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Nutrient Balances in Two Agricultural Watersheds in Southern Malawi

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Abstract: Malawi soils are highly depleted resulting in severe food shortages. The study investigates nutrient fluxes into and from small agricultural watersheds in Southern Malawi. Nutrient balances for N, P and K were calculated in two watersheds (Matipa and Kawanula). Data were obtained on the use of mineral fertilizers, animal manure and crop residues using household interviews. Biological N fixation was estimated from measured N uptake, while stream flow losses were calculated from sediment and soluble nutrient concentrations measured in streams. Wet atmospheric deposition and gaseous losses were estimated based on data from the study. Estimated annual nutrient balances were 45 N, 16 P and -1 K kg/ha/year for Matipa and 25 N, 5 P and -5 K kg/ha/year for Kawanula. The positive nutrient balances for N and P were attributed to nutrient importation through mineral fertilizers outstripping nutrient export. The comparatively low N losses through stream flow for Matipa and Kawanula (10-15 kg/ha/year) based on discharge, supported the hypothesis that a significant portion of eroded and leached nutrients are redistributed in lower slopes rather than being entirely exported from the watershed. Using an alternative farm balance approach, erosion estimates of 35 kg N/ha/year for each watershed and leaching losses of 35-42 kg N/ha/year and negative N balances of -32 and -46 kg N/ha/year for Matipa and Kawanula. The watershed approach may provide opportunities for farmers to judiciously manipulate nutrient flows to achieve a positive nutrient balance.

Key words: NUTMON model, nutrient losses, mineral fertilizer, stream flow, agricultural landscape, Malawi

INTRODUCTION

Improving food production and replenishment of soil resources in smallholder farming systems in Southern Africa is an enormous challenge (Akinnifesi *et al*., 2007). The annual net nutrient depletion exceeds 30 kg nitrogen and 20 kg potassium/ha of arable land (Stoorvogel and Smaling, 1990). This results in significant losses in monetary terms. Malawi alone loses between US$350 million worth of nitrogen and phosphorus through erosion each year, which translates to a gross annual loss of income of US$ 6.6-19.0 million (Bojo, 1996). Farmers, researchers and policy makers have increasingly recognized soil nutrient depletion as one of the major constraints to a sustainable agricultural and rural development (Smaling *et al*., 1996). Nutrient depletion occurs when outgoing nutrients exceeds incoming nutrients. Emerging evidence attributes negative nutrient balance to insufficient nutrient inputs relative to exports, primarily through harvested products, leaching, gaseous loses and soil erosion.

Nutrient balance studies can play an important role in providing insight into the nutrient gains and losses, thereby allowing judicious manipulation of the flows to either reduce nutrient losses or increase nutrient gains (De Jager *et al*., 1998). For many cropping systems evaluated in the region, nutrient balances were often negative indicating soil mining (Bationo *et al*., 1998; De Jager *et al*., 1998). Negative nutrient balances between 20-60 N kg ha^{-1} and 5-15 P kg ha^{-1} annually have been estimated for Sub-Saharan African countries including Malawi (Smaling and Fresco, 1993). It is estimated that soils in Malawi lose nutrients at annual rates of not <40 kg N ha^{-1}, 6.6 kg P ha^{-1} and 33.2 kg K ha^{-1}

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(Smaling *et al*., 1997). These rates are higher than average for Sub-Saharan Africa. In contrast, Scoones and Toulmin (1998) contend that the decline of soil fertility has been overstated for subsistence agriculture in the region and that soil fertility is a dynamic concept, where degradation and buildup of soil fertility occur at different scales over space and time. The extent of on-going losses is difficult to quantify, but the existence of widespread N deficiency and severe P and micronutrient deficiency is well documented (Kumwenda *et al*., 1997).

Several studies have been conducted on nutrient balances in Sub-Saharan Africa (Smaling *et al*., 1993; Stoorvogel *et al*., 1993; Brand and Pfund, 1998; De Jager *et al*., 1998; Van den Bosch *et al*., 1998; Nkonya *et al*., 2005). In these studies, the input-output relationships were generally derived from studies conducted at a field or farm scale. Only one of these studies actually assessed the nutrient flows at a watershed scale (Brand and Pfund, 1998). Estimating a nutrient balance at a watershed level may give a more realistic picture of those fluxes that can be scaled up from a representative portion of the landscape. In a watershed, eroded soil that leaves the farm represents an output, but eroded soil that enters the farm from an upper slope becomes an input. This explains why watershed-level nutrient management practices at the upper slopes, middle slopes and bottomlands are often interlinked (De Jager *et al*., 1998) and may influence each other. The present study was designed to understand the nutrient fluxes into and from small agricultural watersheds. The specific objectives were: to compare nutrient inputs with outputs in a small watershed and to identify nutrient fluxes and losses that are important in a typical agricultural landscape in Southern Malawi.

MATERIALS AND METHODS

Study area: The study was conducted in two small agricultural watersheds in Domasi (15°18.5'S, 35°23.5'E) in the Malosa EPA (Extension Planning Area). Malosa EPA is part of the Zomba Rural Development Project (RDP) in the Machinga Agriculture Development Division (ADD), Southern Malawi. The area has a population density of approximately 400 persons km^{-2} and the land holding size is 0.4 ha, which is typical for Southern Malawi (Kanyama-Phiri *et al*., 1994). The average elevation is 853 m above sea level and receives an average annual rainfall of 1139 mm. The rainfall pattern is unimodal and the rains fall between November and April followed by a dry season from May to October. The soils are classified as Alfisols and Ultisols as described by Kanyama-Phiri *et al*. (1994) with sandy loam textures and the vegetation is semi-deciduous woodland called miombo dominated by *Brachystegia* sp. The cropping systems are dominated by maize (*Zea mays* L.), the main staple food crop in Malawi, while major intercrops include pigeon peas (*Cajanus cajan* L. Mill sp.) and cassava (*Manihot esculenta* Crantz).

