Author: Tankou, Christopher Mubeteneh
Title: The interactions of human mobility and farming systems and impacts on biodiversity and soil quality in the Western Highlands of Cameroon
Issue Date: 2013-12-12

5 Soil Quality Assessment of Cropping Systems in the Western Highlands of Cameroon

C.M. Tankou[1], G.R. de Snoo[2], G. Persoon[3] and H.H. de Iongh[2]*

Accepted for publication in the International Journal of Agricultural Research

1 Faculty of Agronomy and Agricultural Sciences, University of Dschang, P.O. Box 222, Dschang, Cameroon.
2 Institute of Environmental Sciences, Leiden University, P.O. Box 9518, 2300 RA Leiden, The Netherlands
3 Department of Anthropology, Leiden University, P.O. Box 9518, 2300 RA Leiden, The Netherlands.
* Corresponding author; cmtankou@yahoo.com; tel: (237) 77 66 03 04; fax: (237) 33 45 15 66

Abstract

Soil nutrient depletion is a major constraint in agricultural development in sub-Saharan Africa. A study was conducted in the Western Highlands of Cameroon to assess soil nutrient balance and identify household and farm characteristics influencing soil nutrient balance using the procedures outlined in the NUTMON Tool-box. This is based on the assessment of the stocks and flows of nitrogen (N), phosphorus (P), and potassium (K) through the inputs (mineral fertilizers, organic inputs, atmospheric deposition and sedimentation) and outputs (harvested crop products, residues, leaching, denitrification and erosion). The gross margin was estimated as gross return minus variable costs while the net farm income was estimated as total gross margin minus fixed costs. The nutrient budgeting results revealed that nitrogen mining was very common at all levels with the greatest mining carried out by intercropping systems which generally received little or no off-farm inputs. High positive nutrient balances were found in market oriented crops. A general picture of the study site showed that only nitrogen was deficient while there were surplus amounts of potassium and phosphorus. The gross margins of green peppers, leeks and onions were negative while the others were positive. Legume intercrops could significantly modify the nutrient balance and sustainability in this region.

5.1 Introduction

The depletion of soil nutrients is a major constraint to sustainable agriculture (Smaling *et al*. 1993, 1996). Oenema *et al*. (2003) postulated that nutrient budgets of agroecosystems can be used as a tool to increase the understanding of nutrient cycling, or as a performance indicator and awareness raiser in nutrient management and environmental policy. The rural community of Cameroon in general and the Western Highlands of Cameroon (WHC) in particular, depend nearly entirely on agricultural activities to provide food, feed and income. The rising demographic pressure has imposed intensive land use over space and time which in turn demands high amounts of off-farm inputs. Though some studies have been done in the forest region of Cameroon (Stoorvogel & Smaling, 1990), no information so far exists in the WHC. Nutrient monitoring is a method that quantifies a system's nutrient inflows and outflows resulting in nutrient balance which is a useful indication of soil quality. Soil fertility is determined through the quantification of nutrient stocks and flows within the production systems (Bationo *et al*., 1998; Deugd *et al*., 1998). Nutrient balance can be determined at spatial scales ranging from field level to national level. A nutrient balance determined at the level of individual activities within a farm serves as a useful indicator, providing insight into the magnitude of the loss of nutrients from the system and the causes for such losses, which ultimately enables targeted intervention. Understanding the nutrient balance at each crop activity level within the farm and at farm level, can provide a useful guide when planning agricultural policy decisions to sustain the production system at these levels. The importance of this study to elucidate the nutrient dynamics in the breadbasket of Cameroon (Bergeret & Djoukeng, 1993) where no such study has been done before, cannot be overemphasized.

A nutrient balance is the difference between nutrient inputs and outflows (or losses). Positive balance for a particular nutrient means that the nutrient will accumulate in the soil while negative balance reflects the mining of the nutrient concerned. Accelerated rates of nutrient loss are evidence of soil depletion and are unsustainable over the long term. The accumulation of high levels of nutrients, particularly of P and N, are also undesirable, and are associated with increased pollutant export in the form of leachate or runoff (P and K), or in gaseous form through denitrification or volatilization (N). Nutrients are generally taken up by the plant from the solution phase of the soil, which is replenished through ion exchange, by dissolution from the solid mineral phase, or by mineralization of organic compounds. Some of the nutrients are usually returned to the soil in the form of crop residues and the remainder is removed from the field in the form of harvested products. Nutrients can also be lost through soil erosion, water runoff, soil sediment, leaching (mainly N and K) and volatilization (mainly N). The loss of nutrients is countered by biological

N-fixation, atmospheric deposition in rainfall, and the application of mineral fertilizers, animal manures, or compost.

Soil nutrient stocks are not static entities and studies in different parts of Africa at different spatial scales show that nutrients are being depleted at alarming rates (Stoovogel & Smaling, 1990; Van der Pol, 1992; Smaling *et al.*, 1993; Smaling & Braun, 1996; Smaling *et al.*, 1997; Scoones, 2001). Nutrients are annually taken away in crops or lost in processes such as leaching and erosion which far exceed the nutrient inputs through fertilisers, deposition and biological fixation (Smaling & Braun, 1996). Stoorvogel and Smaling (1990) estimated that 21 kg N, 2 kg P and 13 kg K were lost per ha and per year in southern Cameroon.

The concern for soil nutrient depletion and low soil fertility has led to the development of several integrated soil fertility management technologies that offer the potential for improving soil fertility management in Africa (Scoones & Toulmin, 1999). These include improved soil erosion control using living barriers or micro-catchments, inoculation of grain legumes for improved N-fixation, efficient use of manure and other locally available organic materials, use of green manure and cover crops (Delve & Jama, 2002) and use of low levels of N and P fertilisers on maize and beans (Wortmann *et al.*, 1998; Wortmann & Kaizzi, 1998) in eastern Uganda. The application of nutrients to croplands is critically important for improving crop yields and the productivity of farmlands, however only approximately 50% of the applied nutrients are integrated into plant mass. The remaining nutrients accumulate in the soil, are emitted to the atmosphere (NO, NH_3, N_2O) or water bodies as soluble components (NO_3, PO_4) or as a component of soil. Agricultural activities are a significant contributor to the substantial increase of both nitrogen and phosphorus (Smil, 2000; Galloway, 1998) in our environment. These increases have contributed to the degradation of both air and water resources. A holistic approach to tackling the soil fertility problem through the integration of biophysical, socio-economic, institutional and policy factors has been proposed (CGIAR 2002). High input costs, inadequate knowledge of soil fertility management practices, the design of cropping systems exacerbated by pests and disease problems, global policies on the input-out market and institutional failures are amongst the determinants hampering the efforts of smallholder farmers (Van Reuler & Prins, 1993; Hart & Voster, 2006).

