Nutrient flows in smallholder production systems in the humid forest zone of southern Cameroon

J. Kanmegne[1,*], E.M.A. Smaling[2,3], L. Brussaard[4], A. Gansop-Kouomegne[5] and A. Boukong[5]

[1]*Institute of Agricultural Research for Development, IRAD/ICRAF collaborative agroforestry project, P. O. Box 2067, Messa-Yaounde, Cameroon;* [2]*International Institute for Geo-Information Science and Earth Observation (ITC), P.O. Box 6, 7500 AA Enschede, The Netherlands;* [3]*Plant Production Systems Group, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands;* [4]*Department of Soil Quality, Wageningen University, Dreijenplein 10, 6703 HB Wageningen, The Netherlands;* [5]*Faculty of Agronomy and Agricultural Sciences, University of Dschang, P.O. Box 222, Dschang, Cameroon;* **Author for correspondence (jkanmegne@hotmail.com)*

Abstract

The flows and balances of N, P and K were studied in 20 farms in the Campo Ma'an area in Cameroon between March and August 2002 to assess the nutrient dynamics in smallholder farms. Data were collected through farmer interviews, field measurements and estimates from transfer functions. Nutrient input from mineral (IN1), animal feed (IN2a) and inorganic amendments (IN2b) was absent. Major outputs were through crop (OUT1a) and animal (OUT1b) products sold. Partial budgets for farmer managed flows were negative: -65 kg N, -5.5 kg P and -30.8 kg K ha^{-1} year^{-1}. For inflows not managed by farmers, deep capture (IN6) was the major source: 16.6, 1.4 and 6.6 kg ha^{-1} year^{-1} of N, P and K, respectively. Atmospheric deposition (IN3) was estimated at 4.3 kg N, 1.0 kg P and 3.9 kg K ha^{-1} year^{-1}, and biological nitrogen fixation (IN4) at 6.9 kg N ha^{-1} year^{-1}. Major losses were leaching (OUT 3a): 26.4 kg N, and 0.88 kg K ha^{-1} year^{-1}. Gaseous losses from the soil (OUT 4a) were estimated at 6.34 kg N, and human faeces (OUT 6) were estimated at 4 kg N, 0.64 kg P and 4.8 kg K ha^{-1} year^{-1}. The highest losses were from burning (OUT 4c), i.e. 47.8 kg N, 1.8 kg P and 14.3 kg K ha^{-1} year^{-1}. Partial budgets of environmentally controlled flows were negative only for N -4.8 kg N, $+2.4$ kg P and $+9.6$ kg K ha^{-1} year^{-1}. The overall farm budgets were negative, with annual losses of 69 kg N, 3 kg P and 21 kg K ha^{-1}. Only cocoa had a positive nutrient balance: $+9.3$ kg N, $+1.4$ kg P and $+7.6$ kg K ha^{-1} year^{-1}. Nutrients reaching the household waste (1.9 kg N, 2.8 kg P and 18.8 kg K ha^{-1} year^{-1}), animal manure (4.9 kg N, 0.4 kg P and 1.6 kg K), and human faeces (4 kg N, 0.64 kg P and 4.8 kg K ha^{-1} year^{-1}) were not recycled. Five alternative management scenarios were envisaged to improve the nutrient balances. Recycling animal manure, household waste and human faeces will bring the balance at -62.6 kg N, 0 kg P and $+1$ kg K ha^{-1} year^{-1}. If, additionally, burning could be avoided, positive nutrient balances could be expected.

Introduction

In sub-Saharan Africa, stakeholders and decision makers progressively recognize the depletion of soil nutrients as a major constraint to sustainable agriculture and rural development (Smaling et al. 1993, 1996). Stoorvogel and Smaling (1990) estimated for southern Cameroon for 2000: 21 kg N, 2 kg P and 13 kg K loss per ha and per year. One of the difficulties to reverse the trend is the farmers' limited access to fertilizers and the subsequent vicious circle of soil fertility depletion and poverty (Sanginga et al. 2003).

Soil qualities at farm scale depend on the nutrient management by farmers: the manipulation of nutrient stocks and flows, nutrient inputs in the system through organic and chemical amendments, nutrient export via crop harvest and crop residue removal, and conversions within the production systems (Bationo et al. 1998; Deugd et al. 1998). Smallholders in southern Cameroon recognize spatial soil heterogeneity within farms and adjust land management accordingly (Westphall et al. 1981; Buttner and Hauser 2003).

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 (Oenema et al. 2003). In sub-Saharan Africa, information on the dynamics of total nutrient stocks in the primary forest ecosystem and in subsequent land uses, i.e. budgets and flows between the different production compartments, is scarce (Juo and Manu 1996; Kotto-Same et al. 1997).

Smaling et al. (1996) and Van den Bosch et al. (1998) presented the nutrient-monitoring concept, which considers five units within farms: crop production, animal production, household, stock or family store, and redistribution (Figure 1). They considered six nutrient flows into the farm, i.e., inorganic fertilizers (IN1), organic inputs (IN2), wet and dry deposition (IN3), biological nitrogen fixation (IN4), sedimentation (IN5), and deep capture (IN6), and six outflows, i.e. through harvested crop products (OUT1), crop residues leaving the farm (OUT2), leaching (OUT3), gaseous losses (OUT4), water erosion (OUT5), and human faeces (OUT6). Internal flows refer to the redistribution of crop and animal products, crop residues, animal manure and household waste in the different units of the farm.

The present paper uses this approach to calculate nutrient balances in 20 farms of the Campo Ma'an area, focusing on the farm as a whole, and then on the subsystems within the farm (crop fields and the different land uses, farm animals, and household). Codification of the various nutrient flows investigated in this study are summarized in Table 1. The main objective is to contribute to the understanding of the degree of nutrient depletion and identify major constraints to integrated nutrient management. Alternative management scenarios are also envisaged, to redress the system nutrient balance.

Materials and methods

The study site

The study was conducted in four villages: Asseng, Ma'an-village, Messama III and Mvi'illimengale, located in the Ma'an sub-Division of the agroforestry zone of the Campo Ma'an National Park, southern Cameroon. The site is located between longitude 10°10′–10°70′ East and latitude 2°–3° North, and is characterized by a sub-equatorial climate, with a bimodal rainfall regime. The mean annual temperature is 24°C with a relatively small thermal variation. The mean annual rainfall is 1900 mm. The soils are Oxisols/Ultisols, which make up about 80% of the soils in the humid forest region of Cameroon, with low cation exchange capacity, but excellent physical properties, with 24–34% clay. The general soil properties are summarized in Table 2.

The population density of the site is low, 3.5 inhabitants/km^2, the major ethnic groups are Ntoumou, Mvae and Bulu. Agriculture is the main activity of 84% of the population, while hunting and fishing is practiced by 15%. The household size is 5–7.