The two watersheds, Matipa (30 ha) and Kawanula (15 ha) were purposively selected in June of 2002 with special regard to being representative in terms of the presence of distinct landscape positions, agricultural activities, drainage and slope in the region. Each watershed had two landscape positions: upper slopes and lower slopes (valley bottoms locally known as dambo). The different local actors including traditional authority, village headmen and a field assistant, from the Ministry of Agriculture were consulted during the watershed delineation exercise. The targeted farmers were comprised of all farms or homesteads that were inside the delineated watershed. In Kawanula watershed, there were 17 households and in the neighboring Matipa watershed there were 30 households.

Method: Nutrient balances were estimated for the two watersheds by adapting the concepts from the NUTMON (Nutrient Monitoring) model developed by Smaling and Fresco (1993). NUTMON model is an integrated, multidisciplinary methodology, which targets different actors in the process of managing natural resources in general and plant nutrition in particular. The NUTMON concept is based on 5 inputs (mineral fertilizers, manure, atmospheric deposition, biological nitrogen fixation and sedimentation) and 5 outputs (harvested products, crop residues, leaching, gaseous losses and erosion). NUTMON can be applied at the district or farm level. For the present study, it was tailored towards application at a watershed level (Fig. 1) and nutrients of interest were N, P and K. The inputs in this case referred to any nutrient carrier that was imported from outside the watershed and the outputs referred to nutrients that were exported

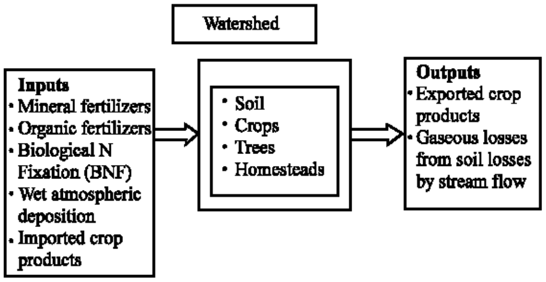

Fig. 1: A conceptual framework of nutrient flows in a watershed (Van den Bosch *et al*., 1998)

leaving the watershed. For instance, crops that were produced and consumed within the watershed were not part of the flow. However, if the crop was sold outside the watershed, this became an output. The calculations were based on a combination of study data and field measurements.

Farmer interviews: The semi-structured questionnaire used by Van den Bosch *et al.* (1998) was adapted to collect and record information during interviews with the individual farmers. The information collected included: demographic structure of the household, quantity and source of fertilizers, manures, crop residues, food/feeds and quantity and destination of harvested products. Farmers were asked to quantify the flows to and from all farm units, all relevant nutrient flows and their sources and destinations. Areas under different land use systems were measured in hectares using a hand-held GPS (Global Positioning System).

Stream flows: To assess nutrient losses by sediment and solution in stream water, a 120° V-notch weir was built with concrete for the ephemeral stream at the outlet of each of the two watersheds. Stream water discharge was monitored in 2003, from January-July during, which streams carried water, by measuring stream gauge height bi-weekly using a known relationship between stream height and discharge (Williams and Melack, 1997). Bi-weekly grab samples were taken during base flow below the weirs. Sediment and soluble nutrient concentrations in the river discharge of the watersheds were determined from the grab samples. Sediment and soluble nutrient concentrations were also measured during two rainfall events (one at the beginning of the rainy season and other in the middle of the rainy season). At each rainfall event, 5 samples were taken (at the beginning of the rain and near the end of the rain and in regular intervals between). Soluble nutrient concentrations were determined from the water samples that were filtered through a Whatman GF/F glass fiber filter paper with a pore size of 0.7 μm. Ammonium and nitrate were analyzed calorimetrically on a Technicon Auto Analyzer. Phosphorus and K were analyzed using Inductively Coupled Plasma (ICP) spectroscopy. To estimate sediment concentration, a known volume of a well-mixed sample was filtered through a pre-weighed Whatman GF/F glass fiber filter paper with a pore size of 0.7 μm. The filter papers were dried at 105°C to a constant weight and their dry weights were recorded. The difference between the two dry weights and the filtered volume were used to estimate the total suspended sediments. Total N was determined by dry combustion after the filters were ground in a ball mill until a very fine powder was obtained. Total P and K in sediments were determined by nitric acid digestion according to Kingston (1994). The extracts were analyzed using Inductively Coupled Plasma (ICP) spectroscopy.

Use of transfer functions: Transfer functions are simple relationships, which are used to calculate difficult to quantify variables as a function of easily measurable parameters such as mean annual precipitation and clay content (Smaling *et al.*, 1993). The functions are derived by curve-fitting using data gathered from the study. In this study, the choice of the functions was based on research by Stoorvogel and Smaling (1990) and Smaling *et al.* (1993) who calculated nutrient balances for Sub-Saharan Africa and the Kisii district in Kenya and modified to adjust for local conditions in the two watersheds. Wet atmospheric deposition was calculated from mean annual precipitation as follows:

$$\text{Input of N (kg/ha/year)} = 0.14\ p^{1/2} \tag{1}$$

$$\text{Input of P (kg/ha/year)} = 0.023\ p^{1/2} \tag{2}$$

$$\text{Input of K (kg/ha/year)} = 0.092\ p^{1/2} \tag{3}$$

where, p is the mean annual precipitation.