To address the importance of the problems faced by smallholder farmers of the WHC, the present research was undertaken by employing the NUTMON-Toolbox to assess the nutrient balance at field (crop activity) level in the WHC. In addition, the study attempts to identify those household socio-economic and biophysical factors which influence soil quality and agro-economic performance and the profitability of cropping practices.

5.2 Materials and Methods

Site description: The study was carried out during the first and second cropping seasons in three villages: Bafou, Baleveng and Fongo-Tongo located in the WHC and found between the geographical coordinates of 05° 27' - 05° 37.62'N and 09° 57.502' - 10° 09.544' E (Figure 5.1). The general characteristics of the farm plot studied are given in Table 5.1. Soil samples were collected from the 17 farm plotsincluded in the study and analysed using standard procedures.

Table 5.1
Characteristics of farms studied

Characteristics	Average value (n = 17)	Standard deviation
Household size	7.18	6.11
Labour units*	2.12	1.36
Distance to the market (km)	2.91	1.52
PPUs	4.41	2.92
Area cultivated (ha)	0.17	0.19
Average slope (%)	11.58	7.92
Slope length (m)	53.61	32.29
pH-KCl	3.99	0.14
Total N (g/kg)	2.38	0.45
Extractable P (mg/kg)	27.08	3.6
Exchangeable K (mol/kg)	0.39	0.26
Organic C (g/kg)	6.03	1.29
Sand (%)	16.00	14.33
Silt (%)	48.00	19.71
Clay (%)	36.00	14.89

*Adult equivalence scale = people aged 18 years or over assigned a weight of 1; children below 18 years assigned a weight of 0.5.

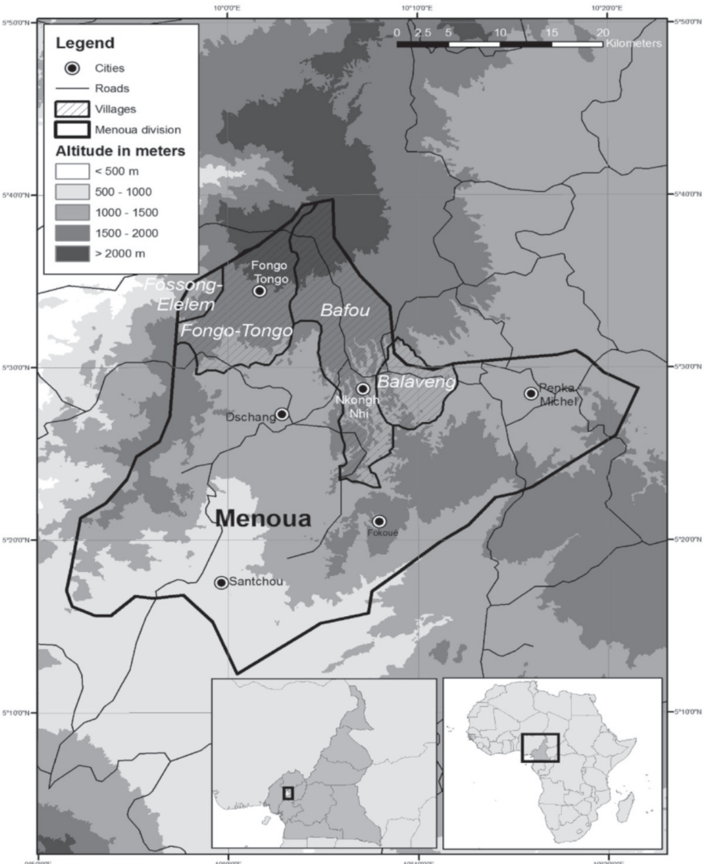

Figure 5.1
Geographical location of research site

5.2.1 Model description

NUTMON-Toolbox is software for monitoring nutrient flows and stock especially in tropical soils (Vlaming *et al.*, 2001). The toolbox enables the assessment of trends based on the local knowledge of soil fertility management and the calculation of nutrient balances. The tool is made up of a structured questionnaire, a database and two models (for calculating nutrient flows and economic parameters). The tool calculates the flows and balances of the macronutrients-N, P and K through an independent assessment of major inputs and outputs using the following equation.

Net soil nutrient balance = Σ (nutrient input) - Σ (nutrient output).

This is based on a set of five inflows (IN 1 to 5 are: mineral fertilizer, organic inputs, atmospheric deposition, biological nitrogen fixation and sedimentation), five outflows (OUT 1 to 5 are: farm products, other organic outputs, leaching, gaseous losses, erosion and human excreta) and six internal flows (consumption of external feeds, household waste, crop residues, grazing, animal manure and home consumption of farm products) as shown in Figure 5.2.

