IMPACT OF UPSTREAM SOIL NUTRIENT LOSSES ON SOIL FERTILITY IN PADDY FIELDS

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Abstract

This paper report results of the five years of an on going research project on nutrient balances in a composite swidden agroecosystem. The study is being carried out in Tat hamlet, a small settlement of Da Bac Tay ethnic minority people in Hoa Binh province in Vietnam's Northern Mountain Region. Nutrient flows from the upland to the paddy field were directly proportional to the amount of rainfall and prevailing soil surface/cropping conditions. Nutrients flows from the upland to paddy fields in this experiment increased from 97 to 227 kg total N between 2000 and 2001 and decreased sharply thereafter, to 78 kg N in 2002 and to 50 kg in 2004. P and K outflows from the watershed showed similar trends.

On average, the inflows of available nutrients to the upper 3 paddy fields were equivalent to available nutrient additions of as much as 453; 58 and 1455 kg/ha for N, P and K respectively. Even when considering the whole paddy area, potential inputs could on average account for up to 151; 19 and 485 kg available N, P and K respectively. Potential total nutrient contributions were even larger. However, in reality, farmers would not divert all of the discharge into the paddy fields, e.g. paddies are drained during rice harvest of summer rice.

The net nutrient flow balance varied considerably between years. In 2000, N flow balances were positive for both total and available N. However, available N was reduced to -0.7 kg in 2001 and even to -21.0 kg in 2002. Net flow P balances varied least. Potassium net in-outflow balances showed as large of a yearly variation as N. Potassium net flow balances, although mostly negative in the first years, became positive in the last year.

Keywords: Watershed; Water discharge; Nutrient flow; Nutrient balance

1. Introduction

In the Uplands of Northern Vietnam, swidden agriculture has come to constitute the most serious threat to the natural environment as human populations have increased well beyond the carrying capacity of traditional swiddening systems. In some parts of this region, however, ethnic minority farmers employ a system of "composite swiddening" a unique type of agro ecosystem that integrates permanent wet rice fields in valley bottoms with rotating swidden pilots on hill slopes to form a single household resource system (Rambo, 1998). Initial field research in 1998 in Tat Hamlet, Hoa Binh province, where the Da Bac Tay ethnic minority population has practiced this systems for centuries, showed that composite swiddening appeared to be a sustainable form of shifting cultivation and could offer a model for use elsewhere in the Northern Mountain Region (Cuc and Rambo, 2001).

The central hypothesis of this research is that the farmers of Tat hamlet manage the swidden and wet rice field subsystems in ways that maintain soil nutrients in each subsystem. In the case of the wet rice fields, nutrient balance is probably maintained over the course of each annual cropping cycle, with nutrient inputs equal to nutrient outputs for each crop (Jae-Young Cho and at el (1999). In the case of the swiddens, however, the question is much more complex and must be studied over the duration of the entire multi-year cycle of cultivation and fallowing. The sustainability of the land-use system as a whole will very much depend on strong positive, functional linkages between the swiddens and wet rice field subsystems. Run-off water from the hill slope swiddens carries nutrients into the paddy fields. Developing a better understanding of these functional linkages among key sub-systems in the composite swiddening agro ecosystem is one of the key objectives of this research project. Our study was designed to measure both water discharge and nutrient flow from upland to low land, and to calculate nutrient balances of the subsystems over the full rotational cycle of cultivation. Also assessed was the contribution of inter-subsystem nutrient flows towards maintaining a nutrient balance in the entire system.

Research Objectives

- The flow of water, soil, and nutrients from the swidden field to the paddy field
- The nutrient balance in the paddy field.

These measurements were necessary in order to:

- Identify the interactions between the upland and lowland areas with regard to water and nutrient flows
- Determine the nutrient balance of the overall system and its components
- Quantify the nutrient contents in the various components of the water balance at the watershed and plot levels

2. Materials and Methods

2.1.The study site

In order to collect nutrient flow data in a controlled fashion, an experimental site was established in Tat Hamlet. The 3.54 ha experimental site is located in a small watershed at east longitude: 105°11' 92" and north latitude: 20° 32'. The site was intentionally selected for having upland fields on the hillside, secondary forest at a stage that was ready to be cleared for swidden cropping, and paddy fields directly below, at the foot of the hill. The hillside had an average slope of between 29.3 and 36.44 degrees. An experimental field was established in 1999 with three patterns of land use: (a) forest (bamboo and trees) on the top of the slope, (b) swidden crops (upland rice, cassava, and fallow) on the middle slope, and (c) paddy rice in the lowland in the valley at the base of the hill slope (Figure 1). The area of the forest was 2.76 ha, the swidden area was 0.76 ha, and the paddy area was 0.21 ha.

