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Land-Use Sustainability of Composite Swiddening in the Uplands of Northern Vietnam: Nutrient Balances of Swidden Fields during the Cropping Period and Changes of Soil Nutrients over the Swidden Cycle

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This study examined the sustainability of the swidden component of the composite swiddening system practiced by the Tay ethnic minority in Tat hamlet, Hoa Binh province in Northern Vietnam. This farming system is thought to be suitable for the uplands where land degradation is a serious problem. The common swidden rotation of two years of rice, two years of cassava and five years of bush-tall grass fallow was evaluated for the extent of land degradation during the cropping period by nutrient balance analysis, and for soil nutrient status throughout the swidden cycle through soil analysis. Four fields representing the individual years of cropping and three fields representing the first, the third and the fifth years of bush-tall grass fallow were selected for field measurements. Nutrient balance analysis indicated substantial losses of all major nutrients, particularly K, in all cropping years. Soil analysis also showed a decline in soil fertility during the cropping period and a partial restoration of soil fertility during the fallow period. However, only five years of bush-tall grass fallow was not sufficient to restore the original level of soil fertility. Thus, swidden fields in Tat hamlet are degrading, posing a serious threat to their land-use sustainability.

Keywords: agricultural sustainability, composite swiddening, nutrient balance, soil nutrient status, Vietnam's Northern Mountain Region

Introduction

Degradation of natural resources is a problem of great concern globally. In Vietnam, although virtually all natural ecosystems are threatened, the uplands are the ecological zone where the threats are most serious. These are sloping lands consisting of hills, mountains, and

plateaus, occupying 24.4 million ha or 74% of the country's total area. These areas are inhabited by some 24 million people, including essentially all of Vietnam's ethnic minorities (Cuc *et al.*, 1990). In these areas, forests are fragmented and degraded (Fox *et al.*, 2000), barren lands are prominent (Phong, 1993), soil erosion is quite severe (Phien & Siem, 1998) and implementation of soil conservation practices is limited (Vien & Thanh, 1996). Consequently, land and forest resources are continuously degrading, and new measures to sustain the productivity of the land resource are strongly needed.

A type of land use that appears to be relatively sustainable is composite swiddening. It is a unique type of agroecosystem that integrates permanent wet rice fields and rotating swidden plots into a single household resource system (Rambo, 1998). This type of land use has existed for centuries not only in the mountains of Northern Vietnam but also in Southwestern China (Rambo, 1998), in Nan province in Northern Thailand (Kunstadter, 1978), in the Cordillera in the Philippines (Prill-Brett, 1986), and in Luang Prabang province of the Lao PDR (Gilligly *et al.*, 1990). The advantage of this system is that the wet rice field component provides a high and stable rice yield, enabling the households to meet their grain consumption needs with a considerable smaller area of rice swidden fields than is needed in pure swidden systems. Consequently, the carrying capacity of a given area of composite swiddening is twice that of rotational swiddening. Composite swiddening is, therefore, thought to be an alternative production system for use in the mountainous tropics where pure

swidden systems are producing excessive environmental degradation or are failing to meet the needs of expanding human populations (Rambo, 1998).

Composite swiddening, however, will ultimately face the same fate with regard to its long-term sustainability as rotational swidden systems, if population density increases beyond its carrying capacity. This has already happened in some areas where the fallow-cycle has been reduced from seven to 10 years to four to five years, which is insufficient for the regeneration of healthy secondary forest. Serious imbalances of nutrients at the hamlet and field levels were also evident (Rambo, 1998; Vien, 1998). Nevertheless, composite swiddening is still thought to have considerable potential for intensification.

This study is a part of the attempt to examine the sustainability of the swidden component of the composite swiddening system in the uplands of Northern Vietnam. The objectives were to evaluate the extent of land degradation of swidden fields during the cropping period through nutrient balance analysis and to assess soil nutrient status throughout the swidden cycle through soil analysis. Information obtained will contribute to the overall understanding of the composite swiddening system, which may eventually lead to the development of appropriate management strategies for sustainable agricultural intensification in the uplands of Northern Vietnam and also elsewhere in Southeast Asia.