Gaseous losses for N were calculated using the Eq. 4:

$$\text{N} = \text{Soil N} + \text{Fert N} \times \left(-9.4 \times 0.13 \times \text{clay\%} + 0.01\text{p}\right) \tag{4}$$

where:

N = The gaseous losses in kg/ha/year
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

The Biological N Fixation (BNF) for leguminous crops such as pigeon peas (*Cajanus cajan*) and groundnuts (*Arachis hypogea*) growing in the watersheds was estimated by the total N uptake in the above ground biomass. The above ground biomass of the legumes was measured from 10×10 m plot when the crops had reached maturation. The above ground biomass (grain plus residues) per unit area multiplied by N content gave N uptake per unit area. The estimate of BNF was 50% of the N uptake. It is assumed that a crop-specific percentage (50-60%) of total N uptake is attributed to symbiotic N fixation (Van den Bosch *et al.*, 1998).

Estimating nutrient contents of crop products and external inputs: Information was obtained on crop products and residues during the interviews and later samples were taken for analysis. The most common external inputs which included fertilizers and food items such as maize rice were sampled at local markets. Samples were analyzed for total N, P and K. Total N was analyzed by dry combustion on 0.5 mg sample as described above. Total P and K in plant tissue were determined by dry ash/acid procedure where, 1 g sample of the ground plant material was placed in a crucible and heated in a muffle furnace at 500°C for 4 h. To extract the ashed material, 10 mL 3 N HCl solution was added and heated on a heating platter. The solution was filtered and analyzed using Inductively Coupled Plasma (ICP) spectroscopy. Absolute amounts of N, P and K in the flow were calculated using the nutrient concentrations of the nutrient carrier.

Data analysis: According to the level of accuracy, the results were classified as primary data and estimates. Primary data were based on field measurements and farmer interviews. These included quantity of mineral fertilizer, crop products and animal manure and stream flow discharges. Estimates were a mixture of field measurements, off-site data and/or transfer functions, which are empirical relations derived on the basis of aggregated knowledge from earlier studies. The estimated data included Biological Nitrogen Fixation (BNF), wet atmospheric deposition and gaseous losses. Coded data from farmer interviews were entered and analyzed using SPSS (version 10.0) to obtain variable frequency and means.

RESULTS AND DISCUSSION

Demographic structure of households: The age distribution of the farmers (household heads) in the study area was skewed towards the older age group (mean = 44.6, median = 46 and mode = 65). The majority of farmers (52% in Matipa and 72% in Kawanula watershed) were over 40 years of age (Table 1). In both watersheds, <50% of the farmers were in the age group of 18-40, which is considered an economic age class in the agricultural sector in Malawi (Kachule, 1994). Over 55% of the farmers were women in both watersheds (69% in Matipa and 56% in Kawanula). The majority of farmers (56-69%) that participated in the two watersheds had at least a primary school education and these farmers are able to read and write. Education facilitates communication between a farmer and extensionist and increases the chances of adopting new technologies, hence leading to a better nutrient balance (Scherr and Hazell, 1994).

Most of the households were male-headed households (86 and 75% for Matipa and Kawanula, respectively). This is contrary to the belief that in a matrilineal society as found in the investigated watersheds, the majority of the households are female-headed households. Gender of household headship and power structure may influence the accessibility to farm resources in Malawi.

Land-use systems: The two watersheds had similar land use systems (Table 2). Most of the land was under cultivation and maize/legume intercropping dominated the system.

However, there were differences with regard to partitioning of the systems. A larger proportion of land (75%) was under maize/legume intercrops in the Kawanula watershed compared to the Matipa watershed (55%). Among the legumes pigeon pea was planted by 96% of the farmers. Groundnut, cowpea and beans were planted

Table 1: Demographic structure of households for two watersheds in Southern Malawi in 2003/04 season (% of the total responses)

Variables	Profile	Matipa (n = 29)	Kawanula (n = 16)
Age	18-40	48	38
	41-60	38	25
	>61	14	47
Gender	Male	31	44
	Female	69	56
Education	No education	21	31
	Primary education	69	56
	Secondary education	10	13
Type of household	Male headed, married	86	75
	Male headed, single	4	0
	Female headed, married	0	0
	Female headed, single	10	25

Table 2: Land-use systems for the two watersheds in Southern Malawi in 2003/04 season

Parameter estimated	Matipa (n = 29)	Kawanula (n = 16)
Contribution of N from mineral fertilizer (%)	50	75
Farmers who owned parcel outside the watershed (%)	63	86
Land put under maize/legume intercrop (%)	75	55
Land under cassava (%)	10	15
Land under rice (%)	1	1
Land under grass fallow (%)	14	29
Farmers owning livestock (%)	50	34

Table 3: Comparisons of nutrient carriers and their respective nutrients for two watersheds in Southern Malawi in 2003/04 season

				Estimated nutrient input/output (g kg^{-1})		
Variables	Profile	Matipa (n = 29) (kg ha^{-1})	Kawanula (n = 16) (kg ha^{-1})	N	P	K
Input	**Mineral fertilizers**					
	Urea	54.5 (0.4)	28.3 (0.6)	460.0	0	0
	CAN	70.0 (0.6)	26.7 (0.6)	260.0	0	0
	23:21:0+4S	71.3 (0.5)	24.0 (0.5)	230.0	210.0	0
	Animal manure					
	Goat	37.5 (0.4)	15.0 (0.5)	14.0	5.0	11.0
	Imported crop products					
	Maize	114.6 (0.7)	117.3 (1.7)	24.0	1.1	20.0
	Rice	183.2 (1.3)	185.3 (4.1)	12.9	1.4	15.0
Output	**Exported crop products**					
	Maize	115.5 (1.2)	16.7 (0.7)	24.0	1.1	20.0
	Rice	70.0 (0.8)	210.0 (7.2)	12.9	1.4	15.0
	Pigeon peas	3.8 (0.6)	0	3.5	1.1	14.0
	Groundnuts	23.8 (0.3)	0	4.0	3.8	26.0
	Cassava	20.0 (0.4)	0	2.5	3.0	17.0