For data collection, 10 plots were designated: six for swidden land-use (Plots 1-6), three for forest land-use (Plots 7-9), and one for paddy land-use (Plot 10). The sizes of the forest and swidden plots were the same, measuring 5 m wide and 20 m long down the slope. The size of the paddy plot was about 1,020 m^2, covering 3 paddy bunds.

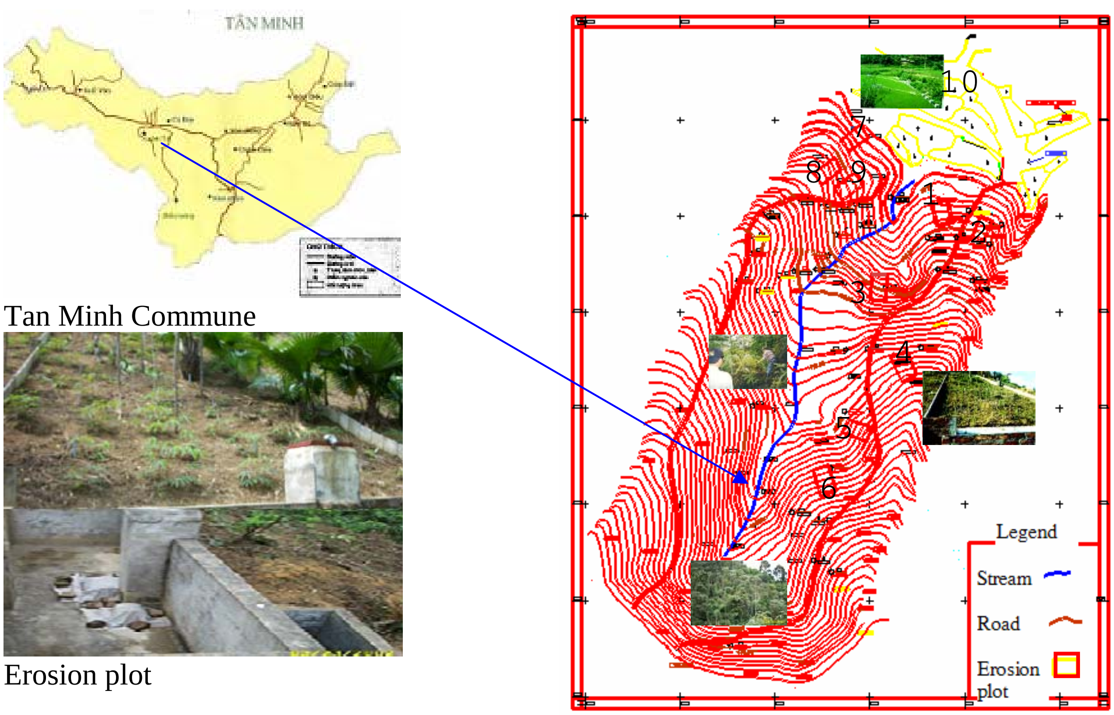

Figure 1: Diagram of the experimental site

2.2. Nutrient inputs from surface inflow from the upland to the paddy field

Nutrient concentration of the water flow from the upland to the paddy field on rainy days and dry days were determined separately. A tank was set up at the end of the stream to collect part of the water from the upland field before it flowed into the paddy field on rainy days. To measure nutrient concentration of the water flow on rainy days, water samples were taken from the tank after each rain event. Three sub-samples were taken at three levels of the tank (top, middle, and bottom), mixed up, and sent for nutrient content analysis. On dry days, water samples were taken directly from the end of the stream, before it flowed into the paddy field, because not enough water flowed into the tank.

