Water and Nutrient Flows under Different Farming Systems on Sloping Lands in Northern Vietnam

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INTRODUCTION

Vietnam occupies an area of approximately 33 million ha, three-quarters of which is considered hilly and mountainous. Nguyen Tu Siem and Thai Phien, (1999) suggest that 24.9%, 11.8% and 63.3% of the hilly and mountainous area is associated with slopes of <15^o, 15-25^o and >25^o, respectively. The strongly weathered red-yellow soils of the mountainous zones are according to the FAO classification (FAO, 1988) predominately Acrisols. The climate of Vietnam is characterized by humid monsoons, with mean annual rainfall varying from 1,500 to 2,500 mm yr^{-1}, of which 80 percent is concentrated in the rainy season, from May to September. The traditional cultivation on uplands is a monoculture of upland rice, cassava, and corn without chemical fertilizer inputs. This has resulted in soil impoverishment and low nutrient pools.

OBJECTIVES

The main objectives of this study were, for upland the areas studied, to estimate the soil water and nutrient flows, evaluate a range of agroforestry systems and identify appropriate soil improvement technologies for dissemination to farmers.

MATERIAL AND METHODS

Site Description

The study was conducted from 1996-1999 in Rong Can village, Lam Son Commune, Luong Son District, Hoa Binh Province. The terrain is undulating with slopes of 8–25^o. On the experimental plots, the slopes ranged from 18–22^o. Plot size was 22.5m x 5m (112.5m$^{2)}$ For treatments with hedgerows (Table 1) hedge rows were 1.5 m wide with 6m intervals between rows.

Methods

The field experiment was set up in a completely randomized block design as indicated in Table 1. Rainfall was measured directly with rain gauges at the site and runoff and soil loss were collected in the collection tanks below each experimental plot. Soil and plant samples were collected and prepared following the methodological guidelines outlined by the International Bureau for Soil Research and Management (IBSRAM, 1991). Organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment and Higginson (1992) and total Nitrogen (T-N) by Kjeldahl steam distillation. Total soil P and K was digested by mixed concentrated HNO_3 + $HClO_4$. Available P was determined following the Bray II method. Available K was extracted as exchangeable K with

1M NH_4OC, pH 7, and measure by flame photometer. Soil pH was measured in 1M KCl at a soil:solution ratio of 1:5. Exchangeable calcium (Exch-Ca) and magnesium (Exch-Mg) were determined using 1M NH_4OAC buffered at pH 7.0 (Rayment and Higginson, 1992).All samples were analyzed in triplicate and a Standard Reference Material (Soil sample No. 1 supplied by ACIAR Project 9414) incorporated within the analytical batches. Soil texture was determined by pipette method.

Table 1. Experimental treatments.

Treatment	1996	1997	1998	1999
T1	R-M	R-M	R-M	R-M
T2	Fal.	Fal.	R-M	R-M
T3	R-H-Mch	R-H-Mch	R-H-Mch	R-H-Mch
T4	R-Mch	R-Mch	R-Mch	R-Mch
T5	Corn–peanut	Corn–peanut	Corn–peanut	Corn–peanut

R-M: Upland rice monocropping; Fal.: Fallow; R-H-Mch: Upland rice with hedgerow of Tephrosia candida and mulching; R-Mch: Upland rice monocropping and mulching with Tephrosia candida.

RESULTS AND DISCUSSION

Soil Characteristics

The chemical properties are given in Table 2 and show that the soil is inherently acidic and infertile as indicated by the low pH, low Org-C, and low T-N. In addition the soil is extremely low in total and available P and K. The inherently low buffering capacity of the soil is indicated by the low exchangeable Ca^{++}, Mg^{++} values (Table 2).

Table 2. Soil chemical properties (March 1996).

Soil depth (cm)	pH_{KCl} (1: 5)	Total content, (%)				Available forms		Exch. cations, meq $100g^{-1}$	
		Org-C	N	P	K	P (mg kg^{-1})	K (mg kg^{-1})	Ca^{++}	Mg^{++}
0–12	3.5	1.63	0.16	0.08	0.62	5.88	12.0	0.52	0.40
12–29	3.6	1.18	0.13	0.07	0.63	3.00	5.0	0.24	0.16
29–42	3.8	0.69	0.10	0.08	0.62	2.00	4.0	0.64	0.36
42–55	3.8	0.40	0.08	0.07	0.60	1.88	3.0	0.48	0.28

According to the USDA classification (Gee and Bauder, 1986) soil texture in the experimental plots ranged from silty clay loam to silty clay, (Table 3).