The numbers in parentheses are standerd error

by 84, 52 and 9% of the farmers, respectively. The legumes are important components of the farming system, primarily because they are a valuable source of protein. Farmers in the tropics have long recognized the role of the legume as a soil improver; this role derives mainly from the ability of legumes to fix atmospheric N in symbiosis with rhizobia (Giller, 1990). Symbiotic N fixation is a common source of N for farmers who do not apply inorganic fertilizer. A considerably larger proportion (29%) was under grass fallow in Matipa while, in Kawanula only 14% of the land was under grass fallow. One possible explanation for the differences could be that, in Matipa, 86% of the farmers had some parcel of land outside the watershed compared to only 63% farmers in Kawanula (Table 2).

Nutrient flows: Inorganic fertilizer was one of the most important nutrient inputs into the watershed (Table 3). The majority of the farmers used inorganic fertilizers and this was largely applied to maize, although the amount used by each farmer was variable and depended on price and availability. From informal discussions, it was noted that most of this fertilizer was from a governments initiative called Targeted Input Program (TIP) formerly known as the starter pack, initiated in 1998. The farmers were given 5 kg of fertilizer for basal and 5 kg for top dressing free of charge. This amount of fertilizer is just enough to cover 0.1 ha of land, thereby serving as a short-term safety net measure to fill the food gap (Starter Pack Logistic Unit, 1999).

Use of animal manure is not very common in the study area, as only 34% of the farmers in Matipa 50% in Kawanula owned livestock (Table 2). The common livestock in the area are chicken and guinea fowl, which are raised using free-range management. This means that the manure produced, is recycled within the watershed. None of the farmers owned cattle in either watershed. Participatory resource mapping exercises showed that although majority of farmers in a Southern Malawi watershed were aware of the benefits of applying animal manure to soil, but 85% of the farmers did not have access to significant amounts of manure because of low livestock populations (Kanyama-Phiri and Snapp, 1997).

The most important food fluxes for both watersheds were maize and rice. Maize is usually imported into the watersheds from a neighboring government market (ADMARC) during the months of December through February, when farmers do not have sufficient maize left from their own production. The reverse happens when farmers have harvested their maize during the months of April and May and sell maize to the government market. Rice was imported into the watershed from a nearby rice

Table 4: Nutrient balances (kg/ha/year) for two watersheds in Southern Malawi in 2003/04 season

		Matipa			Kawanula		
Variables	Profile	N	P	K	N	P	K
Inputs	**Mineral fertilizers**						
	Urea	25.1 (0.18)	0	0	13.1 (0.28)	0	0
	CAN	18.2 (0.16)	0	0	6.9 (0.16)	0	0
	23:21:0+4S	16.0 (0.12)	15.0 (0.11)	0	5.5 (0.12)	5.1 (0.11)	0
	Animal manure						
	Goat	0.5 (0.01)	0.2 (0.002)	0.4 (0.00)	0.2 (0.01)	0.1 (0.00)	0.2 (0.01)
	Imported crop products						
	Maize	2.8 (0.02)	0.1 (0.001)	1.3 (0.04)	2.8 (0.04)	0.1 (0.00)	2.4 (0.03)
	Rice	2.4 (0.02)	0.3 (0.002)	2.7 (0.02)	2.4 (0.05)	0.3 (0.01)	2.8 (0.06)
	Wet atmospheric deposition	4.7	0.8	3.1	4.7	0.8	3.1
	Biological nitrogen fixation	10.0	0	0	15.6	0	0
Outputs	**Exported crop products**						
	Maize	2.8 (0.03)	0.1 (0.001)	2.3 (0.02)	0.4 (0.02)	0.0	0.3 (0.01)
	Rice	0.9 (0.01)	0.1 (0.001)	1.1 (0.01)	2.7 (0.09)	0.3 (0.01)	3.2 (0.11)
	Pigeon peas	0.1 (0.02)	0.0 (0.001)	0.1 (0.01)	0	0	0
	Groundnuts	0.9 (0.02)	0.1 (0.001)	0.6 (0.01)	0	0	0
	Cassava	0.5 (0.01)	0.1 (0.001)	0.3 (0.01)	0	0	0
	Gaseous losses	19.5	0	0	8.4	0	0
	Stream flow losses	10.4	0.3	5.2	14.8	0.9	9.6
	Balance	44.7	15.7	-1.1	24.9	5.2	-4.6

The numbers in parentheses are standard errors

scheme. No significant amounts of grain legumes (pigeon peas and groundnuts) were reported to have crossed into either watershed. Grain legumes were grown mainly for home consumption of the seed and sometimes leaves.