Every year, a mature secondary forest or a long fallow plot is slashed and burned, then planted to ngon (Cucumeropsis manii) and plantain (Musa sp.). This land use is called essep. The ngon is harvested within one year. This land use is the major source of household revenue. The plot will then be managed for banana and plantain production, for one to two years. Usually, after
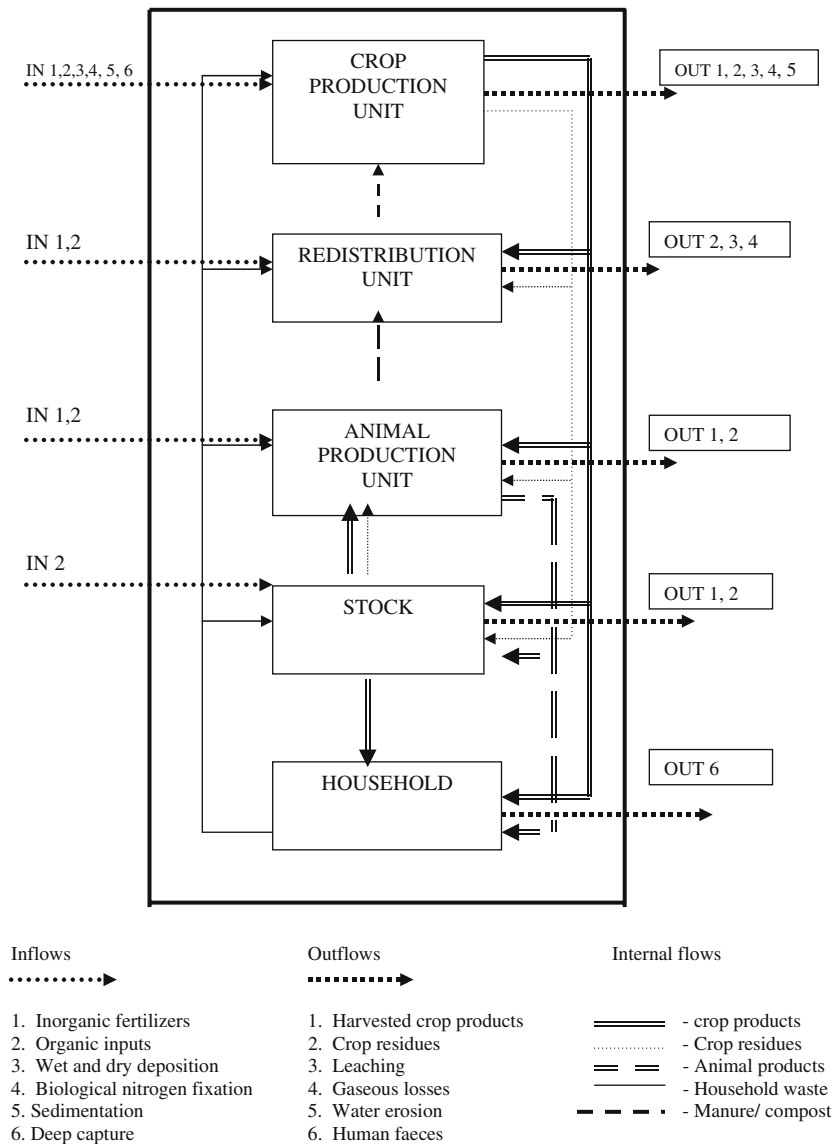
Figure 1. Conceptual framework of nutrient flows and budgets, indicating the major inflows (IN), outflows (OUT) and internal flows (Fl) of nutrients in a farm system.

banana the plot is left for a short fallow of 2–3 years, then slashed and burned and planted to various food crops. The major crops are groundnut (*Arachis hypogeae*) and cassava (*Manihot esculenta*). This land use is called afup owondo, and largely guarantees household food security and, in areas with market access, generates marketable surpluses. Cocoa plantations are a mixture of cocoa, a multitude of trees with food and medicinal values, and timber tree species either

planted by farmers or retained during the initial forest clearing. Cocoa plantations are the predominant productive land use and until the collapse of cocoa prices in the late 80 s, cocoa systems were the main source of household income. Each household on average manages annually 1.16 ha essep, 0.4 ha banana farm, 1.0 ha afup owondo and 3.5 ha cocoa. A total of 120 ha of agricultural land, managed by the 20 selected households, was surveyed in the course of this study.

Table 1. Codification of nutrient flows calculated or estimated in the study.

Code	Flows
Inflows	
IN1:	Inorganic fertilizers
IN2:	Organic inputs
	IN2a: manure, feed, concentrates
	IN2b: organic fertilizers
	IN2c: fuel wood
IN3:	Wet and dry depositions
IN4:	Biological nitrogen fixation
	IN4a: symbiotically fixed nitrogen
	IN4b: non- symbiotically fixed nitrogen
IN5:	Sedimentation
IN6:	Deep capture
Outflows	
OUT1:	Harvested products
	OUT1a: crop products leaving the farm
	OUT1b: animal products leaving the farm
OUT2:	Farm residues
	OUT2a: crop residues leaving the farm
	OUT2b: animal manure leaving the farm
OUT3:	Leaching
	OUT3a: leaching below the root zone
	OUT3b: leaching from the garbage heap
OUT4:	Gaseous losses
	OUT4a: gaseous losses from the soil
	OUT4b: gaseous losses from animal manure
	OUT4c: gaseous losses from
	burning of the natural vegetation
OUT5:	Water erosion
OUT6:	Human faeces
Internal flows	
Fl1:	Animal browsing from crop residues
Fl2:	Household waste
	Fl2a: animal consumption from
	household waste
	Fl2b: decomposition of household waste
Fl3:	Redistribution of crop residues
Fl4:	Animal browsing from external pasture
Fl5:	Redistribution of manure by farm animals
Fl6:	Farm products used by the household
	Fl6a: crop products used for food
	Fl6b: animal products used for food

Table 2. Soil properties of the study site, Ma'an in southern Cameroon (forest soil).

Soil properties	Soil depth (cm)			
	0–5	5–10	10–20	20–50
pH (1:1 soil:water)	3.95	3.98	4.16	4.51
pH (KCl)	3.81	3.91	4.07	4.37
O.M (%)	7.55	5.17	3.55	1.98
C (%)	4.38	3.00	2.06	1.55
Total N (%)	0.215	0.161	0.116	0.067
Ca (cmole kg^{-1})	0.143	0.110	0.074	0.027
Mg (cmole kg^{-1})	0.135	0.095	0.056	0.024
K (cmole kg^{-1})	0.116	0.077	0.056	0.019
Na (cmole kg^{-1})	0.008	0.006	0.025	0.006
Total bases (cmole kg^{-1})	0.402	0.288	0.206	0.075
Extractable P (ppm)	5.96	3.56	1.82	0.29
Sand (%)	66	62	60	54
Clay (%)	24	26	30	34
Silt (%)	10	12	10	12

major farm products and destinations. Nutrient flows were quantified by asking farmers and through direct measurements on the farm or in the household. The inflows investigated by asking farmers were: the quantities of mineral fertilizers (IN1), organic inputs such as manure, feedstuffs, concentrates and outside grazing by farm animals (IN2a) and organic fertilizers (IN2b), and fuel wood (IN2c) entering the farm annually. The outflows included crops (OUT1a) and animal products (OUT1b) leaving the farm as gifts or sales. Outflows measured were crop residues (OUT2a), and animal manure (OUT2b) leaving the farm. Nutrient loss through human faeces (OUT6) was estimated as 80% of nutrients in crop and animal products effectively consumed by the household, assuming that the human body assimilates 20% of the nutrients contained in food. Farmers generally gave quantities in their own units, such as sacks, bags and buckets, which were converted to standard metric amounts. Also all classes of farm animals were counted and weighed. For each farmer, a field survey allowed us to identify the different land uses, the number of plots under each land use, and to estimate the surface area of each plot. This helped to estimate the different yields. The different products were sampled, and analyzed for major nutrients N, P, K, for quantification of the nutrient flows. Nutrient flows presented hereafter refer to a unit farm area.

