^{-1} half year^{-1})	38 ± 20^{a}	47 ± 27^{a}	118 ± 97^{b}	69 ± 52^{a,b}
EF (kg N farm^{-1} half year^{-1})	15 ± 12^{a}	11 ± 9^{b}	18 ± 21^{a}	11 ± 14^{a}
IF/EF^{A}		13 ± 26^{a,b}	28 ± 118^{a,b}	16 ± 30^{b}
RU (kg^{-}farm^{-1})	0.27 ± 0.10^{a}	0.24 ± 0.12^{a}	0.64 ± 0.46^{b}	0.65 ± 0.69^{b}
NFI^{B} (Ksh farm^{-1})	771 ± 15183^{a}	6988 ± 5723^{a}	11573 ± 37541^{a}	2167 ± 33125^{a}
GM crops^{C} (Ksh farm^{-1})	3345 ± 11941^{a}	6360 ± 5460^{a}	22598 ± 23610^{b}	8563 ± 27958^{b}
GM livestock^{C} (Ksh farm^{-1})	538 ± 243591^{a}	3629 ± 32883^{b}	−11132 ± 7178^{a,b}	−10493 ± 4828^{b}

Different letters in superscripts within rows refer to significant differences ($P < 0.05$)

[A] IF/EF were calculated per farm before averaging at FFS level

[B] NFI = Net Farm Income

[C] GM = Gross Margin[s]

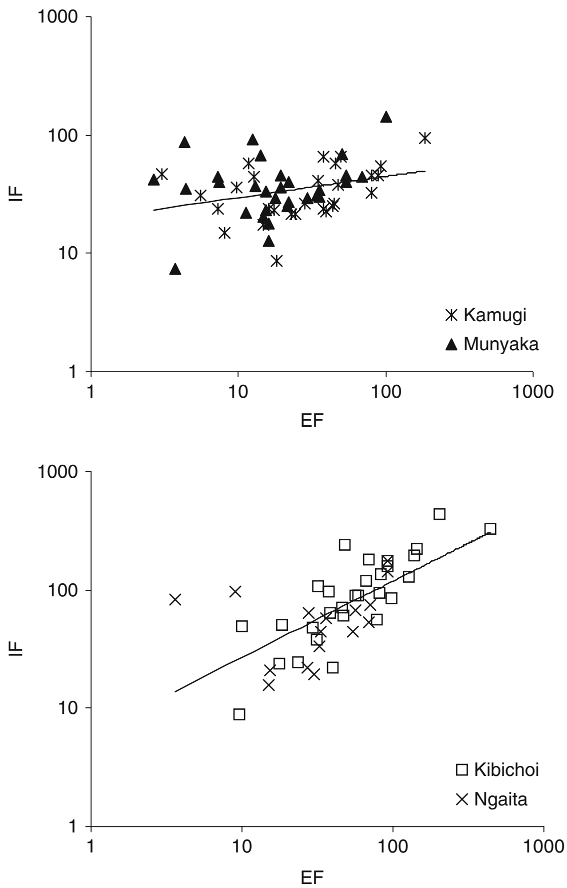

Fig. 2 Internal flows (IF) and external flows (EF) in Mbeere (above) and Kiambu (below). Symbols represent individual farms. Note log-log scale. Lines show linear relation per district ($R^2 = 0.10$, $P < 0.001$ for Mbeere and $R^2 = 0.46$, $P < 0.0001$ for Kiambu)

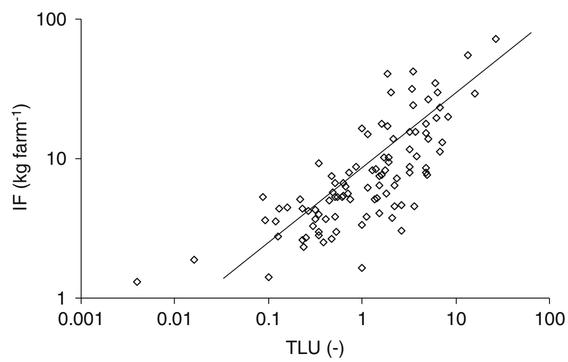

Fig. 3 Tropical livestock units (TLU) and internal flows (IF) at farm level. Data for all FFSs, note log-log scale. Line shows linear relation ($R^2 = 0.56$, $P < 0.0001$)

in Tables 4 and 5). For all FFSs IFs exceeded EFs indicating re-use of N on farm. Or, in other words, more N was circulated within the farm than passed the farm gate.