Nutrient balance: The nutrient balance for the two watersheds were different with Matipa having a more positive N and P nutrient balance than Kawanula (Table 4). The nutrient balance amounted to 45 kg N/ha/year and 16 kg P/ha/year, whereas in Kawanula the respective figures were 25 kg N/ha/year and 5 kg P/ha/year. However, K had a negative balance of -1 kg K/ha/year and -5 kg K/ha/year for Matipa and Kawanula, respectively. These differences were mostly derived from the differences in nutrient inputs especially in inorganic fertilizer. Nutrient input through inorganic fertilizer was higher in Matipa than Kawanula. The inorganic fertilizers imported had high concentrations of N and thus the more fertilizer was imported, the more N was contributed to the balance. For instance, inorganic fertilizer contributed 75% of the total N inputs in Matipa compared to Kawanula, where only 50% of the N inputs were inorganic fertilizer N (Table 3). This was very striking because the two watersheds were adjacent to each other and their socioeconomic background should be nearly identical. The sources of these fertilizers were mostly through a free input program called the starter pack and therefore, the differences could mean that more farmers in Matipa might have received the fertilizer. The observed differences in the demographic structure (Table 1) could also explain the variability in the nutrient balance. Socio-economic factors such as access to farmland, income level and labor resources may have a direct effect on soil fertility management practices. In turn, the soil fertility management practices have a direct influence on nutrient flows (De Jager *et al*., 1998). For example, fertilizer application adds nutrients to the soil and soil and water conservation using terraces and biological methods (agro-forestry) reduces soil erosion and leaching (Nkonya *et al*., 2005). The wealthier farmers who have access to fertilizer are likely to have a positive soil nutrient balance. Increased family labor is likely to allow households to adopt labor-intensive practices that improve soil fertility such as agroforestry and use of composts or manures.

Overall, the N fertilizer use of these two watersheds, which were 59 kg N ha^{-1} and 25 N kg ha^{-1} for Matipa and Kawanula, were within the range reported for Southern Africa (Sakala *et al*., 2000). However, these fertilizer levels were still below the recently recommended rates of 92 kg N ha^{-1} for the country (Malawi Ministry of Agriculture and Livestock Development, 1995). Biological N fixation was high for Kawanula and became the second most important source of N accounting for 30% of the total N input. The variation in BNF for the two watersheds was a result of the differences in the amount of land cultivated with legumes (Table 2). Wet atmospheric deposition, which the farmer has no control over, contributed an estimated 4.7 kg N/ha/year, 0.8 kg P/ha/year and 3.1 kg K/ha/year to both watersheds. The contribution by wet atmospheric deposition was the same for both watersheds because the watersheds are adjacent to each other and received nearly the same amount of mean precipitation on which the calculations were based. Imported crop products (maize and rice) contributed 10 and 6% of total N inputs for Kawanula and Matipa, respectively. This low level of food imports may be explained by the high fertilizer use, which may result in comparatively high crop harvests within the watersheds. The average maize yields reported by farmers were 1660 and 1730 kg ha^{-1} for Kawanula and Matipa, respectively. These yields were far above the average yields of 750 kg ha^{-1} nation wide (Starter Pack Logistic Unit, 2000). Animal manure was the least important nutrient input into the watersheds, contributing <1% of the total nutrient inputs. This is due to lack of cattle rearing in the watersheds.

Gaseous losses accounted for 56 and 32% of the total N output in Matipa and Kawanula, respectively (Table 4). The higher gaseous losses for Matipa resulted from the calculation with higher amounts of mineral fertilizers that were imported in this watershed (Table 4). The gaseous N losses are based on the assumption that they increase with the amount of chemical fertilizer applied (Van den Bosch *et al*., 1998). In Kawanula, stream losses were the major nutrient output accounting for 56% of the total N and 71% of K outputs (Table 4). In comparison, stream losses accounted for 30% of the total N and 54% of K outputs Matipa. The lower nutrient losses by stream discharge in Matipa than Kawanula was attributed to differences in mineral fertilizer use and intensity of cultivation. More land was under cultivation in Kawanula with only 14% under grass fallow compared to 29% in Matipa (Table 2).

Nutrient discharge from watersheds commonly increases as the percentage of cropland increases (Jordan *et al*., 1986). Potassium losses in stream flow were second to N. Very low amounts of P were found in stream flow in both watersheds. Rai and Sharma (1998) also found lower losses of P in river discharges compared to N and the total P concentrations of sediments were not affected by changes in land use. On average, sediments constituted the highest proportion (74%) of the total P loss compared to 46 and 47% for N and K, respectively. Export of crops outside the watershed only contributed 15% of the N in Matipa and 12% in Kawanula. However, crops were the second most important output channels for K with contributions of 46 and 36% for Matipa and Kawanula, respectively. The greater proportion of K than N exports by crops can be explained by the higher relative K than N contents in the produce that was exported. The crops exported were mostly maize for Matipa and rice for Kawanula. The cereal grains were produced within the watershed to supply household food needs during the year. If production exceeds the family's food needs, the excess may be sold to the market. Insignificant amounts of legumes (pigeon peas and groundnuts) were exported.

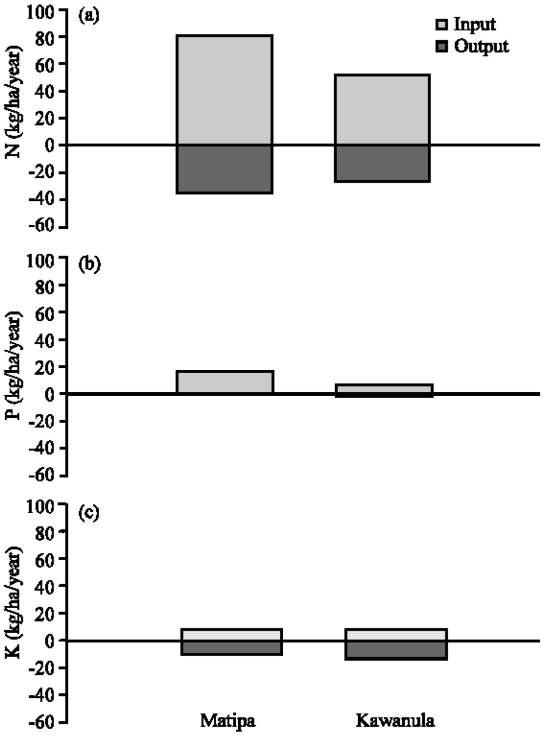

Fig. 2: Annual inputs and outputs of (a) N, (b) P and (c) K (kg ha^{-1}) in two agricultural watersheds in Southern Malawi in 2003/04 season