Materials and Methods

The study site

The study was carried out in Tat hamlet, Hoa Binh province, in the Northern Mountain Region of Vietnam (latitude 20° 32'N and longitude 105° 12'E). The elevation is about 360 m above sea level at the valley floor, but reaching 800–950 m at the peaks of surrounding hills and mountains. Slopes are generally quite steep (40–60°). The hamlet has a population of 476, in 107 households, most of which belong to the Da Bac Tay ethnic minority. The total area of the hamlet is 743 ha, of which 21% is agricultural land and the remaining is forest land (Rambo & Vien, 2001). Paddy occupies only 8.4 ha while 54 ha are swidden. In this hamlet, composite swiddening has been practiced for at least a century. Key components of the system include

wet rice fields, home gardens, fish ponds, livestock, tree gardens, rice swiddens and cassava swiddens (Rambo, 1998; Vien, 1998). Swidden fields are located on the mountain slopes while paddy fields occupy the valley floor. Currently, the common swidden cycle consists of two years of rice followed by two years of cassava and then by five years of fallow, and this crop rotation cycle was selected for this study.

The study approach

A nutrient balance analysis was used to estimate the extent of land degradation of swidden fields during the cropping period, and soil analysis was used to determine changes in nutrient status of the soils during both the cropping and the fallow periods. For nutrient balance analysis, based on the concept of Smaling *et al.* (1999), sources of nutrient inputs for both rice and cassava during the cropping period included: (1) nitrogen fixation, (2) rain and dust, (3) planting materials and (4) run in. Measurements of nutrient inputs through nitrogen fixation were not undertaken. Neither fertiliser nor manure was applied to swidden fields. Sources of nutrient output included: (1) leaching, (2) run off and erosion, (3) harvested materials, (4) loss from burning of crop residues and weeds, and (5) volatilisation. There were also nutrient losses through soil fauna activities and animal consumption (rats, buffalo and insects), but it was not possible to actually measure these outputs. Also, the amount of nutrient loss through volatilisation was expected to be small because neither fertiliser nor compost was applied, and most of the nitrogen would be fixed by organic matter pools in the soils.

This study would require nine years if measurements were to be made on the same field throughout the swidden cycle. To shorten the time, the approach employed by Zinke *et al.* (1978) and Vien (1998) in which measurements were made on fields that were at different stages in the cropping and fallow cycle was used.

Four swidden fields, each of 500–1000 m² were selected for the measurements. These were fields with first-year rice, second-year rice, first-year cassava and second-year cassava, representing the four consecutive years in the cropping cycle. These fields were carefully selected to be as uniform as possible in terms of soil type (Ferrallitic Acrisols), slope gradient (22–27°), position of the fields (middle down to bottom of hill) and similar history of cultivation and fallow

succession (bush and tall grass). In addition, three fallow fields of about 1000–2000 m² were selected in a similar manner to represent the first-year, the third-year and the fifth-year of bush and tall grass fallow type. Field selection was done by a general survey of the hamlet, interviewing key-informants on land use history, and checking the conditions of the selected fields.

Field data collection was done during 2001–2002. All the fields were managed by farmers with their traditional practices. For the rice swidden, rice was planted on 19 May 2001 and harvested on 12 October 2001. After that, the field was left fallow for six months before the next planting. Nutrient balance analysis for rice swidden, thus, covered both the six-month cropping and the six-month fallow periods. During the six-month fallow period, nutrient input was only from rain and dust and nutrient output was the loss from burning of crop residues and weeds before planting the next crop. The decomposition of crop residues and litter was considered nutrient recycling. For the cassava swidden, nutrient balance analysis was done for the entire-year cropping period as the cassava was planted in February and harvested in December. There was no loss from burning for cassava swidden fields.