Quantification of the different nutrient flows

Nutrient flows managed by farmers
The survey was conducted from March to August 2002, in 20 households. 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

Measurement of internal flows. The flows between the different farm compartments were measured and included feed for farm animals (Fl1), household waste (Fl2), its consumption by animals (Fl2a), and the decomposing part (Fl2b), crop residues (Fl3), grazing of vegetation (Fl4), animal manure (Fl5), crop (Fl6a) and animal (Fl6b) products used for food by the household. Data on feed for farm animals (Fl1) was recorded from farmer interviews, and data on household waste (Fl2) determined by weighing daily all the waste from the selected households during the experimental period.

Animal consumption of household waste (Fl2a). Household waste was weighed daily and supplied to farm animals. The residuals not eaten by the animal were weighed in the evening. This operation was conducted during 30 days in the different households, and separately for the different types of waste leaving the kitchen. The consumption factor (Fi) was determined for each type of waste (quantity supplied to the animal over the quantity eaten by the animals). The nutrient flow from the household waste to farm animals was determined for each type of waste i as:

$$Fl2b = (F_i * Q_i * C_i) * (F_s)^{-1}$$

where F is the consumption factor of the waste, Q the quantity of waste deriving from the crop, C the nutrient content of the waste, and F_s the farm size.

Decomposition of household waste (Fl2c). The decomposition of household waste was calculated as the difference between the nutrients in the waste produced by the household (Fl6c), and the quantities of N, P, and K consumed by the farm animals (Fl2b). We assumed that the losses through volatilization and leaching during decomposition were negligible.

Crop residues from farm to household (Fl3): Crop residues were not purposely removed from the farm. All crop residues were mulched on the field.

Animals browsing on external pasture (Fl4). The quantity of fodder eaten by animals from pastures along the road or from the cocoa farm where they freely roam was estimated from the manure

production. We assumed that nutrients in animal manure represent 80% of total consumption of feeds and fodder.

Production of manure by the farm animals (Fl5). The quantity of manure produced by the different animal groups was estimated from the live weight (L_w) of the animal. Small ruminants consume 3.2% of their live weight as feed daily (F_d), and the mean digestibility (D) is 60%. The daily production of manure by pigs was estimated at 0.69% of their live weight, for poultry at 1.68% of their live weight. Daily urine production was estimated at 2–6 litters for pigs, and 0.5–2 litters for sheep and goats (Tchoumboue 1980). It is also considered that 60% of excreted N (Haynes and Williams 1993) and 70–90% of excreted K (Barrow 1987) are through urine. The quantity of a nutrient Y excreted by a small ruminant in manure per unit farm area was estimated through the equation:

$$Fl5(Y) = L_w * F_d * (1 - D) * 365 * Y_m * (F_s)^{-1}$$

where Ym is the Y content in manure. *Farm products used by the household (Fl6)*: The quantity of farm products used by the household was estimated from interviews, and samples of the different products analyzed for nutrient N, P, K.

Estimation of inflows not managed by farmers. Nutrient inflows not managed by farmers were estimated from transfer functions, site climate and soil data. These included atmospheric deposition (IN3) and biological nitrogen fixation (IN4). Atmospheric depositions (IN3) correlate to rainfall (p), and have been estimated from functions developed by Stoorvogel and Smaling (1990).

$$IN3(N) = 0.14 * p^{1/2}$$
$$IN3(P) = 0.023 * p^{1/2}$$
$$IN3(K) = 0.092 * p^{1/2}$$

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

$$IN4 (N) = [(S_{afup} * IN4a) + (F_s * IN4b)] * [F_s]^{-1}$$

where S_{afup} is the groundnut field area or afup, F_s is the farm size, IN4a is the symbiotically fixed

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

$$IN4a = [OUT1(N) + Fl3(N)] * 0.6 + [2 + (p - 1350) * 0.005]$$

where OUT1 (N) is the N exported in groundnuts, and Fl3a, the quantity of N accumulated in crop residues. At the site, groundnut yield (G_y) was 273 kg ha^{-1}, haulm to grain ratio (R) of groundnut was 2.76, and N content was 1.96% in haulms and 3.8 % in grains, therefore:

$$OUT1(N) = 0.038 * G_y$$

and

$$Fl3a(N) = 2.76 * 0.0196 * G_y$$

Non-symbiotic nitrogen fixation was estimated from the function (Smaling et al. 1993)

$$IN4b(N) = 2 + (p - 1350) * 0.005$$

Deep capture (IN6). Litter fall estimation in the different land uses, followed the methodology described by Anderson and Ingram (1993). Litter traps were set in the different land uses, and litter collected over the whole year. The collected material was oven-dried, weighed, sub-sampled and analyzed for N, P, and K. The nutrient input to the system was calculated by multiplying annual litter fall and the nutrient concentration. We assumed that 75% of nutrients in the litter is recycled in the root zone, and that 25% is deep capture from below the root zone, as most trees on acid soils have 70–80% of their roots in the top 50 cm (Szott 1995).

Estimation of nutrient outflows not managed by farmers

Leaching below the root zone (OUT3a). In tropical soils P is tightly bound to soil particles. The quantities of N and K annually lost through leaching (in kg ha^{-1} year^{-1}) were estimated from the transfer functions developed by Smaling (1993):

$$OUT3a (N) = (N_{min} + N_{fert}) * (2.1 * 10^{-2} * p + 3.9)$$
$$OUT3a (K) = (K_{exch} + K_{fert}) * (2.9 * 10^{-4} * p + 0.41)$$

where N_{min} is the quantity of N mineralized in the top 30 cm of the soil, N_{fert} is the fertilizer N, K_{exch} is the exchangeable K and K_{fert} the fertilizer K. N_{min} is determined from soil total N (N_{tot}), the annual relative mineralization rate (M) estimated at 3% (Nye and Greenland 1960), and N_{tot} is 1.1%; then in the top 30 cm soil. We assumed that fertilizer N is brought to the system through litter fall and K through litter fall and ash. Exchangeable K was 48.1 kg ha^{-1} for essep, and 49.4 kg ha^{-1} for afup. Nye and Greenland (1960) estimated K content of ash from forest and short fallow burning to 56.6 and 27 kg ha^{-1}, respectively. In our study we considered 20 ha afup and 23.2 ha essep. Gaseous losses from the soil (OUT4a). The annual loss of N is related to N_{min}, N_{fert} and the percentage of denitrified N (DN).

$$OUT4a (N) = \%DN * (N_{min} + N_{fert})$$

where DN is a function of clay content of the soil, and the annual rainfall (p), through the transfer function (Smaling et al. 1993):

$$DN(\%) = -9.4 + 0.13 * \%clay + 0.01 p$$

Gaseous losses from animal manure (OUT4b). Farmers did not collect animal manure, and we had no hard data to quantify this nutrient loss from the system. Therefore, gaseous losses from animal manure were set to zero although in reality, volatilisation is not negligible especially from urine voided in the field.