The total amount of water flow from the upland to the paddy field was estimated as the sum of the total amount of water losses from the paddy field through evapotranspiration (ET), percolation (P) and discharge (Qout) by water balance (Mao Zhi 1992).

ET and P were measured with lysimeters (Figure 2). Three pairs of lysimeters (one closed-bottom and one open-bottom in each pair) were installed in the paddy field. The closed-bottom lysimeter was used to measure ET, and the open-bottom lysimeter was used to measure ET and P. The net evapotranspiration was determined daily. The ET was measured every day at 7 a.m. by a hook gauge on the open and closed bottom lysimeters. P was calculated by the difference between water levels in the open-bottom and the closed-bottom lysimeters.

Figure 2: Lysimeters were installed in the paddy field

Figure 3: A weir system was set up at three positions on the paddy bunds

A weir system was set up at three positions on the paddy bunds (7 weirs at each position, totaling 21 weirs- Figure 3) to measure the discharge of surface runoff out of the paddy field at each position, an automatic deep probe (Dataflow model 392, Dataflow Company, Australia) was installed to measure water levels. Daily records were used in the calculation of the amount of water flow through the weirs. The discharge was determined by the following equation:

$$Q_{out} = 1838 (L - 0.2H) H^{1.5} (l/s)$$

Where Q_{out} = Discharge (l/s), L = Crest width (m), and H= Difference between the crest and the water surface (m).

3. Results

3.1. Water discharge from watershed

Water discharge from the small Tat watershed was highest in the first two years (Table 1). In 2001, the largest discharge coincided with the highest rainfall during the experimental period. Subsequent declines in water discharge can only partly be explained by decreasing rainfall. For example, rainfall levels in 2000 and 2003 were similar, but discharge was substantially lower in 2003. Thus, the ongoing decline in water discharge over time is likely also to be strongly associated with the change in land-use. During the experimental time, an increasing proportion of the watershed area was becoming fallow which has been shown above to substantially reduce run-off and thus, water discharge.

Table 1: Yearly water discharge from the experimental watershed

Year	Discharge (1000 m^3 Water)
2000	104
2001	119
2002	32
2003	19
2004	18

3.2. Nutrient flows from the upland to the paddy field

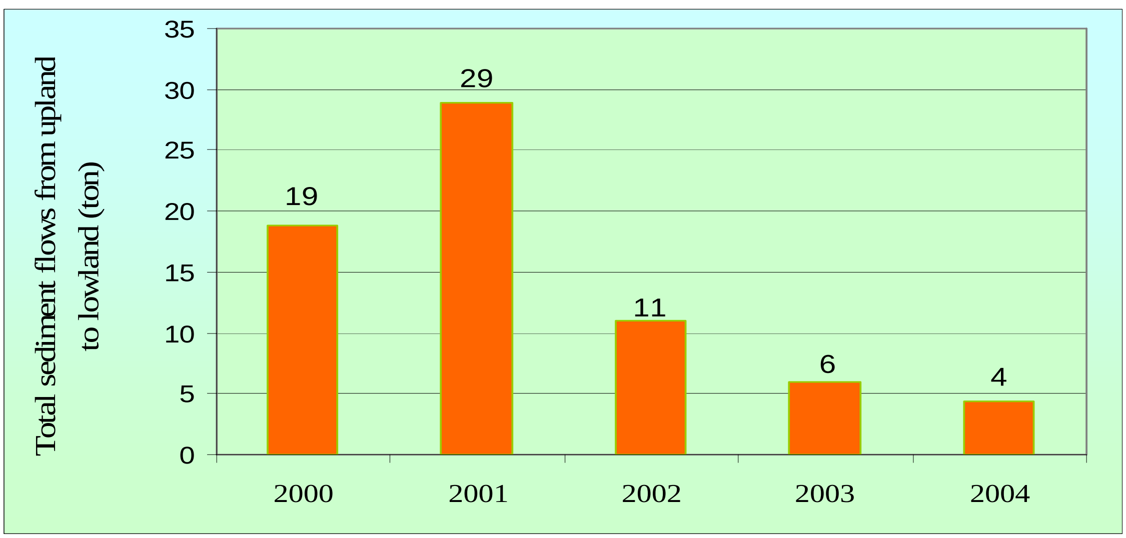

Figure 4: Yearly total fine sediment flow from upland to lowland areas measured at the outlet of the watershed.