Table 3. Soil particle size distribution.

Soil dept (cm)	% dry weight			
	2–0.20 mm	0.20–0.02 mm	0.02–0.002 mm	< 0.002 mm
0–12	7.7	12.3	38.8	41.2
12–29	7.0	14.8	40.5	37.7
29–42	17.5	5.2	29.6	47.7
42–55	19.0	13.4	21.8	45.8

Water Flow and Runoff Budget

Rainfall

At the study site, rainfall is the only water source for cultivation. During the four-year study period, annual precipitation recorded at the study site was 1,664 mm in 1996, 1,441 mm in 1997, 720 mm in 1998, and 836 mm in 1999 (Figure 1).

The rainy season lasts from April to November. The mean cumulative rainfall from June to August was 736 mm, accounting for approximately 63 percent of the mean annual rainfall of 1,165mm. The heavy rainfall associated with June to August generated soil loss and runoff. In contrast, from November to March no rainfall was recorded.

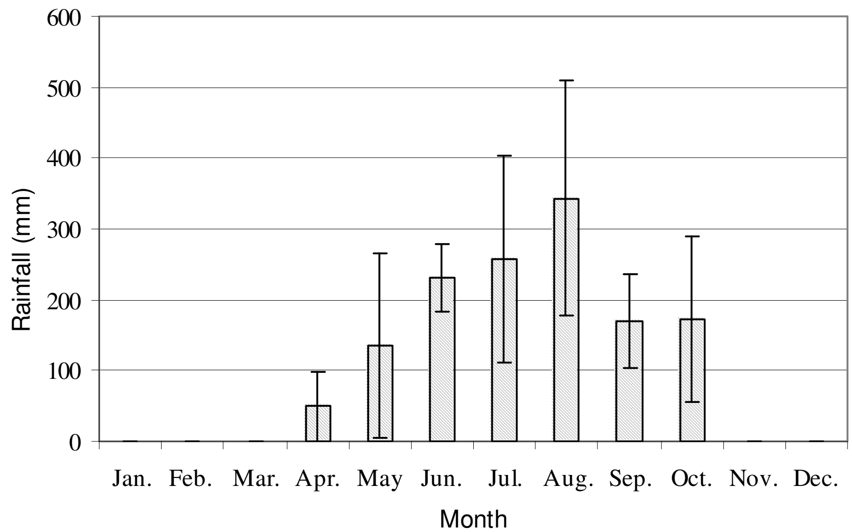

Figure 1. Mean monthly precipitation (mm) at Lam Son-Vinh during the 1996-1999 study period (error bars indicate ±1 STDEV)

Runoff under the treatments evaluated

During the June to August rainy season, rainfall exceeded the soil's water holding and infiltration capacity and runoff was generated. For the treatments evaluated, annual and total runoff is presented in Table 4.

Table 4. Effect of treatment on runoff (m^3 ha^{-1}) during the four year study period.

Treatment	**Year**				**Total**	
	1996	**1997**	**1998**	**1999**	**m^3 ha^{-1}**	**%**
1	1,424	1,941	388	504	4,275	100
2	808	379	89	239	1,515	35
3	1,065	351	60	69	1,545	36
4	1,359	1,240	168	368	3,135	73
5	536	252	67	73	928	22
LSD 0.05	113.2	109.2	27.8	37.4		

Data in Table 4 indicates that the highest rates of runoff occurred in the hill rice monoculture system (T1) and in Years 1 and 2 in the T4 mulching with *Tephrosia candida* treatment. In addition, fallowing (T2) significantly reduced runoff as compare to the control. Hedgerows of *Tephrosia candida* impeded water flow on the soil surface. Following initial establishment during year 1, *Tephrosia candida* hedgerows (T3) reduced runoff. The lowest 4-year runoff occurred in the corn–peanut system (T5). In this system, corn residue and peanut plant mulch covered the soil surface during the rainy season. In general, with improved technologies runoff decreased by 22–73 percent as compared to the control hill rice monoculture system.

Soil Loss under Agroforestry Systems

Soil loss from the treatment plots is presented in Table 5 and showed a similar trend to runoff. Upland rice monoculture had the highest amount of soil loss. The lowest soil loss occurred in the corn–peanut system (T5), which was mulched with crop residues. In addition, mulching with *Tephrosia candida* (T4) for upland rice decreased overland flow resulting in less soil loss than the non-mulched control (T1).