Measurement of individual input and output parameters

Nutrient inputs

The amount of nutrient inputs from rain and dust was obtained from a study conducted at the site in 2002–2003 (Dung, personal communication). In this study, a steel pan of 1 × 1 m² covered with a fine net was installed at the site for trapping rainwater from individual rainfall events. Samples of rainwater were taken for nutrient content analysis, more frequently during the time of field burning. Nutrient contents were determined separately for the dry season (October to March) and for the burning (May) and no burning (remaining months) periods in the rainy season. Amounts of nutrients brought in by rain and dust were calculated monthly using rainfall data from the weather station at the site.

Nutrient inputs from rice seeds and cassava stalks used as planting materials also were obtained from another study conducted in the same area (Huong & Ha, 2001). However, cross checking was done on the amount used per unit

area by interviewing farmers and direct observations.

Nutrient loss through burning

In each rice swidden field, four quadrates were marked before the time of field burning at the end of the six-month fallow period. Just before burning, all biomass in each quadrate was cut. Leaves, branches, and stems were separately weighed, and a composite sample of each plant part was taken for nutrient content analysis. Slashed biomass was laid on the ground to dry and then burned. After burning, ash in each quadrate was collected and weighed, and a composite ash sample (100 g) was taken for nutrient content analysis. Amounts of N, P and K in the biomass before burning and in the ash after burning were calculated, and nutrient losses through burning was obtained as the differences between the amounts of nutrients in the biomass before burning and those in the ash. In the field, there were some unburned parts left after burning. These are considered recycled materials and were not entered in the nutrient balance analysis.

Nutrient loss by erosion

Soil losses by erosion were measured by the erosion pin method as described in Vien (1998). Briefly, steel pins of 10 mm diameter, 1 m long and marked at 50 cm were installed in the selected fields at the beginning of the rainy season. In each field, 25 pins were installed in the centre of the field in five rows along the contour, 2 m apart, with alternate placement of pins between rows (2 m between pins within a row). The pins were half buried in the soil, in an upright position, to the 50-cm mark indicating the reference point. Pin heights to the soil surface level were measured at the end of the cropping cycle (9th November) to reduce the impact of cultivation or soil disturbance (Kelly & Gomez, 1998). For each pin, four measurements were taken at pin cardinal point from four directions, and the average was used as the height of the pin at that particular reading. The depth of soil loss by erosion in that field was obtained as the difference in pin heights at the beginning and at the end of the year, averaging all the pins in the field.

Soil samples also were taken at the beginning of the rainy season, immediately after field burning, at the depths of 0–3 cm. The samples were analysed for bulk density and nutrient

(N, P and K) contents. Enrichment ratio (ER), which is the ratio of nutrient concentration in sediment to nutrient concentration in topsoil of a particular field, was calculated from secondary data obtained from Dung *et al.* (2002). Nutrient losses through erosion were then calculated from the amount of soil loss and nutrient contents of the surface layer of the soil, and its enrichment ratio as recommended by Hashim *et al.* (1998) is described in the following equation:

$$NL = SL * NC * ER \quad (1)$$

where NL = amount of nutrient loss, SL = amount of soil loss, NC = nutrient concentration in the top soil, and ER = enrichment ratio.

Nutrient loss by leaching

Data on nutrient loss by leaching was obtained from another study conducted in the same area (Dung *et al.*, 2002). In this study, the ground water was measured by four automatic water samplers (Dataflow model 392, Dataflow company, Australia) installed in the experimental swidden fields at four depths (0–20, 20–40, 40–60 and 60–80 cm). Samples of ground water were taken after each rainfall event and analysed for nutrient contents (N, P and K). Leaching was considered as downward movement of nutrients below 30 cm. The amounts of leaching nutrients were obtained by multiplying the amount of leaching water with its nutrient concentrations. The amount of leaching water was calculated as the difference between the amount of rainfall and losses from run-off, evapotranspiration, and the change in soil moisture content.