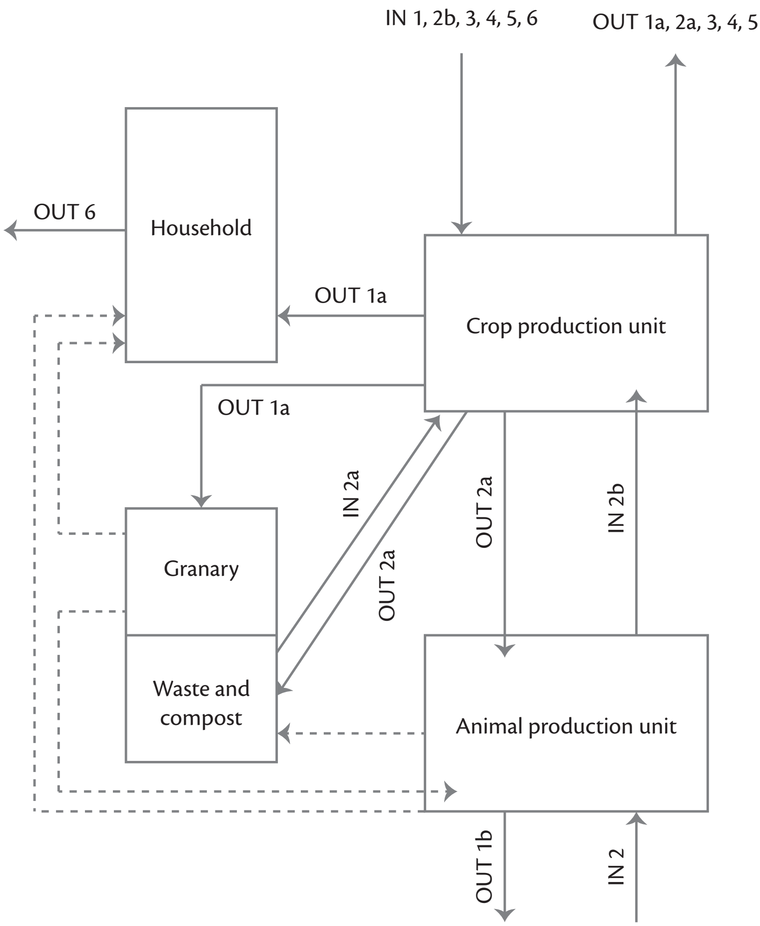

Figure 5.2
Nutrient flow within a farm in the Western Highlands of Cameroon

Farmers' interviews: The semi-structured questionnaire developed by Van den Bosche *et al.* (1998) was adapted to collect data from the heads of households of the selected farm plots. Biophysical, socio-economic and farming system data were collected through household interviews. Farmers gave information on the different production compartments, the different land uses and their major farm products and destinations. Nutrient flows directly related to their way of farming were quantified by questioning the farmers and through direct measurements on the farm or in the household. The inflows investigated by questioning the farmers were: the quantities of mineral fertilizers (IN 1), organic input such as manure (IN 2a) and organic fertilizers (IN 2b), entering the farm annually. The outflows included the quantity of crops (OUT 1a) and animal products (OUT 1b) leaving the farm as gifts or sales. Outflows measured were crop residue (OUT 2a), and animal manure (OUT 2b) leaving the farm. Farmers generally gave quantities in their own units, such as bundles, bags and buckets, which were converted to standard metric amounts. For each farmer, a field survey allowed us to identify the different land uses and the number of plots under each land use. Areas under different land use systems were measured using a hand-held GPS (Global Positioning System). This helped to estimate the different yields.

Use of transfer functions:
In this study the choice of the functions was based on studies conducted by Stoorvogel and Smaling (1990) on nutrient balances for sub-Saharan Africa. Wet atmospheric deposition was calculated from mean annual precipitation as follows:

Input of N (kg/ha/yr) = $0.14\ p^{1/2}$
Input of P (kg/ha/yr) = $0.023\ p^{1/2}$
Input of K (kg/ha/yr) = $0.092p^{1/2}$, where p is the mean annual precipitation.

Biological nitrogen fixation (IN4) in production systems was estimated from the general equation:

IN4 (N) = [(legume field area × IN4a leguminous crop) + (area other crops × IN4b)] $[\text{total land area}]^{-1}$

IN4a is the symbiotically fixed and IN4b the non-symbiotically fixed nitrogen. It was assumed that 60% of the total N demand of leguminous crop (soybeans, groundnut and pulses) is supplied through symbiotic nitrogen fixation (Stoorvogel & Smaling, 1990).

IN4a (N) = [OUT1 (N) + Fl3a (N)] 60% + [(2 + P - 1350) × 0.005]

OUT1 (N) is the N exported in the leguminous crop, and FL3a, the quantity of N accumulated in crop residues.

The non-symbiotic nitrogen fixation was estimated from the function
IN4b (N) = 2 + (p - 1350) × 0.005 (Stoorvogel & Smaling, 1990)

Sedimentation (IN5) takes place in naturally flooded irrigated areas, where salinisation and iodisation naturally occur. No crop was registered on flooded or irrigated areas in the study site. This input was thus considered negligible. Deep capture (IN6) occurs in the presence of trees that exploit the soil layers below the normal root zone of crops. Intensive cultivation has eliminated such components in the system. This input was thus not considered in our study area.

Estimation of nutrient outflows not managed by farmers

Leaching below the root zone (OUT3)
In tropical soils phosphorus is tightly bound to soilparticles, and leaching involves only nitrogen and potassium. The quantity of N and K annually lost (kg ha^{-1} yr-1) was estimated from the transfer functions developed by Smaling *et al*. (1993).

For N leaching the Smaling 1993 model was used:

$OUT3 = (N_s + N_f) \times (0.021 \times p - 3.9)$	c < 35 percent
$OUT3 = (N_s + N_f) \times (0.014 \times p + 0.71)$	35 percent < c < 55 percent
$OUT3 = (N_s + N_f) \times (0.0071 \times p + 5.4)$	c > 55 percent

Where:

N_s = amount of mineralized N in the upper 20 cm of the soil;
The mineralization rate of the site was estimated at 3% (Nye & Greenland, 1960).

N_f = amount of N applied with mineral and organic fertilizers;

p = annual precipitation (mm/year);

c = Clay content of the topsoil (percent).

For K leaching, the Smaling 1993 model was used:

$OUT3 = (K_e + K_f) \times (0.00029 \times p + 0.41)$	c < 35 percent
$OUT3 = (K_e + K_f) \times (0.00029 \times p + 0.26)$	35 percent < c < 55 percent
$OUT3 = (K_e + K_f) \times (0.00029 \times p + 0.11)$	c > 55 percent

Where:

K_e = exchangeable K (cmol/kg);

K_f = amount of K applied with mineral and organic fertilizers;

p= annual precipitation (mm/year);

c= clay content of the topsoil (percent).

OUT4 (gaseous losses) consists of two parts: gaseous N losses from the soil and gaseous N losses related to storage of organic inputs. Gaseous N losses from the soil are calculated as a function of the clay percentage and the precipitation:

$$OUT4 = (N_s + N_f) \times (-9.4 + 0.13 \times c + 0.01 \times p)$$

where:

N_s =	mineralized N in the rootable zone (kg/ha);
N_f =	N applied with mineral and organic fertilizer (kg/ha);
c =	clay content (percent);
P =	mean annual precipitation (mm/year).

Gaseous losses for N were calculated as:

N = Soil N + Fert N * (-9.4*0.13*clay%+0.01p)

where

N = gaseous losses (kg/ha/yr)
Soil N = Mineralizable N in the upper 20 cm of the soil profile
Fert N = Mineral or organic fertilizer
Clay% = the clay content of the upper 20 cm of the soil profile
p = the mean annual precipitation.

Gaseous losses from animal dejections: (OUT 4b).
None of the farmers in the study area depended on animal production. As such animal dejections were not significant in the system. Gaseous losses from animal dejections were therefore assumed to be negligible.

OUT5 (erosion) was calculated using the USLE. A hypothetical soil loss per Farm Section Unit (FSU) was calculated based on slope, slope length, rainfall, soil characteristics and the presence of soil conservation measures. For each Primary Production Unit (PPU) or crop activity, the hypothetical soil loss (in kilograms per hectare per year) was multiplied by a crop cover factor, the nutrient content of the soil and an enrichment factor.

OUT 6 represents human faeces.

Nutrient balance
The NUTMON software quantifies nutrient flows in three ways: through the use of primary data, estimates and assumptions. Nutrient balances were quantified using the in-built transfer functions, equations and assumed values.

To distinguish between primary data and estimates, two different balances were calculated: the partial balance at farm level (IN1 + IN2) - (OUT1 + OUT2) made up solely of primary data and the full balance (ALL IN - ALL OUT) made up of a combination of the partial balance and the immissions (atmospheric deposition and nitrogen fixation) and emissions (leaching, gaseous losses, erosion losses and human excreta) from and to the environment.