Gaseous losses from the burning of the natural vegetation (OUT4c). Losses from burning of the forest vegetation are estimated at 189.6 kg N, 7.4 kg P and 52.2 kg K kg ha^{-1} year^{-1} and for the short fallow at 67.3 kg N, 2.4 kg P and 25 kg K ha^{-1} year^{-1} Nye and Greenland 1960; Hölscher et al. 1997). Losses of nutrient (X) during burning from the forest and short fallow was estimated as:

$$OUT4c (X) = [(S_{afup*}QX_f) + (S_{essep} * QX_F)] * [F]^{-1}$$

where S_{afup} and S_{essep} are the land area under afup owondo and essep, respectively, QX_f the loss from fallow, QX_F the loss from forest.

Losses from erosion (OUT5). Erosion was considered negligible in the humid lowland characterizing the study site.

Nutrient balance

Partial nutrient balances were determined at farm level comprising flows over the farm gate:

$$\text{Partial budget}_1 = (IN1 + IN2a + IN2b + IN2c)$$
$$- (OUT1a + OUT1b + OUT2a$$
$$+ OUT2b + OUT4b + OUT6).$$

Another partial budget was determined with only environmentally controlled flows:

$$\text{Partial budget}_2 = (IN3 + IN4 + IN5 + IN6)$$
$$- (OUT3 + OUT4a + OUT4c$$
$$+ OUT5).$$

The total budget was then determined as partial budget$_1$ + partial budget$_2$. representing nutrient flows entering or leaving the farm. Different management scenarios were then formulated, to identify strategies for system improvement.

Results

The codes used for the different flows in this study are similar to those defined by Smaling et al. (1996) and Van den Bosch et al. (1998).

Nutrients managed by farmers

Inorganic fertilizers (IN1)
No farmer in the study used mineral fertilizers. Farmers depend solely on fallowing and burning of the vegetation to improve the soil fertility, which is the cheapest alternative to mineral fertilizers.

Animal feeds (IN2a)
None of the household surveyed used external feed for farm animals. Pigs, sheep, goats and poultry roam freely with no additional care. They feed on household waste, and/or road side vegetation.

Organic fertilizers (IN2b)
No farmer during the survey reported use of animal manure, compost, kitchen residue or any other organic residue for soil fertility improvement. In the cocoa plantations, farmers rely on soil fertility-indicating/improving tree species and litter fall from shade trees to maintain the soil fertility.

Wood/charcoal from the forest for cooking (IN2c)
Wood/charcoal from the forest for cooking was estimated from the quantity of wood ash produced by the household. An average of 205 kg of wood ash was produced per household, the nutrient equivalent was 1.6 kg P and 15.6 kg K ha^{-1} year^{-1}.

Crop products sold or donated (OUT1a)
Crop species monitored included one from essep (ngon), two from banana farm (plantain and banana), 13 from afup owondo, and 12 from the cocoa plantation. The different crop products leaving the farm as sales and gifts and their nutrient equivalent are presented in Table 3. Crop products sold or donated accounted for export of 9.5 kg N, 2.0 kg P, and 9.8 kg K ha^{-1} year^{-1}.

Animal products sold or donated (OUT1b)
Farm animal groups were pigs, poultry, sheep and goats. The total production of the 20 households, the quantities exported and their nutrient (N, P, K) equivalents are given in Table 4. The nutrient equivalents of animal products leaving the farm were 0.53 kg N, 0.18 kg P, and 0.04 kg K ha^{-1} year^{-1}.

Nutrient loss in human faeces (OUT6)
The total nutrient contents in the food products eaten by the household annually were 6.6 kg N, 2.0 kg P and 9.2 kg K ha^{-1} year^{-1} (Figure 2), out of which 1.9 kg N, 1.2 kg P and 3.2 kg K ha^{-1} year^{-1} were returned in the household waste and added to wood ash (Table 5). Nutrient loss in human faeces was 3.9 kg N, 0.64 kg P and 4.8 kg K ha^{-1} year^{-1}.

The following flows were considered to be zero: Crop residues leaving the farm (OUT2a), animal manure leaving the farm (OUT2b), and gaseous losses from animal manure (OUT4b).

Internal nutrient flows

Feed for farm animals (Fl1)
No farmer reported the use of feed for farm animals.

Table 3. Destination of crop products in a smallholder farming system of the Campo Ma'an area, southern Cameroon (kg household^{-1} year^{-1}).

Farm section	Crop products	Total Products (a + b)	Sales and gifts OUT1a (a)	Household consumption Fl6 (b)	Total household waste F12 (c+d)	Animal feed Fl2a (c)	Decomposed waste Fl2b (d)
Essep (1.16 ha)	*Ngon*	189	154	35.4	0	0	0
Banana farm (0.4 ha)	Banana	525	139	386	222	187	34.5
	Plantain	1918	978	940	459	318	141
Afup owondo 1.0 ha)	Groundnut	276	123	153	43.3	3.0	40.3
	Cassava	6237	2716	3521	886	775.5	111
	Maize	508	123	385	205	54.8	150
	Cocoyam	845	515	330	127	1.9	125
	Sweet potatoes	208	39.9	168	39.6	39.6	0
	Yam	137	25.2	112	15.3	14.3	1.0
	Sugar cane	670	281	388	180	120	60.4
	Pepper	12.7	5.0	7.7	0.60	0	0.6
	Tomatoes	64.7	22.6	42.2	0.10	0	0.1
	Okra	29.6	2.0	27.6	0	0	0
	Beans	3.2	0	3.2	2.2	0.1	2.1
	Djinja	2.1	0	2.1	0	0	0
	Onions	1.7	0	1.7	0	0	0
Cocoa farm (3.5 ha)	Cocoa	593	593	0	0	0	0
	Guava	121	80.2	41.1	0	0	0
	Cola	8.4	5.5	2.9	0	0	0
	Andok	71.1	42.8	28.3	0	0	0
	Citrus	177	102	75.4	52.3	0	52.3
	Safou	176	62.8	112.9	35.6	2.5	33.1
	Papaw	70.7	22.4	48.3	0	0	0
	Pear	1245	534	711	161	1.6	159
	Palm oil	779	421	358	312	60.8	252
	Coco nut	105	67.8	37.7	28.2	0	28.2
	Mangoes	11.2	3	8.3	0	0	0
	Casmango	173	86.4	86.4	0	0	0

Table 4. Animal products and nutrient (N, P, K) equivalents in traditional land uses of Campo Ma'an, southern Cameroon.