At farm level, EFs and IFs were positively related for the FFSs in Kiambu, but for Mbeere the relationships between EFs and IFs were weak (Fig. 2). For the farms in Kiambu there seemed to be a lag-phase for EFs smaller than about 20 (Fig. 2). It is unknown what caused this lag-phase, but apparently there is some kind of basis EF before IFs can set off. Also, Fig. 2 demonstrates the large variability in IFs and EFs within FFSs. The majority of the EFs consisted of externally imported N, i.e. fertilizers and concentrates (Tables 4 and 5) and hence the positive relation between EF and IF indicates that external inputs of nitrogen results in increased IFs.

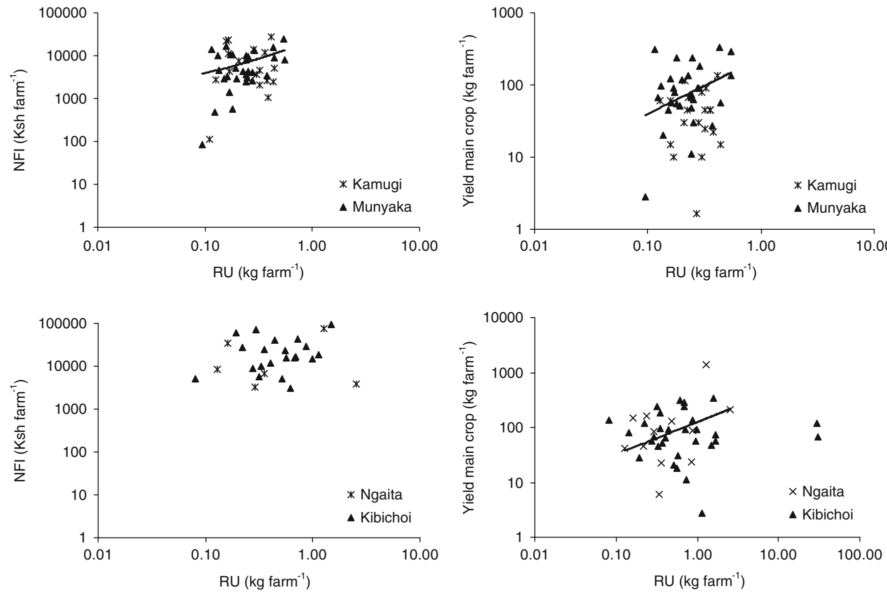

Fig. 4 Re-use (RU) of N and net farm income (NFI, left) and crop yield (right) per farmer field school for Mbeere (above) and Kiambu (below). Where relevant (i.e. $R^2 > 0.10$ and $P < 0.01$) linear relations are presented by solid lines. Note log-log scale

Factors governing the extent of internal flows

In general, EFs were positively related to IFs (Fig. 2) and subsequently IFs were positively related to the number of tropical livestock units (TLU, Fig. 3), but EFs were not related to TLU (not shown). Hence, vice versa, more TLU resulted in higher IFs, but not in increased input or output of N at farm level. Also, RUs were positively related to TLU, but the relationship was less strong compared to IFs ($R^2 = 0.64$ for IF and 0.24 for RU, not shown). In general, relations between RU and farm variables were weak, because RU is an indirect parameter, but some significant effects were observed. In Munyaka RUs were positively related to NFI ($R^2 = 0.19$, $P < 0.001$), but less to crop yields ($R^2 = 0.11$, $P < 0.01$), whereas in Ngaita RUs were positively related to crop yields ($R^2 = 0.15$, $P < 0.001$) but there was no relation with NFI (Fig. 4). The absence of a relation between RU and NFI in Kiambu was probably caused by the relatively high share of off-farm labour in these FFSs (de Jager et al. 2007). Hence, although sometimes scattered, there seems to be a general positive relation between RU and farm performance, and apparently increased mobility of N (higher RU) was reflected in the economic performance or crop production of the farm, but did not (yet) result in less environmental N losses, or were not reflected in our estimates.

Nutrient management strategies

Table 6 showed no consistent differences between NFIs for the two districts, although differences between FFSs were large. The gross margins on crops and livestock greatly differed between the two districts; in Kiambu negative GMs were achieved on livestock, while the presence of livestock was slightly higher in Kiambu compared to Mbeere (Table 2). Livestock management greatly differed between the two districts. In Kiambu livestock was kept in stables (zero-grazing) and fed with Napier grass, crop residues and concentrates, while in Mbeere, the cattle were kept under free range and were grazed outside the farms, but corralled at night. In the free-grazing livestock management system, N was imported to the farm (by consuming grass), but also N was lost by manure deposition outside the farm. In Mbeere, on average 20.12 ± 22.86 kg N farm^{-1} was imported to the farms by grazing during the monitoring period. For the same period N export by grazing was 8.18 ± 8.83 kg N farm^{-1} and consequently for Mbeere free grazing cattle resulted in a net import of N to the farm. In Tables 4 and 5 grazing was not included (because outside farm boundaries) and apparently the imported nutrients through grazing did not become part of the redistribution unit. Hence, one can question whether the net import of nutrients through free ranging is, or can, be used effectively for