The quantified economic flows reveal the profitability of farming activities (Vlaming *et al*., 2001). Economic performance indicators were calculated at both activity level (crop) and farm household levels. The main indicators at activity level were gross margins (gross return minus variable costs) and net cash flows (cash receipts minus cash payments) per unit area. At farm household level, net farm income (total gross margin minus fixed costs) and family earnings (net farm income plus off-farm income) were the important indicators.
Correlation analysis, means, standard deviations and standard errors were calculated using the SPSS version 13.

5.3 Results

5.3.1 Description of the cropping system of sampled farmers based on interviews

The primary production units (PPUs) were sole cropping of vegetable crops practiced on fields generally between one and five kilometers from the homestead with the principal crops being potatoes (*Solanum tuberosum*), cabbages (*Brassica* sp), carrots *Daucus carota*), leeks (*Allium porrum*), onions (*Allium cepa*) and beetroots (*Beta vulgaris*), and intercropping around the homes. Multiple cropping was practiced on farms a few kilometers from the homestead with different combinations of maize (*Zea mays*), beans (*Phaseolus vulgaris*), potatoes (*Solanum tuberosum*), yams (*Dioscorea spp*), aroids (*Xanthosoma* sp and *Colocasia* sp) bananas and plantains (*Musa spp*). The intercropping systems identified from the sample of farmers were:

1. Beans + maize + potato (BMP),
2. Beans + maize (BM),
3. Beans + maize + potato + yam (BMPY) and
4. Maize + potato (MP).

Crop activities are predominant during the rainy season (mid-March to mid-November) and irrigation by gravity is used by some farmers during the off-season (mid-November to mid-March). Livestock or Secondary Production Unit (SPU) activities were uncommon with the farmers included in the nutrient balance study.

The identified nutrient flows into the farms in the research site were mineral fertilizersmostly 20.10.10 and urea (IN 1), off-farm chicken dung (IN 2), atmospheric deposition (IN 3), biological nitrogen fixation (IN 4a) and non-symbiotic nitrogen fixation (IN 4b). The only source of on-farm organic input were crop residue left after harvest which were directly recycled into the farm by incorporation during land preparation. A few farmers made compost around their homes used in home-gardens. In some cases the crop residues were burned and the ash exploited as organic input. Outflows from the farm included, crop uptake (OUT 1), removal in crop residue (OUT 2), gaseous loss (OUT 4), and erosion losses (OUT 5).

5.3.2 Nutrient balance at crop activity (PPU) level

The quantified nutrient balance at crop activity level (PPUs) using NUTMON-Tooolbox are presented in Tables 5.2A, 5.2B and 5.2C for nitrogen, phosphorus and potassium respectively.

Table 5.2
NUTMON-Toolbox generated results.

A Average nutrient balance for Nitrogen for the different PPUs

	Flows (kg)									Partial balance	Full balance
	Inputs				Outputs						
	IN1	IN2	IN3	IN4	OUT1	OUT2	OUT3	OUT4	OUT5	(kg/ha/yr)	(kg/ha/yr)
Nitrogen											
PPU1 Beetroot (.04 ha)	1.25	1.18	0.11	0.05	-1.31	0.00	-0.83	-0.18	-1.24	11.44	-49.96
PPU2 Green pepper (0.29 ha)	51.50	22.44	0.95	0.37	-1.19	0.00	-91.14	-25.36	-19.42	254.49	-216.35
PPU3 Leek (0.21 ha)	11.00	15.11	0.41	0.21	0.00	-3.75	-9.35	-2.32	-1.83	208.11	151.95
PPU4 cabbage (0.09 ha)	13.33	19.50	0.13	0.12	-27.05	0.00	-22.39	-5.70	-3.39	132.29	-118.15
PPU5 carrot (0.08 ha)	10.56	6.01	0.27	0.15	-1.04	0.00	-27.29	-7.80	-6.66	1077.91	552.56
PPU6 Onion (0.01 ha)	20.00	8.73	0.64	0.32	-5.65	0.00	-49.99	-15.85	-9.37	115.25	-183.89
PPU7 Potato (0.19 ha)	27.21	6.31	0.48	0.31	-1.23	-0.03	-43.75	-13.14	-5.59	337.20	-96.25
PPU8 Tomato (0.14 ha)	77.63	4.73	0.09	0.06	-21.74	0.00	-33.35	-9.28	-0.57	939.65	382.54

PPU 9 BMP (0.15 ha)	5.82	3.61	0.64	2.46	-2.51	-1.76	-40.49	-19.46	-94.13	49.44	-697.57
PPU10 BM (0.07 ha)	2.30	1.29	0.19	1.51	-3.50	-0.59	-15.44	-5.48	-11.82	22.58	-572.69
PPU 11 BMPY (0.12 ha)	5.10	3.89	1.12	2.51	-5.04	-1.14	-46.84	-30.60	-65.10	-6.36	-640.19
PPU12 MP (0.04 ha)	5.00	1.01	0.10	0.05	-0.17	-0.01	-14.14	-5.00	-7.39	144.87	-509.78

B Average nutrient balance for Phosphorus for the different PPUs

	Flows (kg)									Partial balance	Full balance
	IN1	IN2	IN3	IN4	OUT1	OUT2	OUT3	OUT4	OUT5	(kg/ha/yr)	(kg/ha/yr)
Phosphorus											
PPU1 Beetroot (.04 ha)	0.28	0.31	0.02	0.00	-0.22	0.00	0.00	0.00	0.00	6.79	7.49
PPU2 Green pepper (0.29 ha)	4.40	5.87	0.16	0.00	-22.50	0.00	0.00	0.00	0.00	-42.77	-42.23
PPU3 Leek (0.21 ha)	1.65	3.95	0.07	0.00	0.00	-2.89	0.00	0.00	0.00	16.02	16.46
PPU4 cabbage (0.09 ha)	2.93	5.10	0.02	0.00	-2.12	0.00	0.00	0.00	0.00	89.88	90.10
PPU5 carrot (0.08 ha)	2.32	1.57	0.04	0.00	-0.43	0.00	0.00	0.00	0.00	256.54	256.87
PPU6 Onion (0.01 ha)	4.40	1.93	0.11	0.00	-1.09	0.00	0.00	0.00	0.00	25.70	26.21
PPU7 Potato (0.19 ha)	5.79	1.66	0.08	0.00	-0.37	0.00	0.00	0.00	0.00	75.18	75.63
PPU8 Tomato (0.14 ha)	16.50	1.24	0.01	0.00	-1.81	0.00	0.00	0.00	0.00	218.98	219.17
PPU 9 BMP (0.15 ha)	1.28	0.65	0.11	0.00	-0.41	-0.17	0.00	0.00	-0.01	12.06	12.63
PPU10 BM (0.07 ha)	0.23	0.21	0.03	0.00	-0.72	-0.09	0.00	0.00	0.00	-0.86	-0.36
PPU 11 BMPY (0.12 ha)	1.66	0.71	0.18	0.00	-1.02	-0.14	0.00	0.00	-0.01	0.78	1.70
PPU12 MP (0.04 ha)	1.10	0.27	0.02	0.00	-0.05	0.00	0.00	0.00	0.00	32.68	33.05