The results indicate that in the first year after clearing, the soil surface was disturbed, and excessive soil loss occurred in all treatments. However there were differences between treatments. The amount of soil loss in treatments T2, T4 and especially T5 was lower than T1 and T4. This was dependent on rainy season soil cover. From the second year (1997) the amount of soil loss decreased significantly in all treatments in comparison with the first year of the experiment (1996). Again, there were major differences between the improved technologies (T2, T3, T4, T5) as compared with the control (T1). Data for the total amount of soil loss in the four-year experiment showed that with improved technologies the amount of soil loss decreased remarkably, being only 19- 44 percent as compared to control (T1).

Table 5. The effect of the treatments evaluated on soil erosion during the four year study period (mt ha^{-1}).

Treatment	**Year**				**Total (1996-99)**	
	1996	**1999**	**1997**	**1998**	**mt ha^{-1}**	**%**
1	55.2	3.7	21.3	5.7	85.9	100
2	22.7	2.8	0	0	25.5	30
3	36.3	0.7	0.7	0	37.7	44
4	57.3	2.5	9.4	1.9	71.1	83
5	15.5	0.4	0	0	15.9	19
LSD 0.05	6.2	0.21	7.4	2.5		

Balance of soil N, P, and K under the Agroforestry Systems evaluated

Nutrient loss from the soil via runoff

The amounts of N, P, and K removed from the soil are presented in Table 6 with the highest losses associated with K followed by N.

Table 6. N, P, and K removed by runoff (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–99		
	N	P	K	N	P	K	N	P	K
1	28.3	2.0	67.3	7.5	0.5	17.8	35.8	2.6	85.1
2	6.6	0.2	35.6	1.8	0.1	9.8	8.5	0.3	45.5
3	11.9	0.6	53.8	1.1	0.1	4.9	13.0	0.6	58.7
4	29.1	1.8	83.2	6.0	0.4	17.2	35.1	2.2	100.3
5	6.6	0.3	25.2	1.2	0.1	4.5	7.8	0.4	29.7
LSD 0.05	4.5	0.5	27.1	0.6	0.1				

It was observed that the lowest amount of nutrient removal occurred in the corn–peanut system (T7), this was followed by upland rice with hedgerows of *Tephrosia candida* (T2). This demonstrated that covering the surface of the soil with biomass prevented nutrient losses via runoff (T2). In T3, *Tephrosia candida* decreased runoff. There was no significant difference between monoculture of upland rice (T1) and monoculture of upland rice with mulching (T4).This may in part have been due to inadequate surface mulching.

Table 7. N, P, K removed through soil loss (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–1999		
	N	P	K	N	P	K	N	P	K
1	82.2	30.6	198.9	10.1	3.8	24.4	184.7	68.7	446.7
2	23.8	9.1	61.3	2.9	1.1	7.6	53.6	20.4	137.7
3	38.9	13.9	120.3	0.7	0.3	2.3	79.2	28.3	245.1
4	68.4	26.7	220.1	4.5	1.8	14.5	145.8	56.9	469.3
5	36.4	11.6	95.3	0.9	0.3	2.5	37.4	11.9	97.8
LSD 0.05	11.5	5.2	57.6	1.2	0.6	4.9			

The amount of N, P, and K removed from the soil surface by soil erosion is reported in Table 7. Nutrient loss via soil erosion was much greater than loss via runoff. Crops absorb nutrients from the soil and accumulate them in tissues. Loss of N, P, and K associated with crop grains is presented in Table 8. Crop grain removed 20–85 kg ha^{-1} of N in the first two years and 31 kg ha^{-1} in the following two years of the four-year rotation. The highest amount of nutrient removal via grain occurred in theT5 (corn–peanut system).

Table 8. N, P, K removed via crop grains (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–99		
	N	P	K	N	P	K	N	P	K
1	22.5	2.7	4.5	19.5	2.7	3.9	42.0	5.7	8.5
2	0	0	0	35.8	4.7	8.4	35.8	4.7	8.4
3	20.4	2.9	4.0	19.1	2.9	3.7	39.5	6.1	7.7
4	31.2	4.7	4.8	32.1	4.7	4.9	63.3	9.4	9.6
5	85	3.9	6.5	30.7	3.9	2.3	115.7	14.8	8.8

Returning N, P, and K to the Soil

For the treatements evaluated, the return of N, P, and K to the soil via crop residues is detailed in Table 9. In treatments with fallow in the first two years (1996-97), where grasses were not cut, no plant residues were returned to the soil. In the second period of the study (1998-1999) in the fallow–upland rice cycle, N, P, and K were returned to the soil via crop residues. The highest amount of N, P, and K was returned into the soil under upland rice with *Tephrosia candida* hedgerows (T3). N, P, and K returned to the soil under the monoculture upland rice system with mulching (T4) was twice that associated with the monoculture upland rice system without mulching (T1).