Nutrient loss through harvest materials

At harvesting time, the removed materials (rice grain and straw, cassava root) were harvested from five quadrates in each field, each of 1 m². Crop residues and weeds (aboveground biomass only) in each quadrate were also cut to determine the amount of nutrients remaining in the field at the time of harvest. Fresh weights of both harvested materials and crop residues and weeds were measured directly in the fields. Then a composite sample of each type of biomass (rice grain, rice straw, cassava root and residues) was taken from each field, oven-dried at 70°C for moisture content determination, and analysed for its nutrient contents (N, P and K). The amounts of dry

weights per ha of removed materials were calculated for rice grain and straw and cassava root, and for crop residues and weeds in the rice swidden fields. Their corresponding amounts of nutrients (N, P and K) per ha were also calculated.

Nutrient balance analyses

Balances of N, P and K were calculated for each field as the differences between nutrient inputs and outputs. Balances for swidden fields with subsequent years of cropping were combined to get the estimates of nutrient losses for the entire four-year period of cropping.

Soil sampling and analysis

To determine soil nutrient status of swidden fields at different stages of cropping and fallow periods, soil samples were collected from each field at specific times and analysed for major nutrients. In each swidden rice field, soil samplings were taken after burning of fallow vegetation but before planting (18 May 2001) and at the end of the six-month fallow period after burning of rice stubble and weeds (28 May 2002). In each swidden cassava field, soil samples were collected before planting (6 February 2001) and at harvesting of the cassava crop (9 December 2001). For fallow fields, soil samples were taken at the end of the dry season (April 2002) and at the end of the rainy season (October 2002). In each field, three composite soil samples were taken, each from 10 soil cores (0–15 cm) from different places in the whole field. The samples were sent for analysis at the JICA laboratory of Hanoi Agricultural University. Each sample was analysed for organic carbon, pH, total N, total P, total K, mineral N, extractable P and exchangeable K.

Organic carbon was determined by the Walkley and Black method. Soil pH was measured at soil to water ratio of 1 : 5. Determinations of total and mineral N were done by the Kjeldahl method. Total and mineral P were measured by digestion with mixed acids (H₂SO₄ and HClO₄-double acid method) and by Bray 2 methods, respectively, and then determined by UV-VIS Spectrophotometer (1240 Japan). Total K was measured by the double-acid method (digested by HF and H₂SO₄ and determined by photometer ANA-135 Tokyo), and exchangeable K by 1 N neutral normal ammonium acetate

($\text{CH}_3\text{COO}\cdot\text{NH}_4$) – extracted and determined by flame emission spectrometry.

Results and Discussion

Nutrient balance analysis of swidden cropping fields

Nutrient inputs

Sources of nutrient inputs to swidden cropping fields considered in this study were only atmospheric deposition from rain and dust and planting material (rice seed and cassava stalk). Amounts of nutrients brought in by both of these sources were rather small. The nutrient inputs from rain and dust were 16.6 kg of N, 1.6 kg of P and 25.4 kg of K $\text{ha}^{-1} \text{Y}^{-1}$. Rice seeds provided only 1 kg N ha^{-1} , 0.1 kg P ha^{-1} and 0.3 kg K ha^{-1} while cassava planting stalks provided 4.1 kg N ha^{-1} , 0.5 kg P ha^{-1} and 6.1 kg K ha^{-1} . From observation, there were not many leguminous weeds in these fields. Thus, nutrient input through nitrogen fixation was expected to be small. As measurement of soil erosion was done using the pin method, run in of nutrients should have already been accounted for by the erosion measurement. These latter two inputs were not considered in this study. In normal practice, no chemical fertiliser or manure was applied to swidden fields. It was quite evident that, in swidden cultivation of both rice and cassava, nutrient inputs were very small.