C Average nutrient balance for Potassium for the different PPUs

	Flows (kg)									Partial balance	Full balance
	IN1	IN2	IN3	IN4	OUT1	OUT2	OUT3	OUT4	OUT5	(kg/ha/yr)	(kg/ha/yr)
Potassium											
PPU1 Beet-root (0.04 ha)	0.52	0.29	0.07	0.00	-1.46	0.00	-0.01	0.00	0.00	-41.63	-38.97
PPU2 Green pepper (0.29 ha)	8.99	5.59	0.62	0.00	-30.00	0.00	-0.12	0.00	0.00	-53.93	-52.20
PPU3 Leek (0.29 ha)	3.11	3.78	0.27	0.00	0.00	-0.56	-0.06	0.00	0.00	29.21	30.75
PPU4 cab-bage (0.09 ha)	5.53	4.94	0.09	0.00	-22.85	0.00	-0.07	0.00	0.00	-138.68	-138.68
PPU5 carrot (0.08 ha)	4.38	1.50	0.18	0.00	-3.32	0.00	-0.04	0.00	0.00	292.00	290.61
PPU6 Onion (0.01 ha)	8.30	2.38	0.42	0.00	-7.25	0.00	-0.08	0.00	0.00	16.37	18.04
PPU7 Potato (0.17 ha)	10.92	2.05	0.32	0.00	-2.04	-0.02	-0.10	0.00	0.00	123.43	124.15
PPU8 Toma-to (0.14 ha)	31.12	1.18	0.06	0.00	-14.50	0.00	-0.27	0.00	0.00	334.08	331.30
PPU 9 BMP (0.15 ha)	2.42	1.51	0.42	0.00	-1.23	-1.04	-0.02	0.00	-0.01	17.59	19.79
PPU10 BM (0.07 ha)	0.43	0.64	0.13	0.00	-1.27	-0.19	-0.01	0.00	0.00	6.00	8.02
PPU 11 BMPY (0.12 ha)	2.46	0.92	0.73	0.00	-2.03	-0.62	-0.02	0.00	-0.01	-2.54	1.16
PPU12 MP (0.04 ha)	2.07	0.50	0.06	0.00	-0.23	0.00	-0.02	0.00	0.00	58.18	59.27

The only positive full balances were observed with leek (PPU3), carrot (PPU 5) and tomato (PPU 8) for nitrogen. The highest negative full balance for nitrogen was observed with mixed intercropping of bean, maize and potato (PPU 9). All the intercropping systems showed high negative full balance for nitrogen. For phosphorus, the highest positive full balance was observed with carrot (PPU 5) and the lowest positive was observed with the beetroot (PPU 1). The highest negative full balance for phosphorus was observed with green pepper (PPU 2). For potassium, the highest positive full balance was observed with mixed intercropping of maize and potatoes (PPU 12) and the lowest positive full balance was observed with the intercropping of beans, maize, potato and yams (PPU 11). The highest negative full balance was observed with cabbage (PPU 4). With the partial NPK balances, except for the mixed intercropping system of beans, maize, potato and yams, all the others were positive for nitrogen while the partial balances for phosphorus and potassium followed trends similarto the respective full balances.

5.3.3 Nutrient balance for the research area:

With regard to the average results of the research site, the full balances were positive for potassium and phosphorus, which are less susceptible to loss and negative for nitrogen while the partial balances were positive for all three (Table 5.3).

Table 5.3
NUTMON-Toolbox generated average farm-level nutrient budget (kg/ha/yr) for the study site

Types of flow	N	P	K
Farmer managed			
IN1: Mineral fertilizers	126.25	24.95	47.07
IN2a: Organic fertilizer	57.71	14.82	16.57
IN2b: Grazing	0.00	0.00	0.00
OUT1: Farm products	-28.10	-9.32	-32.92
OUT2a: Farm residues	-4.62	-2.31	-1.34
OUT2b: Grazing	0.00	0.00	0.00
Partial budget 1	151.25	28.14	29.38
Not farmer managed			
IN3: Atmospheric deposition	2.91	0.48	1.91
IN4: Biological N fixation	4.60	0.00	0.00
OUT3: Leaching	210.57	0.00	-0.48
OUT4: Gaseous losses from the soil	-66.07	0.00	0.00
OUT5: Erosion	-65.83	-0.01	-0.01
Partial budget 2	-334.96	0.47	1.42
Total Budget	-183.71	28.61	30.80

Table 5.4 shows the yield and gross margin of the principal vegetable cash crops of the WHC.

Table 5.4
Yield and gross margin of the principal vegetable cash crops

Crop	Yield (kg/ha)	S.E.	Gross margin (US$/ha)[1]	S.E
Beetroot	4269.48	1412.34	42666.67	42666.67
Green pepper	988.91	663.34	-5617.82	6365.82
Leek	8364.75	3588.25	-3631.30	2749.11
Cabbage	7632.37	3016.41	1699.91	2046.87
Carrot	1992.52	584.49	1019.27	562.95
Onion	2274.28	605.24	-2910.39	1713.99
Potato	1319.09	204.64	69140.11	51709.27
Tomato	2619.87	1636.65	269.34	587.63

[1] 1 USD is approximately 500 FCFA

There were great variations in the yield and gross margin data and three of the crops cultivated showed negative gross margin values.

5.3.4 Household economics and farm characteristics

Table 5.5 shows the significant relationships between household economic and farm characteristics.

Table 5.5
Main significant correlations (Pearson) of household economic and farm characteristics

Characteristic	Positive correlation	Negative correlation
Farm N balance (kg/ha/yr)		Farm slope (%) (r = -0.67, r<0.01)
Farm P balance (kg/ha/yr)		Net farm income (US$) (r = -0.25, p<0.05)
Farm K balance (kg/ha/yr)	Total farm area (ha) (r = 0.55, p<0.05)	Farm slope (%) (r = -0.53, p<0.05)

There was a significant relationship between household economic characteristics and soil nutrient balance and also between farm characteristics and soil nutrient balance (Table 5.5).