Table 9. Return of N, P, and K to the soil from crop residues (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–99			
	N	P	K	N	P	K	N	P	K	NPK
T1	17.4	2.1	87.8	16.6	2.0	83.7	34.0	4.1	171.5	209.6
T2	0	0	0	24.0	3.0	133.0	24.0	3.0	133.0	159.6
T3	82.0	6.0	135.0	67.0	6.0	148.0	149.0	12.0	283.0	444.0
T4	80.0	6.0	135.0	61.0	5.0	130.0	141.0	11.0	266.0	417.6
T5	91.0	12.0	30.0	88.0	11.0	29.0	179.0	23.0	59.0	260.5

Soil nutrient balances under the farming systems evaluated

The N-nutrient balance was calculated as the difference between that returned by crop residues and the total amount of N removed via soil loss, runoff, and crop grain. Figure 2 illustrates the N balance in the soil under the different farming systems evaluated. During the first two years, the N balance was negative with the greatest negative balance associated with the upland rice monoculture. After a further two years, soils under the upland rice monoculture without mulching and natural fallow continued to exhibit a negative N balance. In contrast, the upland rice monoculture treatement with mulching via hedgerows of *Tephrosia candida* (T3) had a positive N balance. Dry cultivation with hedgerows of *Tephrosia candida* (T3 and T5) effectively prevented soil loss via erosion. Therefore, soil under these farming systems had the lowest imbalance of N.

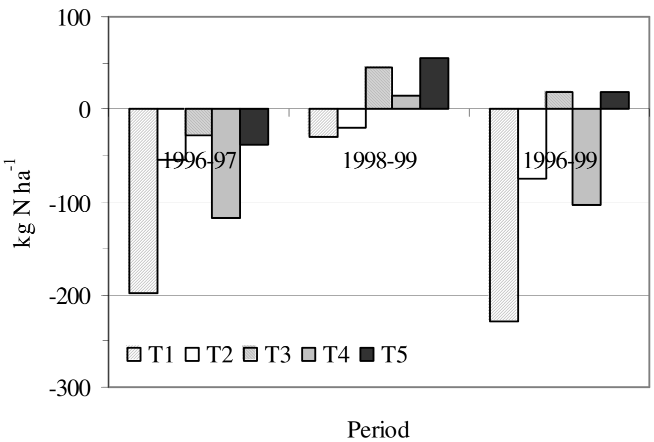

Figure 2. Soil N-balance (kg N ha^{-1}) for the cropping systems evaluated.

For treatments T1, T2 and T4 the net N-balance was negative (Figure 2). The loss of N from the soil was greatest in the natural fallow (T1). Soil N-loss was slightly reduced in treatments with mulching by *tephrosia candida* residue (T4). The T3 *Tephrosia candida* hedgerow and mulching treatment was associated with the lowest soil N-loss. In the first 2 year period (1996-1997) the N balance for the T3 treatment was negative with a value -28.1 kg N ha^{-1}. However, in the second 2 year period (1998-1999) and taken cumulatively over the 4 year study period, the T3 treatment was associated with a positive N-balance (Figure 2). The Corn-peanut system (T5) in association with the return of residues to cover the soil surface was also associated with a net cumulative N-balance. In summary, the farming systems with hedgerows namely T3 and T5 had the highest balance of N, as compared to control

In comparison, the soil P-balances for the treatments evaluated are shown in Figure 3. The results indicate that for all treatments, the net cumulative 4 year P-balance is negative. However, it is of note that during the second half of the study period (1998-1999) the beneficial role the *Tephrosia candida* hedgerows enabled a positive balance for the T3 and T5 treatments.