The measurements showed that each year substantial amounts of fine sediment flowed from the upland to the paddy fields (Figure 4). The amount of fine sediment flow increased from 19 tons in 2000 to 29 tons in 2001 but thereafter greatly decreased to 11 tons in 2002, 6 tons in 2003 and 4 tons in 2004. This pattern of sediment flow was closely correlated to rainfall patterns in the different years, e.g., rainfall was also highest in 2001. It has to be noted that these measured sediment flows represent only the fine sediment transport since larger sediment particles were not able to pass the fine mesh screen at the sampling point. Thus actual total sediment flows were likely to have been somewhat higher.

Nutrient flows from upland to lowland associated with sediment transport and in water dissolved nutrients showed a similar pattern (Figure 5). Hence, the nutrient flow was shown to be directly proportional to the amount of rainfall and prevailing soil surface/cropping conditions. In the year 2001, associated with large rainfalls, N, P and K losses in the stream from the watershed were considerably larger than in other years. In this year total N loss from the watershed amounted to 227 kg and available N loss was 79 kg. Even larger were total and available K outflows from the watershed, i.e. 380 kg and 253 kg respectively in 2001. These high K losses from the watershed are in accordance with the high K losses in the upland swidden systems. However, the relationship between K and N losses measured in the upland nutrient balances showed a wider K:N ratio suggesting that substantial amounts of K are deposited on lower areas during landscape erosion processes on their way to the stream. In contrast to K, N and P discharges were largely in accordance with nutrient losses measured in runoff and erosion. Nutrients flows from upland to paddy fields in this experiment increased from 97 to 227 kg total N between 2000 and 2001 and decreased thereafter sharply to 78 kg N in 2002 and to 50 kg in 2004. P and K outflows from the watershed showed similar trends.

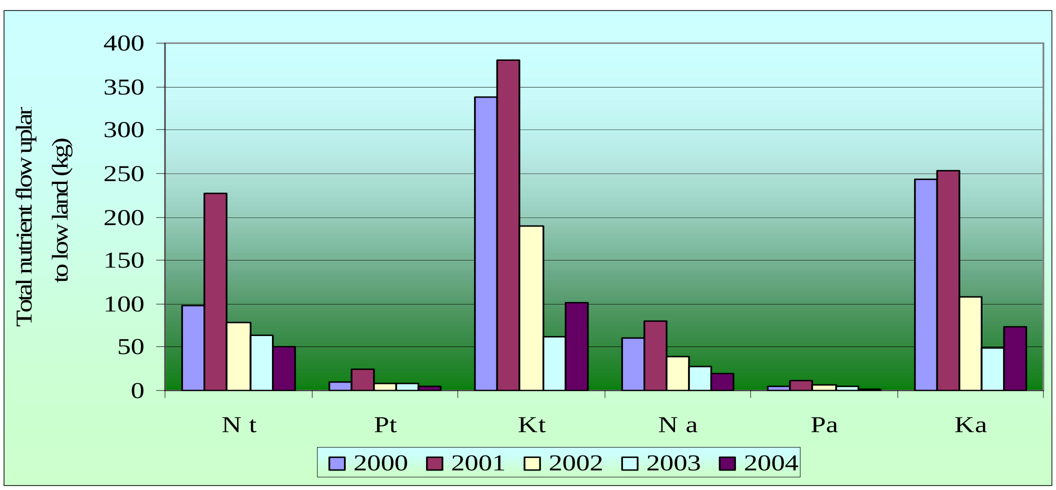

Figure 5: Yearly nutrient flows from upland swidden areas to lowland paddy fields (t=total. a= available)

3.3. Nutrient losses through leaching and overflow in paddy fields

In the small watershed under study, the ratio of upland area to paddy field area was high, e.g. the upland area was 3.24 ha, and occupied 91% of the study area. In contrast, the paddy area from were the outflow measurements were taken was only 1020 m^2 and occupied 3.39% of the area while total paddy area associated with the watershed was 0.3 ha. The width of the paddy area at the outlet was on average 35 m from the hill base. Thus, in cases of heavy rains the water velocity flowing in and out of the paddy fields was very high and consequently could carry large quantities of sediments and nutrients with it. The sediments flowing out of the paddy field amounted to 13.5; 13.4; 4.3; 2.6 and 2.1 tons in 2000, 2001, 2002, 2003 and 2004 respectively (Figure 6).