Animal groups	Total[a] (kg)	Sales and gifts (OUT1b) (kg year^{-1})				Household consumption (Fl6b) (kg)			
		Products	N	P	K	Products	N	P	K
Pigs	4539	2575	25.7	12.9	2.6	1964	19.6	9.8	2.0
Poultry	895	302	9.1	1.8	0.30	593	17.8	3.6	0.59
Sheeps and goats	1578	1138	28.4	6.8	2.3	440	11.0	2.6	0.88
Mean (kg ha^{-1} year^{-1})			0.53	0.18	0.04		0.40	0.13	0.03

[a]Total of 20 households.

Nutrient transfer from the household to household waste (Fl2)

It was estimated that 1.9 kg N, 1.2 kg P and 3.2 kg K ha^{-1} year^{-1} is transferred from the household to the waste, as food remains that can be consumed by animals. By including nutrient from the wood ash (1.59 kg P and 15.6 kg K ha^{-1} year^{-1}), total nutrients in the kitchen household waste are 1.9 kg N, 2.79 kg P and 18.8 kg K ha^{-1} year^{-1}.

Animal consumption of household waste (Fl2a)

Farm animals annually recycle from the household waste 0.7 kg N, 0.6 kg P and 1.6 kg K per ha of total farm area.

Decomposition of household waste (Fl2b)

The difference between nutrients transferred to household waste, and nutrients recycled by farm animals is 1.1 kg N, 2.2 kg P and 17.2 kg K ha^{-1}
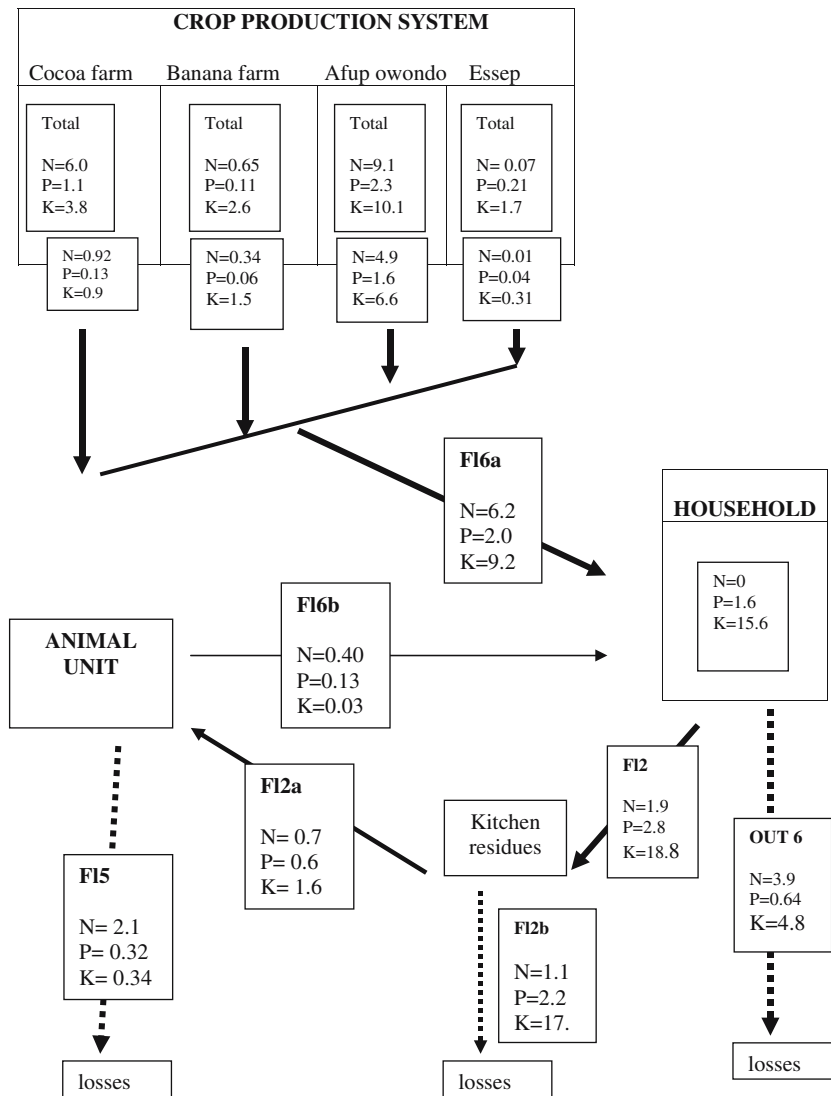
CROP PRODUCTION SYSTEM

Cocoa farm	Banana farm	Afup owondo	Essep
Total N=6.0 P=1.1 K=3.8	Total N=0.65 P=0.11 K=2.6	Total N=9.1 P=2.3 K=10.1	Total N= 0.07 P=0.21 K=1.7
N=0.92 P=0.13 K=0.9	N=0.34 P=0.06 K=1.5	N=4.9 P=1.6 K=6.6	N=0.01 P=0.04 K=0.31

Fl6a
N=6.2
P=2.0
K=9.2

HOUSEHOLD
N=0
P=1.6
K=15.6

ANIMAL UNIT

Fl6b
N=0.40
P=0.13
K=0.03

Fl2
N=1.9
P=2.8
K=18.8

OUT 6
N=3.9
P=0.64
K=4.8

Fl2a
N= 0.7
P= 0.6
K= 1.6

Kitchen residues

Fl5
N= 2.1
P= 0.32
K= 0.34

Fl2b
N=1.1
P=2.2
K=17.

losses

losses

losses

Figure 2. Internal nutrient flows in a traditional farming system of southern Cameroon.

year^{-1}, accumulating in household waste and thus lost from the system.

Nutrient transfer in crop residues within the crop unit (Fl3)
Transfer of crop residues was not recorded in the course of this study.

Browsing animals (Fl4)
Animal browsing from roadside vegetation was estimated as 1.25*Fl5, equivalent to 6.1 kg N, 0.5 kg P and 2 kg K ha^{-1} year^{-1}.

Production of manure by the farm animals (Fl5a)
Farm animals excreted 2.1 kg N, 0.32 kg P and 0.34 kg K ha^{-1} year^{-1} in manure (Table 6).

Crop products eaten by the household (Fl6a)
From the farm products used for family consumption, the estimated quantity of nutrients was 6.2 kg N, 1.9 kg P and 9.2 kg K ha^{-1} year^{-1}. High K value products such as cassava and leafy legumes are the staple food. Products with high N contents such as cocoa and groundnuts are mostly sold.

Table 5. Nutrient export and destination through crop products in the traditional farming systems of the Campo Ma'an area, southern Cameroon.