Soil loss and nutrients removed by erosion

Table 1 shows the amount of soil and nutrients losses by erosion of the individual fields

representing four consecutive years of swidden cropping. The corresponding nutrient contents of topsoil and enrichment ratios on which the estimation of nutrient losses were based are also given. The amounts of soil loss per year in the first three years of cropping (first-year rice, second-year rice and first-year cassava) were not much different (26.43–29.64 t ha^{-1}) but were much less than the loss in the fourth year when cassava was grown for the second time (40.24 t ha^{-1}). This could be explained by a greater soil disturbance of the second-year cassava field from uprooting the first-year cassava crop during harvesting, while plantings of crops in the first three years (two rice crops and the first-year cassava) were done without much soil disturbance. Information from local farmers also indicated that fields with serious soil loss from erosion were cassava fields after the crop was harvested. These results, however, differed somewhat from the earlier study of Vien (1998) who found that soil loss increased over the first three years of swidden rice cropping but substantially reduced in the following two years of cassava cropping. The amounts of soil losses from rice fields in this study (26.43–29.64 t ha^{-1}) were also much less than those of Vien (1998) (75.0–87.0 t ha^{-1}). These differences could be due to differences in soil conditions among the fields investigated in the two studies.

The contents of N, P and K in the topsoil were highest in the first-year rice field and gradually declined in the succeeding years (Table 1). Enrichment ratios were relatively low for N and P but high for K in the first-year rice field, and remained more or less the same for the three succeeding years for all three elements. The first-year rice field was the field in the first year of cropping

Table 1 Soil and nutrient losses by erosion, nutrient content of topsoil (0–3 cm) and enrichment ratio of each measured field

Field	Soil loss		Nutrient loss			Nutrient content of topsoil		
	Depth (cm)	Amount (t ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Rice, first year	0.24	26.43	90.95	4.64	838.94	1.850	0.010	0.333
Rice, second year	0.28	29.64	114.40	5.83	387.91	1.550	0.007	0.239
Cassava, first year	0.25	27.63	103.40	4.06	282.50	1.540	0.006	0.203
Cassava, second year	0.38	40.24	135.92	5.92	357.69	1.390	0.006	0.177
SE ^b	0.04	4.07	14.18	0.66	62.71	0.060	0.001	0.006

^aCalculated from data of Dung *et al.* (2002), assuming the same ER value for cassava fields in both years.

^bStandard error of the difference between two means; d.f. = 96 for soil and nutrient losses, d.f. = 8 for nutrient content of topsoil.

following the fallow stage, and fallow vegetation was just cleared and burned. Certainly, soil fertility of the field was expected to be higher than the fields in the succeeding years of cropping. Ash from fallow vegetation burning also resulted in a high enrichment ratio for K in the first cropping year.

The amount of nutrient losses by erosion in the individual years ranged from 90.95–135.92 kg ha⁻¹ for N, 4.06–5.92 kg ha⁻¹ for P and 282.50–838.94 kg ha⁻¹ for K (Table 1). N loss was slightly lower but K loss was much higher in the first year than those of the latter years. Apparently, most of the ash from fallow vegetation burning would have been washed away in the first year making K loss substantially higher. The amounts of nutrient losses by erosion in this study were comparable to those obtained from the study of Dung *et al.* (2002) conducted in a similar condition in which nutrient losses were estimated at 93 kg N ha⁻¹, 9 kg P ha⁻¹ and 718 kg K ha⁻¹.

Nutrients removed by harvesting

Yields of swidden rice decreased from 1075 kg ha⁻¹ in the first year to 932 kg ha⁻¹ in the second year, but the amount of rice straw removed was slightly higher in the second year (Table 2). In total, the amounts of nutrients removed by swidden rice were more or less the same in the two cropping years, being

10.53 kg N, 2.38 kg P, 5.36 kg K for the first-year and 9.87 kg N, 2.13 kg P, 5.02 kg K for the second-year. Most of the losses in N and P were through rice grain as the amounts of nutrients in the removed rice straw were negligible. However, potassium removed in the rice straw was about two-thirds of the potassium in the rice grain.

Cassava maintained more or less the same yield level (14–15 ton ha⁻¹) during the two cropping years. Amounts of nutrients removed were estimated at 65.5 kg N, 24.3 kg P, 234.0 kg K for the first-year and 71.6 kg N, 26.6 kg P and 255.6 kg K for the second-year. It can be seen that much larger quantities of nutrients were removed by cassava than by rice, and the amount of K lost through harvested cassava roots was quite substantial.