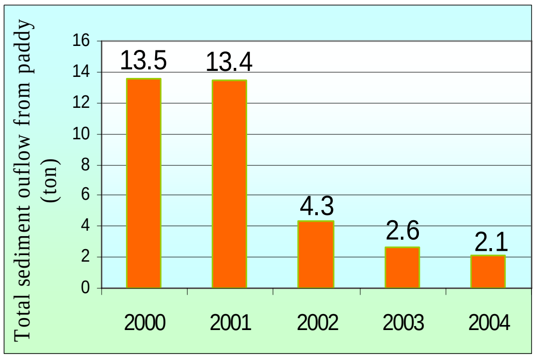

Figure 6: Yearly sediment outflow from paddy fields.

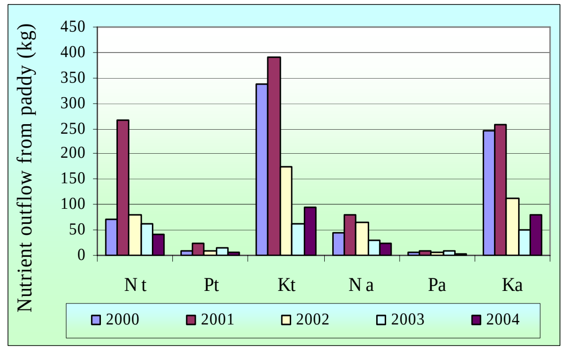

Figure 7: Yearly nutrient outflows from paddy fields. (t=total, a= available)

The highest nutrient losses associated with the overflow from the paddy fields were of potassium. The amounts of K flowing out of the three paddy fields were 392 kg total K and 258 kg available K in 2001 (Figure 7). Potassium nutrient losses from the paddy fields were particularly high in the first two years but became relatively small in 2003 and 2004. Associated with highest rainfall, nitrogen losses from the paddy fields were also largest in 2001, e.g. 260/80 kg total/available N respectively. These outputs decreased in 2003 and 2004 to only 62/42 kg total nitrogen and 30/22 kg available nitrogen.

3.4. Impact of upland water discharge on nutrient status of the paddy fields

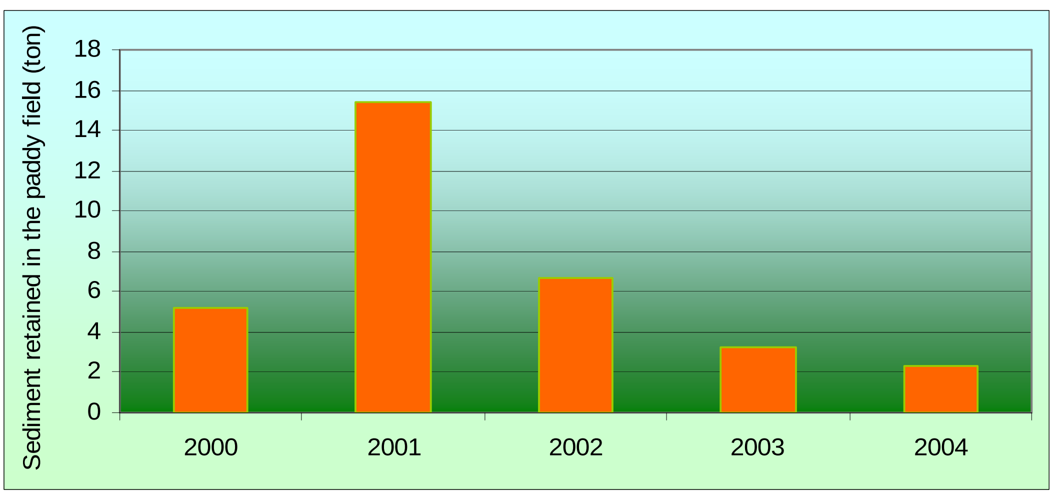

Figure 8: Yearly amount of sediment retained in the 3 upper paddy fields.