	Farm sections				
	Essep (1.16 ha)	Banana (0.4 ha)	Afup (1.0 ha)	Cocoa (3.5 ha)	Total (kg ha^{-1})
Total production					
N	0.42	3.99	55.3	36.5	15.8
P	1.3	0.7	14.7	6.8	3.7
K	10.2	15.9	61.3	23.1	18.1
Sales and gifts (OUT1a)					
N	0.34	1.8	25.2	30.8	9.5
P	1.1	0.34	4.7	6.6	2.0
K	8.3	7.0	27.3	17.6	9.8
Household consumption (Fl6b)					
N	0.08	2.1	30.1	5.6	6.2
P	0.25	0.4	9.9	0.8	1.9
K	1.9	8.9	40.0	5.5	9.2
Household waste (Fl2)					
N	0	0.9	8.1	2.3	1.9
P	0	0.2	6.8	0.3	1.2
K	0	5.6	10.7	2.9	3.2
Animal feed from the waste (Fl2a)					
N	0	0.7	3.6	0.2	0.7
P	0	0.2	3.0	0.04	0.6
K	0	4.3	5.3	0.2	1.6
Residues (Fl2b)					
N	0	0.2	4.6	2.1	1.1
P	0	0.05	0.8	0.2	0.8
K	0	1.3	5.5	2.7	1.6

Table 6. Production of manure by farm animals and nutrient (N, P, K) equivalents, in the Campo Ma'an area, southern Cameroon.

Animal groups	Live weight (kg)	Manure produced (kg)	Concentration (g kg^{-1} manure)			Nutrient equivalent in animal manure (kg year^{-1})		
			N	P	K	N	P	K
Pigs	1149	2896	2.5	0.48	0.65	72.4	13.9	18.8
Chicken	210	1286	2.2	0.37	0.20	28.3	4.8	2.6
Ducks	63.3	450	0.95	0.01	0.16	4.3	0.04	0.72
Sheeps	567	2649	3.2	0.32	0.40	84.8	8.5	10.6
Goats	367	1717	3.8	0.67	0.50	65.5	11.5	8.6
Total	2357	8997				255	39	41
Mean (Fl5a) (kg ha^{-1} year^{-1})						2.1	0.32	0.34

Animal products used for food (Fl6b)

From the animal products used for family consumption, the estimated quantity of nutrients was 0.4 kg N, 0.13 kg P and 0.03 kg K ha^{-1} year^{-1}.

Nutrient inputs not controlled by farmers

Atmospheric deposition (IN3)

With annual rainfall of 1900 mm, deposition was estimated at 4.35 kg N, 1 kg P and 3.92 kg K ha^{-1} year^{-1}.

Biological nitrogen fixation (IN4)

$$IN4 \ (N) = [(20 \times 17.84) + (100 \times 4.75)][120]^{-1}$$
$$= \ 6.93 \, \text{kg ha}^{-1} \text{year}^{-1}$$

Deep capture (IN6)

Annual litter fall in the production systems was 5 t/ha, and the equivalent nutrient input is 66.4 kg N, 5.15 kg P and 26.2 kg K ha^{-1} year^{-1}.

We then estimated IN6 as 16.6 kg N, 1.38 kg P, and 6.55 kg K ha^{-1} $year^{-1}$.

Nutrient outputs not controlled by farmers

Nutrient loss through leaching (OUT3)

$$OUT3a(N) = 66 \times (2.1 \times 10^{-2} \times 1900 + 3.9)$$
$$= 26.37 \ kg \ ha^{-1} \ year^{-1}$$

$$K_{fert} = [(27 \times 20) + (56.6 \times 23.2)][20 + 23.2]^{-1}$$
$$= 42.9 \ kg \ ha^{-1} \ year^{-1}$$

$$OUT3a \ (K) = (48.7 + 42.9) \times (2.9 \times 10^{-4} \times 1900$$
$$+ 0.41) \times 0.01 = 0.88 \ kg \ ha^{-1} \ year^{-1}$$

Gaseous losses from the soil (OUT4a)

$$OUT4a \ (N) = (N_{min.} + N_{fert})(-9.4 + 0.13 \times 0.22$$
$$+ 0.01 \times 1900) = 66 \times 0.096$$
$$= 6.34 \ kg \ ha^{-1} \ year^{-1}$$

Gaseous losses through burning of the natural vegetation (OUT4C)

$$OUT4c \ (N) = [(20 \times 67.3) + (23.2 \times 189.6)][120]^{-1} = 47.8$$
$$OUT4c \ (P) = [(20 \times 2.4) + (23.2 \times 7.42)][120]^{-1} = 1.83$$
$$OUT4c \ (K) = [(20 \times 25) + (23.2 \times 52.2)][120]^{-1} = 14.25$$

Therefore, losses through burning of the natural vegetation is estimated at 47.8 kg N, 1.8 kg P and 14.2 kg K ha^{-1} $year^{-1}$.

Partial budget of flows managed by farmers

The balance of nutrients managed by farmers is −65 kg N, −5.5 kg P and −30.8 kg K ha^{-1} $year^{-1}$ (Table 7). Burning during land preparation accounts for 70% of N, 25% of P and 30% of K losses. No input is brought into the farm, except for firewood, and a considerable quantities of nutrients are exported in crop products leaving the farm. There is a high export of K, compared to N and P. Most of the K in sold products comes from the afup owondo, 4.8 kg, 1.36 from essep and 1.15 kg from the banana farm. In terms of crops, each household exports 11.4 kg in cocoa, 8.30 kg

Table 7. Farm-level nutrient budgets in traditional systems of southern Cameroon. (kg ha^{-1} $year^{-1}$)

Type of flows		N	P	K
Farmer managed				
IN1:	Mineral fertilizers	0	0	0
IN2a:	Animal feeds	0	0	0
IN2b:	Organic fertilizers	0	0	0
IN2c:	Fuel wood	0	1.6	15.6
Fl5	Losses from animal manure	2.1	0.32	0.34
Fl2c:	Losses from household waste	1.1	2.2	17.2
OUT1a:	Crop products sold	9.5	2.0	9.8
OUT1b:	Animal products sold	0.53	0.18	0.04
OUT2a:	Export of crop residues	0	0	0
OUT2b:	Animal manure leaving the farm	0	0	0
OUT4c:	Gaseous losses from burning	47.8	1.8	14.3
OUT6:	Human faeces	4.0	0.64	4.8
Partial budget 1		−65	−5.5	−30.8
Not farmer managed				
IN3:	Atmospheric deposition	4.4	1	3.9
IN4:	Biological N fixation	6.9	0	0
IN5:	Sedimentation	0	0	0
IN6:	Deep capture	16.6	1.4	6.6
OUT3a:	Leaching	26.4	0	1.0
OUT4a:	Gaseous losses from the soil	6.3	0	0
OUT5:	Water erosion	0	0	0
Partial budget		−4.8	+2.4	+9.5
Total budget		−69.8	−3.1	−21.3

in ngon, and 8.23 kg in plantain. Most of the nutrients consumed by the household originate from the afup owondo, 4.93 kg N, 1.62 P and 6.56 K (Figure 2).

Partial budget of flows not managed by farmers

Table 7 indicates a balance of -4.8 kg N, $+2.4$ kg P and $+9.6$ kg K ha^{-1} year^{-1}, for nutrient flows not managed by farmers. The major input is through deep capture by trees; farmers maintain many trees especially in cocoa farms as shade trees, which significantly contribute to nutrient recycling in the system. Despite the absence fertilizer input, cocoa fields are sustainable through recycling by the trees and the high litter production. Main losses originate from burning of the vegetation, either directly through volatilisation, or indirectly through leaching.