Aboveground biomass and nutrient loss due to burning

Generally, after harvesting a swidden field, crop residues remain in the field and continue to decompose. At the same time, nutrients are accumulated in natural vegetation, which is later slashed and burned. In this study, the amount of rice stubble remained in the field after harvesting was about 4 tons ha⁻¹ in both years, which contained about 24 kg N, 3 kg P and 79 kg K ha⁻¹ (Table 3).

Table 2 Amount of removed plant parts and their corresponding nutrient removals from rice and cassava swidden fields

Field/plant part	Amount removed ^a (kg ha ⁻¹)	Nutrient removed (kg ha ⁻¹) ^a		
		N	P	K
Rice, first year				
Grain	1046 ± 96.8	9.93 ± 0.92	2.30 ± 0.21	3.35 ± 0.31
Straw	107.3 ± 10.7	0.60 ± 0.06	0.08 ± 0.01	2.01 ± 0.20
Total	1153 ± 108	10.53 ± 0.98	2.38 ± 0.22	5.36 ± 0.51
Rice, second year				
Grain	932 ± 32.9	9.23 ± 0.33	2.05 ± 0.07	2.98 ± 0.11
Straw	114.5 ± 11.7	0.64 ± 0.07	0.08 ± 0.01	2.14 ± 0.22
Total	1046 ± 44.6	9.87 ± 0.38	2.13 ± 0.08	5.02 ± 0.31
Cassava, first year				
Root	14,040 ± 2260	65.5 ± 10.1	24.3 ± 0.38	234.0 ± 37.7
Cassava, second year				
Root	15,340 ± 1970	71.6 ± 9.3	26.6 ± 0.34	255.6 ± 32.9

^aMean of five replications ± standard deviation (d.f. = 4).

Table 3 Aboveground biomass and nutrient losses through burning in rice swidden fields

<i>Field/material</i>	<i>Dry weight^a (t ha⁻¹)</i>	<i>N^a (kg ha⁻¹)</i>	<i>P^a (kg ha⁻¹)</i>	<i>K^a (kg ha⁻¹)</i>
Rice, first year				
Rice stubble after harvest	4.48 ± 1.34	25.10 ± 6.31	3.14 ± 0.79	82.93 ± 20.9
Biomass before burning				
Rice straw	0.92 ± 0.16	5.70 ± 1.02	0.36 ± 0.06	8.79 ± 1.57
Weeds	1.89 ± 0.49	21.84 ± 4.54	7.79 ± 1.28	50.22 ± 9.54
Ash after burning	1.01 ± 0.02	2.81 ± 0.21	1.10 ± 0.02	31.53 ± 0.49
Loss through burning		24.73 ± 4.17	7.05 ± 1.29	27.48 ± 9.63
Rice, second year				
Rice stubble after harvest	4.03 ± 1.23	22.58 ± 6.20	2.82 ± 0.77	74.61 ± 20.5
Biomass before burning				
Rice straw	0.82 ± 0.44	5.08 ± 2.75	0.32 ± 0.17	7.83 ± 4.24
Weeds	0.83 ± 0.45	11.09 ± 3.05	4.47 ± 0.39	26.82 ± 5.14
Ash after burning	0.43 ± 0.01	0.45 ± 0.07	0.26 ± 0.01	18.83 ± 0.31
Loss through burning		15.72 ± 0.79	4.53 ± 0.25	15.82 ± 1.80

^aMeans of five replications ±SD (d.f. = 4).