5.4 Discussions

The nutrient balance results showed that adequate attention was given by the farmers to nutrient management of vegetable cash crops of the area. Similar results for market oriented crops were also noted by Surendran *et al* (2005). However De Jager *et al.* (1998) found a more negative N and K balance for higher market oriented crops in Kenya. Negative full balances for all three nutrients were seen with green beans and the bean+maize+potato+yam (BMPY) mixed intercropping system, implying that the amount of nutrients applied in these systems were sub-optimal. All three nutrients had positive balances with leek, carrot and tomato production. Such a situation needs to be checked because of the risk of environmental pollution, habitat destruction and the risk to human health and welfare (Hode, 1993).

As the yield-determining nutrient in most farming systems, adequate, but not excessive amounts of N are needed to sustain yields and contribute to the maintenance of soil organic matter (Goulding *et al.*, 2008).The net negative nitrogen balance for the research site could be attributed to the high outflow of N through harvested products, crop residues, losses from manure, leaching and gaseous loses as reported by Kroeze *et al.* (2003). Increasing the N fertilizer rates for crops grown, use of slow N release fertilizers or use of urease/nitrification inhibitors to improve Nitrogen Use Efficiency (NUE), growing insitu, incorporation of green manure during the fallow period to contain leaching losses that take place and the incorporation of organic manure to recycle nutrients in order to improve soil fertility, are the possible options to mitigate the negative N balance (Vos *et al.*, 2000). Nitrogen Use Efficiency canbe improved by applying the necessary nutrients in the correct amounts at the correct times (Krupnik *et al.*, 2004). The nitrogen uptake of the bean intercropping systems (BMP, BM and BMPY) was greatly influenced by the atmospheric nitrogen fixation (IN4) of the bean component. Traditionally, legumes have been viewed as excellent sources of N in agriculture (Kinzig & Socolow, 1994).

Nitrogen and potassium balances were found to be negatively influenced by the steepness of the farm slope similar to the findings of Schwab *et al.* (1993). Increasing population has resulted in farming of vulnerable areas like steep slopes. Practices like terraces and contour ploughing can help remedy the situation.

Full and partial balances of P were positive. This positive balance was mainly due to the optimal use of P fertilizers and the absence of pathways of losses of P other than crop uptake (OUT 1) and loss in crop residues (OUT 2). Use of P solubilizing (Phospho-bacteria) and mobilizing (VAM) microorganisms as biofertilizers could improve the utilization of native soil P in such situations of

P fertility buildup in soil (Debnath & Basak, 1986). The popular view that P is strongly held in soils has resulted in the build-up of excessive P levels in some soils, resulting in enhanced leaching (Heckrath *et al.*, 1995). Even where soil Plevels are at or near the optimum, the loss by erosion of small amounts of P adsorbed on sediments or insolution can trigger the eutrophication of freshwaters (Leinweber *et al.* ,2002). In this study, the household net farm income was negatively related to the soil phosphorus balance. This result is different from those of De Jager *et al.* (1998) who found that household net farm income showed no relation with the nutrient balance in three districts in Kenya.

Full and partial balances for K were also positive indicating an absence of deficiency in the study area. Similar results were found in the humid forest of Cameroon by Ehabe *et al.* (2010). Crop uptake of K is usually as much as N uptake and sometimes higher, as in the case of roots and tubers. There appear to be nohealth or environmental problems associated with K leaching and there are no gaseous emissions(Goulding *et al.*, 2008). However, over fertilization with potassium can induce a magnesium deficiency and also cause a loss of soil structure (Goulding & Annis, 1998). While the total farm area cultivated was positively correlated with the K balance in this study, De Jager *et al.* (1998) found in their study that the the cultivated area had a negative correlation with the level of nutrients leaving the farm through agricultural products sold.

The yields of the principal vegetable cash crops of the study area showed very high variations and the negative gross margins of green pepper, leek and onion indicated that either they were not profitable or that the cropping practices were not adequate. The negative gross margin of green pepper could be linked to the fact the cropping practices resulted in negative balances in all the three nutrients studied. Generally one of the causes of the low profit obtained by the farmers is due to widespread problems in the market and improving the relationship between farmers and buyers could contribute to a better economic situation for the farmers (Schipmann & Qaim, 2011).

5.5 Conclusion and recommendations

Resource flows and nutrient balances from this study show that soil nitrogen depletion is a major problem in the study area. Nutrient mining is more intense in the intercropping production system of the smallholder farmers in WHC but the inclusion of legume crops in the intercropping system alleviates the situation. Harvesting of crops for food and for sale and soil erosion are the most important sources of nutrient mining in the crop production systems. Therefore attempts to correct the imbalance need to address these and other socio-economic factors. Given the high costs of fertilizers, the recycling of kitchen residues, animal dejections and/or human faeces, and intensified use of legume as intercrops could significantly modify the nutrient balance and the sustainability of the systems. There exist findings that support the fact that intercropping enhances sustainable plant production (Ledgard, 2001; Aggarwal *et al*., 2002). There is good evidence that adding organic matter and fertilizers together improves NUE, as nutrients are held by the microbial biomass but that the microbial biomass plays animportant role in facilitating nutrient loss from soils insome situations (Turner & Haygarth, 2001). In research reported by Olesen *et al.* (2004), cover crops that reduced fertilizer N requirement by 27 kg/ha K1 and increased NUE from 42 to 52%, found however, that nitrate leaching increased by 14 kg/ha.

The magnitude of nutrient mining as a result of crop harvests in Africa is huge. Net losses of about 700 kg N. 100 kg P and 450 kg K per hectare during the past years have been estimated for 100 million ha of cultivated land which is the fundamental biophysical reason for the declining food production in smallholder farms in Africa (Sanchez *et al*., 1995; Smaling, 1993). Research findings have shown that leguminous trees in alley cropping systems can produce up to 20 t/ha/yr dry matter of prunings, containing as much as 358 kg N, 28 kg P, 232 kg K, 144 kg Ca, and 60 kg Mg (Young, 1989; Szott*et al*., 1991, Bowen, 1984), more than enough to meet most crop requirements. There exist many types indigenous soil enriching species such as *Tephrosia sp* and *Sesbania sp* including some recently introduced species in the WHC such as *Leucaena sp, Calliandra sp* and *Crotalaria sp* which if well managed, can significantly substitute chemical input in the system, prevent leaching, erosion and provide deep capturing of nutrients.

This study is one of the first attempts to create a database on nutrient balance studies in the WHC, providing a useful guide to policy makers, extension specialists and farmers alike in dealing with nutrient management.

Acknowledgements

This study was made possible by funding from Volkswagen foundation. The authors wish to thank Maarten van't Zelfde of the Institute for Environmental Sciences (CML), Leiden, for producing the map of the research site. We are very grateful to the extension workers of the Menoua Division who participated in the data collection and the household members who provided the useful data for the study.