Total farm nutrient budget and scenario results

Figure 3 summarizes the major nutrient inflows and outflows of the system. The total budgets (Table 7) of the farming system are negative: -69.8 kg N, -3.1 kg P and -21.3 kg K ha^{-1} year^{-1}. The deficit in nitrogen results mostly from volatilisation during burning and that of K from non-recycled household waste and animal manure. Recycling household waste, animal manure and even human faeces could be envisaged as management options to improve the nutrient balance. To explore the options for improvements in the system, six management scenarios have been formulated (Table 8): (S1) the actual management system is maintained, the nutrient (N, P, K) balance (kg ha^{-1} year^{-1}) are (-69.8, -3.1, -21.3); (S2) household waste and animal manure are recycled (balance: -66.6, -0.62, -3.8). If the human faeces are also recycled (S3) the balance will be: -62.6, 0, $+1$. If burning is avoided and the actual management level maintained (S4), the budget will be: $+4.4$, -1.3, -6.1. Two scenarios resulted in completely positive nutrient balances: no burning and recycling of household waste and animal manure (S5), with balances of: $+7.6$, $+1.2$, $+1.5$, and no burning and all residues recycled (S6): $+11.6$, $+1.82$, $+16.2$.

Discussion and conclusions

Farm level results

Previous work on nutrient budgets has targeted densely populated and agriculturally intensive areas, where farmers invest in soil fertility improvement. Organic and chemical amendments, household residues and crop residues are actively recycled and redistributed in the different production compartments (Smaling et al. 1993; Baijukya and De Steenhuijsen Pieters 1998; Hoffmann et al. 2001). The system investigated in this study is structurally different, as burning and fallowing are the sole mechanisms for soil fertility management, resulting in extremely "depletive" cropping system. As there is no addition of nutrients from outside the system, it survives on natural soil fertility. In the forest zone, the animal component is small and poorly documented; farmers do not actively redistribute animal manure in the farm. In northwest Nigeria farmers combine application of organic and mineral fertilizers in an effective way to maintain the fertility of their soils, adding annually 87 kg N, 33 kg P, and 120 kg K ha^{-1} (Hoffmann et al. 2001). In cattle producing areas in North West Tanzania, animal manure redistributes 68 kg N, 15 kg P and 56 kg K ha^{-1} year^{-1} (Baijukya and De Steenhuijsen Pieters 1998). Inputs of 44 kg N, 23 kg P and 11 kg K ha^{-1} year^{-1} as inorganic fertilizers have also been reported in the sub-humid zone of Kenya (Van den Bosch et al. 1998). Many African countries have removed subsidies on fertilizers and they are no longer available or smallholders cannot afford them. Nutrient flows not directly managed by farmers, and estimated from transfer functions are generally site-specific, depending on rainfall and soil texture. Very little information is available for the humid forest zone. However, most of the nutrient flows calculated in this study were similar to those reported for the humid forest of Ivory Coast (Janssen et al. 1990), humid Amazonian forest (Hölscher et al. 1997), and the humid savannas of eastern Africa (Smaling et al. 1993; Van den Bosch et al. 1998).

Animal production is small-scale probably because of limited animal feed (Table 6), resulting in low production of manure compared to the savannah. The only external input into the system by farmers was fuel wood. Substantial losses
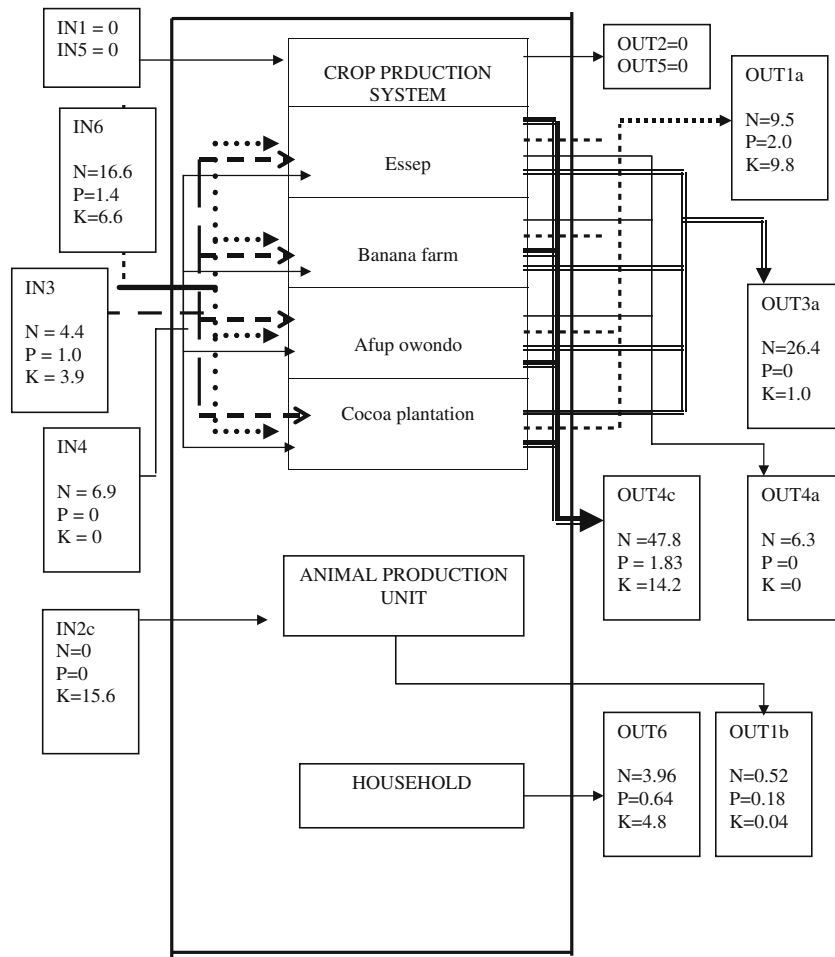
Figure 3. Inflows and outflows of nutrients in a traditional farming system of southern Cameroon.

through burning, leaching, non-recycled household waste and animal manure could not be balanced by nutrient inputs though natural processes. The system thus shows negative nutrient balances: -70 kg N, -3 kg P and -21 kg K ha^{-1} year^{-1}. Main losses occurred from burning and leaching. Nutrient export in crop products represented 14% of N, 45% of P and 25% of K. Main inputs into the cocoa system are through deep capture.