Part of the sediment discharged from the watershed settled in the paddy fields. Approximately 27-63% of the sediment discharged remained in the upper 3 paddies under measurement. The amount of sediment retained in the paddy field increased from 5.2 tons to 15.4 tons between 2000 and 2001 and decreased to 6.7 tons in 2002 and to a low of 2.1 tons in 2004 (Figure 8).

As a consequence of sedimentation, soil texture in the paddy fields near the discharge inlet was altered. Three plots in the paddy field were established 10, 20 and 30 m from the foothill representing for paddy plot 1, 2, and 3 respectively. The sand ratio increased from 46% to 72% for plot one and from 46% to 64% for plot 2 from 1999 to 2000, mainly because the sediment that remained in the paddy field was predominantly sand. Silt content only changed in plot 1 but clay content was not changed for the entire experimental period (Figure 9). The reason why plot 1 was most affected was due to its position nearest the water inlet.

The amount of sediment in the paddy fields depended on the distance from the base of the hill and the velocity of the water flow. At a distance of 10 meters from the hill base, sand accumulated probably because silt and clay particles were carried out of the paddy field with out-flowing water (Figure 10). The proportion of sand near the inlet was 62%, and decreased to 41% at 30 meters from the base of the hill.

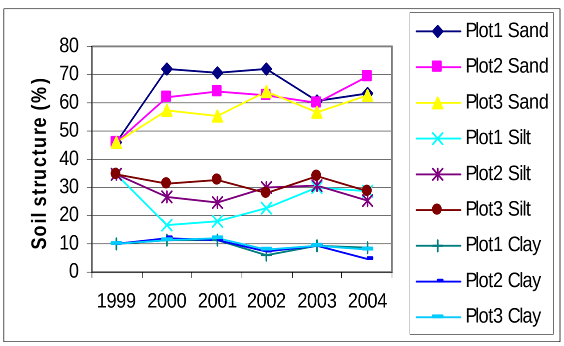

Figure 9: Changes in soil texture with time in paddy fields.

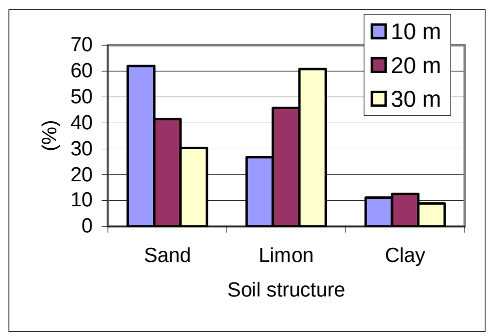

Figure 10: Effect of sedimentation on distribution of soil texture at different distances from the base of upstream discharge inlet into the paddy fields.

3.5. Nutrient balances in paddy fields

On average, the inflows of available nutrients to the upper 3 paddy fields were equivalent to available nutrient additions of as much as 453; 58 and 1455 kg/ha for N, P and K respectively (Table 2). Even when considering the whole paddy area, potential inputs could on average account for up to 151; 19 and 485 kg available N, P and K respectively. Potential total nutrient contributions were even larger. However, in reality, farmers would not divert all of the discharge into the paddy fields, e.g. paddies are drained during rice harvest of summer rice.

Table 2: Average (2000-2004) yearly available (a) nutrient contribution of uplands to lowland paddies.

Inflow	Unit	N_a	P_a	K_a
Total inflow	kg/year	45	6	146
Inflow paddy (0,1ha)	kg/ha equivalent	453	58	1455
Inflow paddy (0,3ha)	kg/ha equivalent	151	19	485

Note: 0,1 ha denotes measurement area and 0,3 ha total paddy area at bottom of watershed

Respective yearly, outflows were often offsetting nutrient inflows so that the net balance between inflow and outflow of nutrients in the paddy system was often slightly negative (Figure 11). The net nutrient flow balance varied considerably between years. In 2000, N flow balances were positive for both total and available N. However, available N was reduced to -0.7 kg in 2001 and even to -21 kg in 2002. Net flow P balances varied least. Potassium net in-outflow balances showed similar large yearly variations as N. Potassium net flow balances although mostly negative in the first years became positive in the last year. There was no consistent relationship in the net in-outflow balances between the three nutrients tested.