References

Aggarwal, P.K., Garrity, D.P., Liboon, S.P. & Morris, R.A. (2002) Resource use andplant interaction in rice-mungbeanintercrop. *Agron. J.* 84: 71-78.

Baijukya, F.P. & De Steenhuijsen, P.B. (1998) Nutrient balances and theirconsequences in the banana based land use systems of Bukoba district, NorthWest Tanzania. *Agriculture, Ecosystems* & *Environment* 71: 147-158.

Bationo, A., Lompo, F. & Koala, S. (1998) Research on nutrient flows and balances in West Africa: state-of-the-art. *Agricult. Ecosyst. Environ.* 1: 19-35.

Bergeret, P. & Djoukeng, V. (1993) Evaluation économique des systèmes des cultures en pays Bamiléké (Ouest Cameroun). *Cahiers Agricultures* 2: 187-96.

Bowen, G.D. (1984) Tree roots and the use of soil nutrients. In: Bowen, G.D. & Nambiar, E.K.S. (eds) Nutrition of Plantation Forests, pp. 147-179. London, UK: Academic Press.

CGIAR (2002) Combating Soil Degradation in Africa. Consultative Group on International Agriculture Research Annual General meeting held in Washington DC, USA, October 30-31 2002. Document number AGM02/5/ii.

Debnath, N.C. & Basak, R.K. (1986) Effect of rock phosphate and basic slag on available P in acid soils in relation to soil characteristics, seasons and moisture regimes. *J. Ind. Soc. Soil Sci.* 34: 464-470.

De Jager, A., Kariuki, I., Matiri, F.M., Odendo, M. & Wanyama, J.M. (1998) Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Linking farm economic performance and nutrient balances in three districts in Kenya. *Agriculture, Ecosystems and Environment* 71: 81-92.

Delve, R.J. & Jama, B. (2002) Developing organic resource management options with farmers in eastern Uganda. 17th World Congress of Soil Science. Bangkok, Thailand.

Deugd, M., Roling, N. & Smaling, E.M.A. (1998) A new praxeology for integrated nutrient management, facilitating innovation with and by farmers. *Agricult. Ecosyst. Environ.* 71: 269-283.

Ehabe, E.E., Bidzanga, N.L., Mba, C.M., Njukeng, J.N., Inacio de Barros & Enjalric, F. (2010) Nutrient Flows in Perennial Crop-Based FarmingSystems in the Humid Forests of Cameroon. *American Journal of Plant Sciences* 1: 38-46.

Floret, C. (1998) *Raccourcissement du temps de jachère, biodiversité et développement-durable en Afrique Centrale (Cameroun) et en Afrique de l'Ouest (Mali, Sénégal).* Final Report, Comm. des Communautés européennes, Contrat TS3-CT93-0220 (DG 12 HSMU), IRD, Paris, 245 p.

Galloway, J.N. (1998) The global nitrogen cycle: changes and consequences. *Environ. Pollut.* 102: 15-24 Suppl. 1.

Gomez, A.A., Kelly, D.E., Syers, J.K. & Coughlan, K.J. (1996) Measuring Sustainability of Agricultural Systems at the Farm Level. Methods for Assessing Soil Quality. *SSSA Special Publication* 49: 401-409.

Goulding, K.W.T. & Annis, B. (1998) *Lime, liming and themanagement of soil acidity*. In Proc. no. 410, International Fertiliser Society, p. 36. York, UK: International Fertiliser Society.

Goulding, K., Jarvis J. & Whitmore, A. (2008) Optimizing nutrient management for farm systems. *Phil. Trans. R. Soc.* B 363: 667-680.

Hart, T. & Voster, I. (2006) I*ndigenous knowledge on South African Landscape. Potential for African Development*. Cape Town, South Africa: Human Sciences Rsearch Council (HSRC) Press.

Heckrath, G., Brookes, P.C., Poulton, P.R. & Goulding, K.W.T. (1995) Phosphorus leaching from soils containingdifferent phosphorus concentrations in the Broadbalkexperiment. *J. Environ. Qual.* 24: 904-910.

Hodge, I. (1993) *Sustainability: Putting Principles into Practice. An Application to Agricultural Systems.* Paper presented to Rural Economy and Society Study Group, Royal Holloway College, December 1993.

Hoffman, I., Gerling, D., Kyogwom, U.B. & Mane-Bielfeldt (2001) Farmers management strategies to maintain soil fertility in a remote area in northwest Nigeria. *Agriculture, Ecosystems* & *Environment* 86(3): 263-275.

Howlett, D.J.B. (1996) Development of social, economic and biophysical indicators forsustainable land management in the South Pacific. In: Howlett, D. (ed.) *Sustainable Land Management in the South Pacific*. Network Document no. 19. International Board for Soil Research and Management. Bangkok, Thailand: IBSRAM.

Ikerd, J. (1993) Two related but distinctly different concepts: organic farming and sustainable agriculture. *Small Farm Today* 10(1): 30-31.

Juo, A.S.R. & Manu, A. (1996) Chemical dynamics in slash-and-burn agriculture. *Agriculture, Ecosystems* & *Environment* 58: 49-60.

Kinzig, A.P. & Socolow, R.H. (1994) Human impacts on the nitrogen cycle. *Phys. Today* 47(11): 24-31.

Kroeze, C., Aerts, R., Van Breemen, D., Van Dam, K. & Van der Hoek (2003) Uncertainties in the fate of nitrogen I. An overview of sources of uncertainity illustrated with a Dutch case research. *Nutrient Cycling in Agroecosystems* 66: 43-69.

Kotto-Same, J., Woomer, P.L. Moukam, A. & Zapfack, L. (1997). Carbon dynamics inslash-and-burn agriculture, and land-use alternatives of the humid forest zone in Cameroon. *Agriculture, Ecosystems* & *Environment* 65: 245-256.

Krupnik, T.J., Six, J., Ladha, J.K., Paine, M.J. & Van Kessel, C. (2004) An assessment of fertilizer nitrogen recoveryefficiency by grain crops. In: Mosier, A.R., Syers, J.K. & Freney, J.R. (eds) *Agriculture and the nitrogencycle. Assessing the impacts of fertilizer use on food productionand the environment*. SCOPE 65, ch. 14: 193-207. Washington, DC: Island Press.

Ledgard, S.F. (2001) Nitrogen cycling in lowinput legume-based agriculture, with emphasis on Legume/grass pastures. *Plantand Soil* 228: 43-59.

Leinweber, P., Turner, B.L. & Meissner, R. (2002) Phosphorus. In: Haygarth, P.M. & Jarvis, S.C. (eds) *Agriculture, hydrology and water quality*, ch. 2: 29-55. Wallingford, UK: CAB International.

Müller, S. (1996) *How to measure sustainability: an approach for agriculture and natural resources*. Discussion Paper series on sustainable agriculture and natural resources. IICA/BMZ/GTZ.