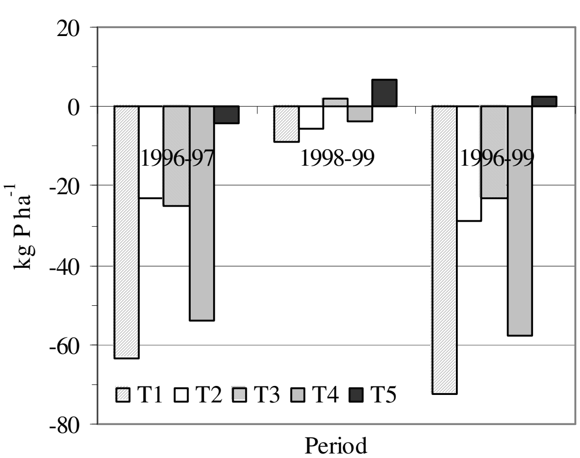

Figure 3. Soil P-balance (kg P ha^{-1}) for the cropping systems evaluated.

The balance of K in the soil is presented in Figure 4. The results indicate that the removal of K was much greater in the first two years of the study period (1996-1997). This may in part be due to the high rates of runoff and soil erosion associated with plot clearance and implementation (Tables 4 and 5). In contrast, for the period 1998-1999 more K was returned to the soil with crop residues than was removed resulting in net positive K-balances for all treatments (Figure 4). However, net cumulative K-balances for all treatments evaluated were negative.

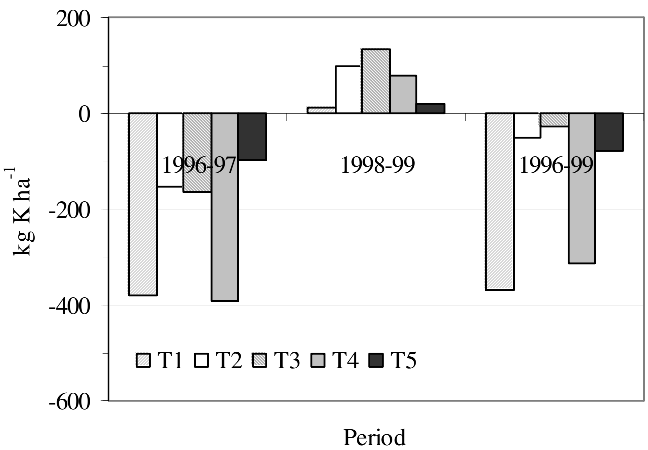

Figure 4. Soil K-balance (kg K ha^{-1}) for the cropping systems evaluated.

CONCLUSION

Water and nutrient flow on sloping land are strongly affected by rainfall and farming systems. Rainfall not only supplies water for plants, but also influences the nutrient balance in the soil. These flows vary very much from farming system to farming system, depending on the cropping systems. The results of this study indicate that for the soil type investigated the adoption of an upland rice monoculture and short fallow systems resulted in stronger negative balances of N, P, and K than the upland rice system with hedgerows of *Tephrosia candida.* Mulching with crop residues in combination with hedgerow technology reduces soil erosion and can effectively prevented nutrient loss.

REFERENCES

Bo, N.V.; and Nguyen Trong Thi. 1997. Mineral fertilizer's utilization-resolution for safety food in Vietnam. In *Proceedings of the workshop on ventilation and soil Environment,* Hanoi, 22–24 January. pp 43–51.

FAO. 1988. *Guidelines for soil profile description.* 3rd ed. Rome: FAO.

Gee, G.W.; and Bauder, J.W. 1986. Particle-size analysis. Methods of Soil Analysis Part 1, Physical and Mineral Methods. Second Edition, Madison. Wisconsin: SSSA.

IBSRAM, March,1991. Methodological guidelines for IBSRAM's soil management networks.

Mutert, E.; and Fairhurst, T. 1997. Nutrient management on sloping land in Southeast Asia: limitations, challenges and opportunities. In *Proceedings of the workshop on water and plant nutrition management on sloping land in Northern Vietnam.* pp 8—20.

Thai Phien; and Nguyen Cong Vinh. 1993. The management of acid upland soils for sustainable agriculture in Vietnam. Reports and papers on the management of acid soils, IBSRAM/*ASIALAND*. Network Document No. 6. pp 201–216.

Thai Phien; and Nguyen Cong Vinh. 1998. Nutrient management for cassava-based cropping systems in northern Vietnam. In *Cassava breeding, agronomy and farmer participatory research in Asia.* CATAS, CIAT, NIPON. pp 268–279. Bangkok, Thailand, April, 1998.

Nguyen Tu Siem; and Thai Phien. 1999. Upland soils in Vietnam - degradation and rehabilitation. Hanoi: Agricultural Publishing House.