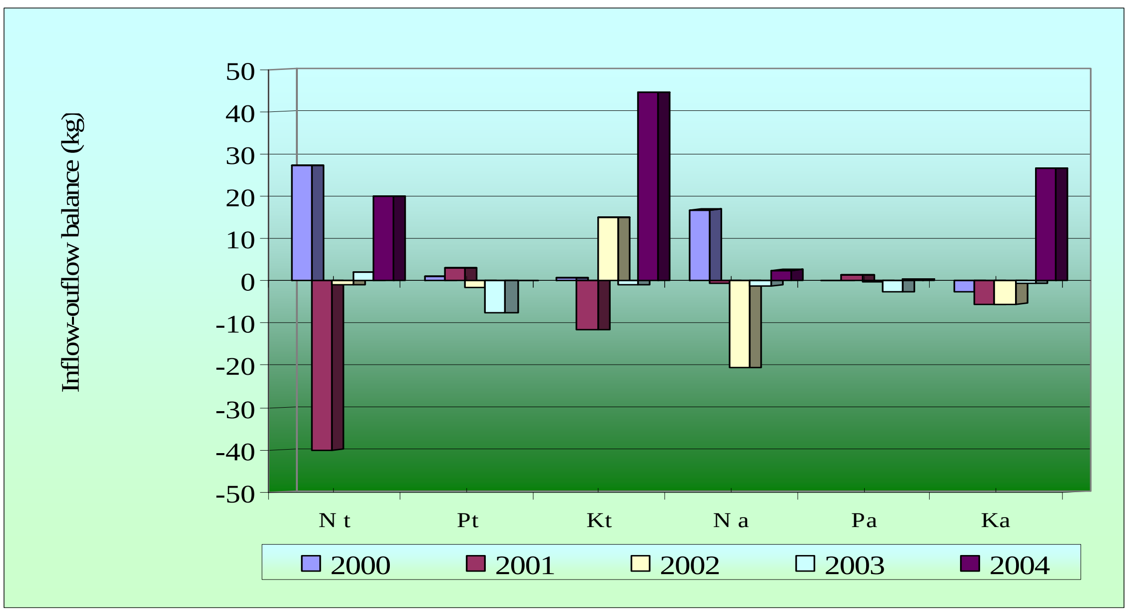

Figure 11: Net nutrient balance between inflow and outflow of nutrients in the paddy system (t=total. a= available)

These net inflow-outflow balances can not fully account for the upland's impact on paddy soil fertility and plant nutrition, due to the additional input occurring in paddy fields. However, it can be concluded that due to the often fast water flow through the paddy system, the paddy field and its plants seemed to be able to catch only a small fraction of the nutrient provided by run-off, erosion and leaching events of upstream swidden fields. It thus appears that for a small watershed like this one, it might be necessary to supplement nutrients in order to increase yields of paddy rice.

The complete system's paddy nutrient balances revealed that the N and P balance were generally positive. In fact, they were strongly positive for P, e.g. up to +88 kg P/ha in 2001 (Table 3). This was due to the high P fertilizer inputs. As excess P was not lost in the out-flowing water, it is likely to build up in the soil system and would probably lead to reduced input requirements over time. N was also positive in most years, with levels of up to about 94 kgN/ha/year. Unless there occurred a build up of organic matter in the soil, it is likely that a large proportion of this excess was lost by denitrification, which was not accounted for in the partial balance approach applied. As in the upland nutrient balances, K balances in the paddy system were negative, suggesting that despite the large upstream flow-through of K, not enough was retained in the paddy fields to offset losses. It thus appears that in the current upland and lowland systems, the nutrient replenishment patterns of K are least understood and need further investigation.

4. Conclusion and discussion

This research was conducted with the aim of investigating the long-term sustainability of the composite swidden system in terms of soil productivity and the functional linkage between the swiddens and the paddy fields that would contribute to the sustainability of the composite swidden system as a whole. Particularly, we found that nutrients eroded from swidden upland fields would help replenish soil fertility in the paddy fields, making the nutrient inputs more or less in balance with the outputs, thus maintaining the soil productivity of the paddy fields.