Müller, S. (1998) *Evaluating the sustainability of agriculture*. Eschborn, Germany: GTZ.

Oenema, O., Kros, H. & De Vries, W. (2003) Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. *Eur. J. Agron.* 20: 3-16.

Olesen, J.E., Sørensen, P., Thomsen, I.K., Eriksen, J., Thomsen, A.G. & Berntsen, J. (2004) Integrated nitrogeninput systems in Denmark. In: Mosier, A.R., Syers, J.K. & Freney, J.R. (eds) *Agriculture and the nitrogencycle. Assessing the impacts of fertilizer use on food productionand the environment*. SCOPE 65, ch. 9: 129-140. Washington, DC: Island Press.

Palm, C.A. & Sanchez, P.A. (1991) Nitrogen release from the leaves of some tropical legumes asaffected by their lignin and polyphenolic contents. *Soil Biology* & *Biochemistry* 23: 83-88.

Rigby, D., Woodhouse, P., Burton, M. & Young, T. (2001) Constructing a Farm-LevelIndicator of Agricultural Sustainability. Sustainability. *Ecological Economics* 39: 463-478.

Salazari, A., Szott, L.T. & Palm, C.A. (1993) Crop-tree interactions in alley cropping systems onalluvial soils of the Upper Amazon Basin. *Agroforestry Systems* 22: 67-82.

Sanchez, P.A. (1976) *Properties and Management of Soils in the Tropics*. New York, NY, USA: John Wiley and Sons.

Sanchez, P.A. (1995) Science in agroforestry. *Agrofor. Syst.* 30: 5-55.

Schipmann, C. & Qaim, M. (2011) Supply chain differentiation, contract agriculture, and farmers marketing preferences: The case of sweet pepper in Thailand. *Food policy* 36(5): 667-677.

Scoones, I. (2001) *Dynamics and diversity: soil fertility and farming livelihoods in Africa: case studies from Ethiopia, Mali, and Zimbambwe*. London: Earthscan Publications Ltd., 244 p.

Scoones, I., Toulmin, C. (1999) *Policies for soil fertility management in Africa*. London: Department of International Development (DFID), 128 pp.

Szott, L.T., Fernandes, E.C.M. & Sanchez, P.A. (1991) Soil-plant interactions in agroforestry systems. *Forest Ecology* & *Management* 45: 127-152

Smaling, E. (1993) *An agro-ecological framework for integrating nutrient management, with special reference to Kenya*. Agricultural University of Wageningen, the Netherlands, 250 p. (Ph.D. Thesis).

Smaling, E.M.A., Fresco L.O. & de Jager, A. (1996) Classifying, monitoring and improving soil nutrient stocks and flows in Africa agriculture. *Ambio* 25(8): 492-496.

Smaling, E.M.A., Stoorvogel, J.J. & Windmeijer, P.N. (1993) Calculating soil nutrient balances in Africa at different scales. II District scale. *Fert. Res.* 35: 237-250.

Smaling, E.M.A., Stoorvogel, J.J. & de Jager, A. (2002) Decision making on integrated nutrient Management through the eyes of the scientist, the land-user and the policy maker. In: Vanlauwe, B., Diels, J., Sanginga, N. & Merckx, R. (eds) *Integrated* *plant nutrient management in sub-Saharan Africa: fromconcept to practice*, pp. 265-284. Wallingford, UK: CAB International.

Smaling, E.M.A., Braun, A.R. (1996) Soil fertility research in sub-Saharan Africa: New dimensions, new challenges. *Commun. Soil Sci. Plant Anal.* 27: 365-386.

Smaling, E.M.A., Nandwa, S.M., Janssen, B.H. (1997) Soil fertility in Africa is at stake. In: Buresh, R.J., Sanchez, P.A. & Calhoun, F. (eds) *Replenishing Soil Fertility in Africa.* Soil Science Society of America Special Publication No. 51. Madison, Wisconsin, USA: Soil Science Society of America, American Society of Agronomy, pp. 47-61.

Smil, V. (2000) Phosphorus in the environment: Natural flows and Human interferences. *Annu. Rev. Energy Environ.* 25: 53-88.

Stoorvogel, J.J. & Smaling E.M.A. (1990) A*ssessment of soil nutrient depletion in sub-Saharan Africa, 1983-2000.* Report 28. Wageningen: The Winand Centre for Integrated Land, Soil and Water Research (SC-DLO).

Surendran, U., Murugappan, V., Bhaskaran, A. & Jagadeeswaran, R. (2005) Nutrient Budgeting Using NUTMON – Toolbox in an Irrigated Farm of Semi Arid Tropical Region in India – A Micro and Meso Level Modeling Study. *World Journal of Agricultural Sciences* 1: 89-97.

Schwab, G.O., Fangmeier, D.D., Elliot, W.J. & Frvert, R.K. (1993) *Soil andwater conservation engineering*, 4th ed. New York, NY: Wiley, pp. 41-42.

Turner, B.L. & Haygarth, P.M. (2001) Phosphorussolubilisation in rewetted soils. *Nature* 411: 258-258.

Van der Pol, F. (1992) *Soil Mining. An Unseen Contributor to Farm Income in Southern Mali*. Bulletin of the Royal Tropical Institute No. 325, KIT Press, 47 p.

Vlaming, J.H., Van den Bosch, M.S., Van Wijk, A., De Jager, A.B. & Van Keulen, H. (2001) *Monitoring nutrient flows and economic performance in tropical forming systems (NUTMON).* Publishers: Alterra, Green World Research and Agricultural Economics Research Institute, LEI, The Netherlands.

Van Reuler, H. & Prins, W.H. (1993) *The role of plant nutrients for sustainable food crop production in Sub-Saharan Africa*. Leidschendam, The Netherlands: Dutch Association of Fertilizer Producers (VKP), AK.

Vos, J. & Van Dder Putten, P.E.L. (2000) Nutrient cycling in a cropping system with potato, spring wheat, sugar beet, oats and nitrogen catch crops. I. Input and off take of nitrogen, phosphorus and potassium Nutrient Cycling. *Agroecosystems* 56: 87-97.

Wortmann, C.S., Fischler, M., Alifugani, F. & Kaizzi, C.K. (1998) *Accomplishments of participatory research for systems improvement in Iganga District, Uganda 1993 to 1997*. OccasionalPublication Series, No. 27. Kampala, Uganda: CIAT, 40 p.

Wortmann, C.S. & Kaizzi, C.K. (1998) Nutrient balances and expected effects of alternativepractices in the farming systems of Uganda. *Agriculture, Ecosystems and Environment* 71: 117-131.

Young, A. (1989) *Agroforestry for Soil Conservation*. Wallingford, UK: International Council for Research and Agroforestry and CAB International.