Nitrogen was by far the most imported nutrient, but at the same had the highest losses compared to P and K (Fig. 2). This trend was the same for both watersheds. The major input channel for P was mineral fertilizer and the positive balance was expected because the losses through leaching were considered to be negligible. In many tropical soils, applied P is susceptible to strong retention by amorphous Fe and Al oxides (Kamprath, 1980) and this P is retained in the root zone. Potassium losses were second to N due to crop exports and stream losses. Its supply was largely through wet atmospheric deposition and by crop products. None of the fertilizer applied contained K, because the fertilizers used in the area are typically targeted towards N amelioration and sometimes P depending on the type of soil. African farmers apply fertilizers containing K sparsely, as the element is in general, less yield limiting than N and P (Stoorvogel *et al*., 1993).

Using the farm approach of Smaling *et al.* (1993), erosion estimates were calculated to 35 kg N/ha/year, 15 kg P/ha/year and 25 kg K/ha/year for each watershed. Using the same farm balance approach leaching estimates of N amounted to 42 and 35 kg N/ha/year for Matipa and Kawanula, respectively. The total nutrient balance then calculated to -32 kg N/ha/year, 1 kg P/ha/year and -23 kg K/ha/year for Matipa and -46 kg N/ha/year, -9 kg P/ha/year and -22 kg K/ha/year for Kawanula. These estimates of total nutrient balances were significantly higher than in the study by Smaling *et al.* (1993), where the nutrient balance of Malawi were estimated at -68 kg N/ha/year, -10 kg P/ha/year and -44 kg K/ha/year. In a study calculating nutrient balances for Africa, Stoorvogel *et al.* (1993) categorized Malawi as one of the countries with high rates of nutrient depletion (N >40 and K >25 kg/ha/year). However, in all these studies, estimates were made at a national level. This observation may indicate the need for obtaining nutrient budgets for different regions within the countries surveyed in order to achieve more accurate estimates that allow better-targeted interventions.

While, the calculated nutrient balances using farm budgets were less negative at our site than in previously published studies on regional budgets cited above, these balances still indicated nutrient depletion in contrast to the positive balances (N and P) obtained from the watershed balance approach. The watershed approach assumes that not all eroded or leached nutrients leave the watershed. Soil erosion, leaching, adsorption and deposition may merely represent a lateral transfer of nutrients between fields, or between farms at different positions in the landscape, or may indeed represent a loss of soil and nutrients to river and lake sediments (Van Noordwijk *et al*., 1997). When nutrients erode from upper slopes, they may merely be redistributed within the landscape and accumulate in the lower slopes and therefore, remain within the watershed. Those nutrients that constitute a net loss for the studied watersheds were captured in stream flow. This concept also holds true for leached nutrients. Nutrients leached from the root zone of crops at upper slopes are either adsorbed in the deep soil or move laterally with groundwater and shallow subsurface flow to lower lying areas and may be adsorbed to soil in valley bottoms such as the dambos in the study. This flow path in part explains the high Ca and Mg levels of dambo soils also found at the study sites (Harawa, 2006). Alternatively, nutrients may flow through groundwater or return flow and surface sheet flow into the stream and become a component of stream export (Elsenbeer, 2001). In rare cases, nutrients may leach into deep aquifers that may be part of a larger catchment system or stored in groundwater systems without immediate connection to surface waters (Molénat *et al*., 2002). At the watersheds, rock underlying relatively shallow soils made it possible to determine both eroded and leached nutrient losses from the watershed by determining nutrients in stream discharge.

The strikingly positive nutrient balances were not only a result of the comparatively low nutrient exports by leaching and erosion using the watershed approach, but also of the fact that most of the external inputs were derived from inorganic fertilizer, which was derived from a free input program that may be curtailed at any time. However, calculations using the average fertilizer use of 18 kg N/ha/year that has been reported for Malawi (Snapp *et al*., 2001) still yield positive balances i.e., 3 kg N/ha/year for Matipa and 17 kg N/ha/year for Kawanula. This is not always the case as shown by the negative balances of -12 kg N/ha/year, -0.2 kg P/ha/year and -5 kg K/ha/year found by Brand and Pfund (1998) using a watershed approach in Madagascar. This negative N balance may be attributed to the higher losses through volatilization since the agricultural fields were under shifting cultivation where frequent phytomass burning occurred. On the other hand, some studies conducted in Africa have also reported positive nutrient balances. In Northern Nigeria, nutrient balances varied from -16-8 kg N ha^{-1} and -4-10 kg P ha^{-1} (Harris, 1998). The differences were attributed to differences in inorganic fertilizer input. The use of nutrient-rich fertilizer tree systems can provide a remedy to negative nutrient balance, especially N (Akinnifesi *et al*., 2008). Abundance of cattle can also improve the nutrient balance of farming systems. For example, in Tanzania, Baijukyam and De Steenhuijsen (1998) found positive nutrient balances for home gardens with cattle and a negative balance for those without cattle.