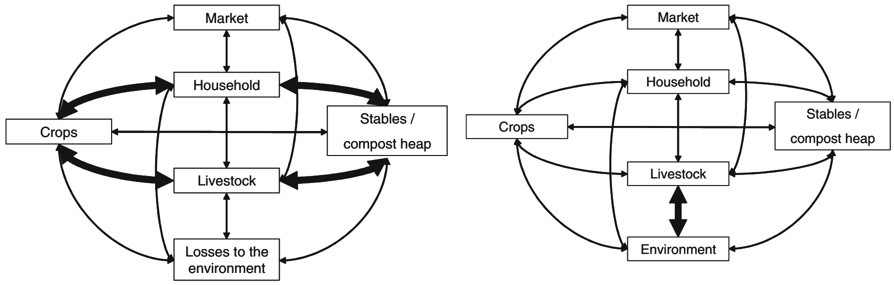

Fig. 5 Schematized farm strategies in Kiambu (left) and Mbeere (right). The thickness of the arrows indicates the intensity of nutrient flows. The differences in farm nutrient management strategies were mostly caused by differences in livestock management (see text)

in-farm nutrient use. However, we can not exclude biases through inaccurate default parameters on nutrient contents of consumed roughages as it remains unknown what was exactly consumed by the free grazing cattle. In Kiambu livestock largely depended on imported feeds (mainly concentrates) and manure was collected in manure pits. Apparently, the Kiambu farmers were able to retain more N for crop production from livestock production than the Mbeere farmers, partially resulting in high crop yields and crop GMs, and in lower GMs for livestock (Table 6). In total, both strategies, however, did not differ in terms of NFIs (Table 6) and the two strategies are conceptually visualized in Fig. 5.

In Kiambu RUs and partial N balances were higher compared to Mbeere, indicating increasing soil N stocks. Hence, from a soil sustainability point of view the farm strategy of Kiambu seems the better option, because of the increased RU. However, the farm strategy of the Kiambu FFSs is highly adjusted to the vicinity of Nairobi and depends on the availability of manure. In the free grazing system of Mbeere, manure is scarcely available. This limited availability of manure is a major problem in many parts of East-Africa and therefore, combined use of inorganic nutrient sources (mineral fertilizers) and manure is encouraged within the framework of integrated nutrient management (Bayu et al. 2004). Also, the negative full balances for the Kiambu district (Table 2) indicate that the soils were suffering from nutrient depletion. Data on full nutrient balances refer to estimated losses which are weakly supported for small scale studies like the one presented in this paper. Therefore, the net effect of increased RU on soil sustainability demands for verification of hard to control nutrient losses.

The main advantage of using RUs as an indicator for sustainable agricultural production is that it does not rely on chemical analysis like the soil stock approach and that it only uses easy and relatively rigidly quantified data. Although full N balances may in theory be a better indicator, the quantification of e.g. denitrification can only justly be made on plot scale, whereas erosion can only be accurately quantified at the watershed scale. Most often, however, the quantification of hard to measure N fluxes relies on simple (regression) equations. Hessel et al. (2006) showed that for erosion these estimates were only reliable when parameterized on-site, which is rarely done. Therefore, we prefer to use an indicator that does not rely on those estimates for assessing the sustainability of farm management.

In this paper we focussed on N use, because (i) N is a key element in plant production, (ii) has an intensive turn-over and (iii) is very reactive, i.e. response times are generally fast. For P, comparable results are expected, but the results may be less clear because of the prolonged response time of P to alternating conditions.

Conclusions

In both districts livestock keeping was an important farm activity and more livestock resulted in higher IFs, but not in increased farm income. In the Kiambu FFSs livestock largely depended on imported feeds (mainly concentrates), while in the Mbeere FFSs livestock was left grazing on the pastures. As a consequence, the Kiambu farmers were able to retain more nutrients for crop production from livestock production than Mbeere farmers. This was expressed in the higher RUs for Kiambu compared to Mbeere. Although in Kiambu more emphasis was put on livestock management, less financial margins were achieved from it compared to Mbeere. Investments made in livestock production in Kiambu paid off in increased crop production, partly due to improved availability of manure. Overall, there were no significant differences in economic performance between the two districts and apparently farm management strategies evolved to comply with the local production constraints. RUs were positively related to partial N balances and hence are a potential valuable indicator for farm sustainability. However, the relation between RUs and full N balances needs further verification before a final statement can be made.

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