Subsystem level results

Table 9 compares nutrient budgets in the different land uses. We assumed that because of very few trees maintained in essep, banana and afup, deep capture in those farming system components is

negligible. In cocoa, farmers maintained a large number of trees that prevent nutrient leaching, and act as "pumps" for deep capture of nutrients. We also assumed that the presence of these trees in cocoa reduced leaching by 75%. Major inflows into the four sub-systems are atmospheric depositions and biological N fixation. Nutrient balances in essep and afup were negative, with high N and K deficits. Major losses in essep an afup were through burning. In banana however, the P and K balance were positive. Nutrient balances in the cocoa plantation were positive: 9.3 kg N, 1.4 kg P and 7.6 kg K ha^{-1} year^{-1}. Cocoa can therefore be considered as a sustainable system interms of nutrient balances. The nutrient balance in banana is positive for K: $+1.9$ kg ha^{-1} year^{-1}. Table 5 indicates banana production requires 39.8 kg of

Table 8. Total nutrient balance for different management scenarios in the slash and burn agricultural system in southern Cameroon. (kg ha^{-1} year^{-1})

Flows	Management scenario[a]														
	S2			S3			S4			S5			S6		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Inflows															
IN1: Mineral fertilizers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN2a: Animal feeds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN2b: Organic fertilizers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN2c: Fuel wood	0	1.6	15.6	0	1.6	15.6	0	1.6	15.6	0	1.6	15.6	0	1.6	15.6
IN 3: Atmospheric depositions	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9
IN 4: Biological N fixation	6.9	0	0	6.9	0	0	6.9	0	0	6.9	0	0	6.9	0	0
IN 5: Sedimentation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN 6: Deep capture	16.6	1.4	6.6	16.6	1.4	6.6	16.6	1.4	6.6	16.6	1.4	6.6	16.6	1.4	6.6
Total Inflows	27.9	4	26.1	27.9	4	26.1	27.9	4	26.1	27.9	4	26.1	27.9	4	26.1
Outflows															
OUT 1a: Crop products sold	9.5	2	9.8	9.5	2	9.8	9.5	2	9.8	9.5	2	9.8	9.5	2	9.8
OUT 1b: Animal products sold	0.53	0.18	0.04	0.53	0.18	0.04	0.53	0.18	0.04	0.53	0.18	0.04	0.53	0.18	0.04
OUT 2a: Export of crop residues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUT 3a: Leaching	26.4	0	1.0	26.4	0	1.0	0	0	0	0	0	0	0	0	0
OUT 4a: Gaseous losses from soil	6.3	0	0	6.3	0	0	6.3	0	0	6.3	0	0	6.3	0	0
OUT 4c: Gaseous losses from burning	47.8	1.8	14.3	47.8	1.8	14.3	0	0	0	0	0	0	0	0	0
OUT 5: Erosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUT 6: Human faeces	4	0.64	4.8	0	0	0	4	0.64	4.8	4	0.64	4.8	0	0	0
Fl5: Losses from animal manure	0	0	0	0	0	0	2.1	0.32	0.34	0	0	0	0	0	0
Fl2c: Losses from household waste	0	0	0	0	0	0	1.1	2.2	17.2	0	0	0	0	0	0
Total outflows	94.5	4.62	29.9	90.5	4.0	25.1	23.5	5.3	32.1	20.3	2.8	14.6	16.3	2.18	9.8
Balance	−66.6	−0.62	−3.8	−62.6	0	+1	+4.4	−1.3	−6.1	+7.6	+1.2	+1.5	+11.6	+1.82	+16.2

[a] S1: Actual balance, see Table 7.
S2: household waste and animal manure recycled.
S3: S2 plus human faeces recycled.
S4: Actual management, but burning avoided.
S5: No burning + S2.
S6: No burning + S3.

K ha^{-1}, which is less than K requirements of afup (61.3 kg ha^{-1}). Banana is the staple food, and 56% of the crop is used for household consumption. The area under banana represents only 6% of the total farm area. The small production scale and the high internal recycling explain the positive K balance in banana. Market-oriented intensification of banana production would rapidly lead to negative K balance, unless amendments are provided.

In afup and essep 74 and 76 kg N ha^{-1} are lost annually, respectively. Introduction of nitrogen-fixing tree species in essep and afup as planted fallow might be a suitable technological innovation to remedy the N depletion in the system, provided adequate residue management is developed to avoid losses during land preparation. Most of the household nutrients supply is from the essep: 4.9 kg N, 1.6 kg P and 6.6 kg K ha^{-1}year^{-1}. However, from the total nutrients supply to the household, 60% of

Table 9. Nutrient budgets in the different land use system components of the slash and burn chronosequence in southern Cameroon (kg ha^{-1} year^{-1}).

Flows	Land uses											
	Essep			Banana			Afup			Cocoa		
	N	P	K	N	P	K	N	P	K	N	P	K
Inflows												
IN1: Mineral fertilizers	0	0	0	0	0	0	0	0	0	0	0	0
IN2a: Animal feeds	0	0	0	0	0	0	0	0	0	0	0	0
IN2b: Organic fertilizers	0	0	0	0	0	0	0	0	0	0	0	0
IN2c: Fuel wood	0	0	0	0	0	0	0	0	0	0	0	0
IN3: Atmospheric deposition	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9
IN4: Biological N fixation	0	0	0	0	0	0	6.9	0	0	0	0	0
IN5: Sedimentation	0	0	0	0	0	0	0	0	0	0	0	0
IN6: Deep capture	0	0	0	0	0	0	0	0	0	16.6	1.4	6.6
Total Inflows	4.4	1.0	3.9	4.4	1.0	3.9	11.3	1.0	39	21	2.4	10.5
Outflows												
OUT1a: Crop products sold	0.06	0.17	1.39	0.31	0.05	1.1	4.2	0.7	3.5	5.1	0.97	2.9
OUT1b: Animal products sold0	0	0	0	0	0	0	0	0	0	0	0	0
OU 2a: Export of crop residues	0	0	0	0	0	0	0	0	0	0	0	0
OU 3a: Leaching	26.4	0	0.88	26.4	0	0.88	26.4	0	0.88	6.6	0	0.20
OUT4a: Gaseous losses from soil	6.6	0	0	6.6	0	0	6.6	0	0	6.6	0	0
OUT4c: Gaseous losses from burning	47.8	1.8	14.3	0	0	0	47.8	1.8	14.3	0	0	0
OUT6: Human faeces	0	0	0	0	0	0	0	0	0	0	0	0
Total outflows	80.9	1.97	16.6	33.3	0.05	2.0	85.0	2.5	18.6	11.7	0.97	2.9
Balance	−76.5	−0.97	−12.7	−28.9	+0.95	+1.9	−73.7	−1.5	−14.7	+9.3	+1.43	+7.6

N, 32% of P and 52% of K are lost in deep latrines. Large quantities of K enter household waste through wood ash, but are recycled.

Management scenarios

Recycling household waste, animal manure and/or human faeces, and the abolishment of burning could significantly modify the nutrient balances of the system. From the management scenarios proposed (Table 8), scenarios S2 and S3 are feasible, without major difficulties; in densely populated areas of western Cameroon, human faeces are recycled as feeds for pigs, or used as organic manure. The major challenge in the system will be to reduce burning during land preparation, which is necessary to achieve a positive nutrient balance. Farmers cannot avoid burning in essep and afup, and cannot do without afup, since it is the main source of food for the household. Completely avoiding burning is therefore difficult. The trade-off will be to reduce farmer dependence on essep and afup as sources of income, and develop alternative tree-based systems with high income generating potentials. The strategy might involve enriching cocoa plantations with fruit and medic-inal tree species of high commercial value, i.e. reducing essep and afup at household consumption scale, and developing tree-based systems at commercial scale.

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