The positive nutrient balance on a watershed scale does not imply that soils were not degrading or that nutrient mining did not occur on a field or farm scale. Indeed, nutrient levels of N, P and Ca were low in soils of a large portion of agricultural fields in the studied watersheds (Harawa, 2006). However, the watershed perspective to nutrient balances provides opportunities for farmers to judiciously manipulate nutrient channels to maintain a positive balance. This is especially important in Malawi, since, the per capita consumption of inorganic fertilizers is sub-optimal (Carr, 1997), except with fertilizer subsidies. Current economic conditions such as exchange rate devaluation and high inflation are not conducive to high use of external inputs for smallholder farmers (Helsey and Mwangi, 1996). To maintain a positive balance and improve the production potential under these circumstances requires integrated soil fertility management, where all inputs and outputs are harmonized on a watershed scale in a judicious way.

CONCLUSION

Nutrient balances of N and P were positive for both Matipa and Kawanula watersheds. This was mainly a consequence of the low nutrient exports by leaching and erosion compared to other studies, which were a result of the watershed approach to calculating nutrient exports. Another reason for the positive balance was due to the use of chemical fertilizers. Nutrient losses were much higher, when a field or farm approach was adopted compared to a watershed approach the latter leading to positive nutrient budgets. The use of a watershed approach to nutrient budgeting made apparent that redistribution of nutrients in the landscape has to be considered in nutrient management of agricultural landscapes in southern Malawi and probably elsewhere. These findings highlight the need for whole-watershed approaches to nutrient management to minimize nutrient exports and to guide allocation of fields and implementation of policies that affect nutrient management beyond farm boundaries. Future research may address whether nutrient gradients within watersheds are significantly decreasing overall watershed productivity and how nutrients could be effectively retained in areas of the watershed that exhibit nutrient depletion.

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REFERENCES

Akinnifesi, F.K., W. Makumba, G. Sileshi, O.C. Ajayi and D. Mweta, 2007. Synergistic effect of inorganic N and P fertilizers and organic inputs from *Gliricidia sepium* on productivity of intercropped maize in Southern Malawi. Plant Soil, 294: 203-217. DOI: 10.1007/s11104-007-9247-z.

Akinnifesi, F.K., P. Chirwa, O.C. Ajayi, G. Sileshi, P. Matakala, F.R. Kwesiga, R. Harawa and W. Makumba, 2008. Contributions of agroforestry research and development to livelihood of smallholder farmers in Southern Africa: 1. Taking stock of the adaptation, adoption and impact of fertilizer tree options. Agric. J., 3 (1): 58-75. http://www.medwelljournals.com/fulltext/aj/2008/58-75. pdf.

Baijukyam, F.P. and P.B. De Steenhuijsen, 1998. Nutrient balances and their consequences in the banana-based land use systems of Bukoba district, northwest Tanzania. Agric. Ecosyst. Environ., 71: 147-158. DOI: 10.1016/s0167-8809(98)00137-6.

Bationo, A., F. Lompo and S. Koala, 1998. Research on nutrient flows and balances in West Africa: State-of-art. Agric. Ecosyst. Environ., 71: 19-35. DOI: 10.1016/s0167-8809(98)00129-7.

Bojo, J., 1996. The cost of land degradation in sub-Saharan Africa. Ecol. Econ., 16: 161-173. DOI: 10.1016/0921-8009(93)000-9.

Brand, J. and J.L. Pfund, 1998. Site-and watershed-level assessment of nutrient dynamics undershifting cultivation in eastern Madagascar. Agric. Ecosyst. Environ., 71: 169-183. DOI: 10.1016/s0167-8809(98)00139-x.

Carr, S.J., 1997. A green revolution frustrated lessons from Malawi experience. Afr. Crop Sci. J., 5: 93-98.

De Jager, A., S.M. Nandwa and P.F. Okoth, 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) 1. Concepts and methodologies. Agric. Ecosyst. Environ., 71: 63-80. DOI: 10.1016/s0167-8809(98)00130-3.

Elsenbeer, H., 2001. Hydrologic flowpaths in tropical rainforest soilscapes: A review. Hydrol. Proc., 15: 1751-1759. DOI: 10.1002/hyp.237.

Giller, K.E., 1990. Assessment and improvement of nitrogen fixation in tropical *Phaseolus vulgaris* L. Soil Use Manage., 6: 82-84. DOI: 10.1111/j.1475-2743.1990.tb00809.X.

Harawa, R., 2006. Nutrient bakances and fluxes in agricultural watersheds in Southern Malawi. PhD. Thesis. Cornell University, Ithaca, New York, USA.

Harris, F.M.A., 1998. Farm-level assessment of the nutrient balance in northern Nigeria. Agric. Ecosyst. Environ., 71: 201-214. DOI: 10.1016/S0167-8809(98) 00141-8.

Helsey, P.W. and W. Mwangi, 1996. Fertilizer use and maiz production in Sub-Saharan Africa. CIMMYT, Mexico.

Jordan, T.E., D.L. Correll, W.T. Peterjohn and D.E. Weller, 1986. Nutrient flux in landscape: The Rhode river watershed and receiving water. Washington DC, Smithsonian Institution Press.

Kachule, R., 1994. Economic analysis of bean production in Nothern Malawi: Implications for agricultural policy. Msc Thesis. Bunda College of Agricultiral, Lilongwe, Malawi.

Kamprath, E.J., 1980. Soil Acidity in Well-drained Soils in the Tropics as a Constraint for Food Production. In: Priority for Alleviating Soil Related Constraints to Food Production in the Tropics. IRRI, Los Banos, Philippines.