Our results clearly showed that swidden fields under crop cultivation are degrading. The longer the field is under cropping, the more nutrients are removed from the soil. Both negative nutrient balance and soil analyses indicated substantial losses of all major nutrients, particularly K, and consequently a continuous decline in soil fertility throughout the successive years of cropping. The major sources of nutrient outputs were erosion and runoff, which were reduced substantially when land use was changed to agroforestry and fallow.

Our data showed that there were substantial amounts of nutrient inflows to the paddy field from eroded sediments and runoff from upland fields as had been hypothesized, but nutrient losses through water outflows were also quite large, and appeared to offset the inflows of nutrients. As water outflows also carried nutrients from applied manure and fertilizers, it was not possible to separate them from inflow nutrients from upland fields. Thus, the question of the beneficial effects of upland fields providing nutrients to paddy fields remains unanswered and requires further study. As K fertilizer was not applied, the negative K balance suggested that despite the large upstream flow-through of K, not enough was retained in the paddy fields to offset losses. It thus appears that in the current upland and lowland systems, the nutrient replenishment patterns of K are least understood and need further investigation.

Table 3: Nutrient balances in paddy fields adjacent to upland stream outlet.

2000	Total		
In put	N	P	K
Seeding	1.95	0.63	1.97
Rainfall	29.30	6.73	36.85
Organic fertilizer	9.90	7.42	71.78
Chemical fertilizer	38.30	65.56	-
Water inflow	97.33	9.68	337.98
Total	**176.78**	**90.03**	**448.58**
Out put			
Harvesting	95.65	30.56	109.73
Herbivores	4.70	2.10	6.89
Water outflow	70.19	8.81	337.35
Total	**170.54**	**41.47**	**453.97**
Nutrient balance	**6.24**	**48.56**	**-5.39**

2001	Total		
In put	N	P	K
Seeding	1.10	0.20	0.30
Rainfall	29.30	6.73	36.85
Organic fertilizer			
Chemical fertilizer	115.00	98.00	-
Water inflow	227.23	25.23	379.90
Total	**372.63**	**130.16**	**417.05**
Out put			
Harvesting	70.40	17.70	41.00
Herbivores	4.70	2.10	6.89
Water outflow	267.27	22.34	391.52
Total	**342.37**	**42.14**	**439.41**
Nutrient balance	**30.26**	**88.02**	**-22.36**

2002	Total		
In put	N	P	K
Seeding	1.10	0.20	0.30
Rainfall	29.30	6.73	36.85
Organic fertilizer			
Chemical fertilizer	115.00	98.00	-
Water inflow	77.87	7.95	188.98
Total	**223.27**	**112.88**	**226.13**
Out put	-	-	-
Harvesting	114.26	31.28	131.88
Herbivores	1.14	0.31	1.32
Water outflow	104.15	9.69	222.89
Total	**219.56**	**41.28**	**356.09**
Nutrient balance	**3.71**	**71.60**	**-129.96**

2003	Total		
In put	N	P	K
Seeding	1.10	0.20	0.30
Rainfall	29.56	11.86	15.96
Organic fertilizer	-	-	-
Chemical fertilizer	115.00	98.00	-
Water inflow	64.44	7.56	62.49
Total	**210.10**	**117.62**	**78.74**
Out put			
Harvesting	93.54	21.08	123.13
Herbivores	0.65	0.15	0.86
Water outflow	62.37	15.17	63.45
Total	**156.56**	**36.40**	**187.45**
Nutrient balance	**53.53**	**81.22**	**-108.70**

2004	Total		
In put	N	P	K
Seeding	1.10	0.20	0.30
Rainfall	29.03	1.61	57.74
Organic fertilizer	-	-	-
Chemical fertilizer	115.00	98.00	-
Water inflow	50.52	4.66	101.50
Total	**195.65**	**104.47**	**159.54**
Out put			
Harvesting	70.16	21.40	109.57
Herbivores	0.77	0.24	1.21
Water outflow	30.45	4.63	56.87
Total	**101.38**	**26.26**	**167.65**
Nutrient balance	**94.27**	**78.21**	**-8.11**

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