Kumwenda, J.D.T., S. Waddington, S.S. Snapp, R.B. Jones and M.J. Blackie, 1997. Soil Fertility Management in Smallholder Maize-based Cropping Systems of Eastern and Southern Africa. In: Eisher C. (Ed.). The Emerging Maize Revolution. Michigan State University, E lansing, MI, USA, pp: 153-172.

Kanyama-Phiri, G.Y., K. Wellard and J.B. Kamangira, 1994. Preliminary findings on adoption of agroforestry technologies by smallhood farmers in Zomba RDP. A paper presented at the agroforestry Symposium, Bvumbwe Agricultural Research Station. Limbe, Malawai.

Kanyama-Phiri, G.Y. and S.S. Snapp, 1997. Developing improved organic matter technologies in partnership with smallholder farmers in southern Malawi. Afr. Crop Sci. Conf. Proc., 3: 375-884.

Kingston, H.M., 1994. Skip EPA Method 3051: Microwave assisted acid digestion of sediments, sludges, soils and oils. Duquesne University, Pittsburgh, PA. http://www.sampleprep.duq.edu/dir/305/method.html.

Malawi Ministry of Agriculture and Livestock Development, 1995. Guide to Agriculture Production. Malawi Government Press, Lilongwe, Malawi.

Molénat, J., P. Durand, C. Gascuel-Odoux, P. Davy and G. Gruau, 2002. Mechanisms of nitrate transfer from soil to stream in an agricultural watershed of French Britanny. Water, Air Soil Pollut., 133: 161-183. DOI: 10.1023/A:101293626192.

Nkonya, E., C. Kaizzi and J. Pender, 2005. Determinants of nutrient balances in a maize farming system in eastern Uganda. Agric. Syst., 85: 155-182. DOI: 1016/jagsy. 2004.04.004.

Rai, S.C. and E. Sharma, 1998. Comparative assessment of runoff characteristics under different land use patterns within a Himalayan watershed. Hydrol. Process., 12: 2235-2248. DOI: 10.1002/(SICI)1099-1085 (19981030)12:13/14<2235::AID-HYP732>3.0. C0;2-5.

Sakala, W., G. Cadisch and K.E. Giller, 2000. Interactions between residues of maize and pigeon pea and mineral N fertilizers during decomposition and N mineralization. Soil Biol. Biochem., 32: 679-688. DOI: 10.1016/s0038-0717(99)00204-7.

Scherr, S. and P. Hazell, 1994. Sustainable agricultural development stratigies in fragile lands. Environment and production Technology Division Discussion Paper No. 1, International Food Policy Research Institute, Washington, DC.

Scoones, I. and C. Toulmin, 1998. Soil nutrient balances: What use for policy? Agric. Ecosyst. Environ., 71: 255-267. DOI: 10.1016/S0167-8809(98)00145-5.

Smaling, E.M.A., L.O. Fresco and De Jager, 1996. Classifying and monitoring soil nutrient stocks and flows in African agriculture. Ambio, 25: 492-496.

Smaling, E.M.A. and L.O. Fresco, 1993. A decision-support model for monitoring nutrient balances under agricultural land use (NUTMON). Geoderma, 60: 235-256. DOI: 10.1016/S0016-7061(93) 90029-K.

Smaling, E.M.A., J.J. Stoorvogel and P.N. Windmeijer, 1993. Calculating soil nutrient balances in Africa at different scales. II. District scale. Fert. Res., 35: 237-250. DOI: 10.1007/BF00750642.

Smaling, E.M.A., S.M. Nandwa and B.H. Jansen, 1997. Soil Fertility in Africa at Stake. Replenishing soil fertility in Africa. In: Buresh, R.J., P.A. Sanchez and F. Calhoun (Eds.). SSA Special Publication No. 51. Madison, Wisconsin, USA. ISBN: 0-89118-829-0.

Snapp, S.S., H. Borden and D. Rohrbach, 2001. Improving nitrogen efficiency: Lessons from Malawi and Michigan. Sci. World J. Suppl., 2: 42-48. DOI:10.1100/tsw.2001.307.

Starter Pack Logistic Unit, 1999. Starter Pack Logistic Unit Report, Ministry of Agricultural, Lilongwe, Malawi.

Starter Pack Logistic Unit, 2000. Starter Pack Logistic Unit Report, Ministry of Agricultural, Lilongwe, Malawi.

Stoorvogel, J.J. and E.M.A. Smaling, 1990. Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Report 28, DLOWinand Staring Center for Intagrated land, Soil and Water research (SC-DLO), Wageningen, Netherlands.

Stoorvogel, J.J., E.M.A. Smaling and B.H. Janssen, 1993. Calculating soil nutrient balances at different scales. I. Supra-national scale. Fert. Res., 35: 227-235. DOI: 10.1007/bf00750641.

Van den Bosch, H., J.N. Gitari, V.N. Ogaro, S. Maobe and J. Vlaming, 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III. Monitoring nutrient flows and balances in three districts in Kenya. Agric. Ecosyst. Environ., 71: 63-80. DOI: 10.1016/s0167-8809(98) 00132-7.

Van Noordwijk, M., C. Cerri, P.L. Woomer, K. Nugroho and M. Bernoux, 1997. Soil carbon dynamic in humid tropical forest zone. Geoderma, 79: 187-225. DOI: 10.1016/S0016-7061(97) 00042.6.

Williams, M.R. and J.M. Melack, 1997. Solute export from forested and partially deforested catchments in the central Amazon. Biogeochem., 38: 67-102. DOI: 1023/A:1005774431 820.