Over the summer months, the rice stubble decomposed and less than one ton ha⁻¹ remained at the time of field burning. The amounts of nutrients contained in the remaining stubble were much less than the original amounts at harvest, indicating that most of the nutrients in the rice stubble were lost through decomposition. However, there were weeds growing in the field during the summer months. These weeds constituted half of the biomass in the field at the time of field burning, but contained much more nutrients than the remaining rice stubble component. The relatively high amounts of nutrients in these weeds compared to those in the rice stubble at harvest suggest that these weeds captured most of the nutrients in the stubble that were released through decomposition. Most of these nutrients, however, were lost when the field was burned for planting the next crop. As the amount of weeds was less in the second year, the amounts of nutrients captured were much less, as were the losses of nutrients from field burning (Table 3). Nutrient losses from field burning amounted to 24.73 kg N, 7.05 kg P and 27.48 kg K ha⁻¹ in the first-year rice field and 15.72 kg N, 4.53 kg P and 15.82 kg K ha⁻¹ in the second-year rice field. There was no loss from field burning in cassava fields, as field burning was not practiced in growing swidden cassava.

Nutrient balance analysis

All nutrient inputs, outputs, and balances of the individual years of cropping are summarised in Table 4. For all cropping years, rainfall and dust were the only major source of nutrient input, contributing 16.6 kg N, 1.6 kg P and 25.4 kg K ha⁻¹y⁻¹ to the nutrient inflow. The amounts of all these nutrients brought in by planting materials were very small. The most important nutrient outflow was soil erosion, contributing to substantial losses of all three nutrients. Losses through crop removal were considerable, particularly the removal of K by the cassava crop. Losses from field burning and leaching, though significant, constituted a small portion of the total nutrient outflow.

Substantial negative balances were shown for all three nutrients in all fields, indicating a continuous loss of these nutrients throughout the period of swidden cropping. During the first two years of rice cultivation, nutrient losses ranged from 116–137 kg ha⁻¹ for N, 12–13 kg ha⁻¹ for P and 400–864 kg ha⁻¹ for K. Losses of N and P were not much different in the two years, but K loss was much higher in the first year corresponding to the amount of K loss by erosion. For cassava cultivation, N losses (159–203 kg ha⁻¹) were slightly higher than those from rice cultivation, P losses (27–32 kg ha⁻¹) were more than double, and K losses (501–594 kg ha⁻¹) were quite substantial.

Table 4 Inputs, outputs and balances of N, P and K for the fields under different years of swidden cropping

	<i>Component</i>	<i>N (kg ha⁻¹)</i>	<i>P (kg ha⁻¹)</i>	<i>K (kg ha⁻¹)</i>
Rice, first year				
Input	Rain and dust	16.6	1.6	25.4
	Seed	1.0	0.1	0.3
	Total input	17.6	1.7	25.7
Output	Burning	24.7	7.1	27.5
	Harvested material	10.5	2.4	5.4
	Erosion	91.0	4.6	838.9
	Leaching	7.1	0.6	17.4
	Total output	133.3	14.7	889.2
Balance		-115.8	-13.0	-863.5
Rice, second year				
Input	Rain and dust	16.6	1.6	25.4
	Seed	1.0	0.1	0.3
	Total input	17.6	1.7	25.7
Output	Burning	15.7	4.5	15.8
	Harvested material	9.9	2.1	5.0
	Erosion	114.4	5.8	387.9
	Leaching	11.3	1.0	17.0
	Total output	151.3	13.4	387.9
Balance		-133.7	-12.0	-400.0
Cassava, first year				
Input	Rain and dust	16.6	1.6	25.4
	Planting stalk	4.1	0.5	6.1
	Total input	20.7	2.1	31.5
Output	Harvested material	65.5	24.3	234.0
	Erosion	103.4	4.1	282.5
	Leaching	10.6	0.9	15.7
	Total output	179.5	29.3	532.2
	Balance		-158.8	-27.0
Cassava, second year				
Input	Rain and dust	16.6	1.6	25.4
	Planting stalk	4.1	0.5	6.1
	Total input	20.7	2.1	31.5
Output	Harvested material	71.6	26.6	255.6
	Erosion	135.9	5.9	357.7
	Leaching	16.2	2.0	12.2
	Total output	223.7	34.5	625.5
	Balance		-203.0	-32.0
Total four-year balance		-611.2	-84.0	-2358.0

Both crop removal and soil erosion accounted for substantial losses of K from cassava fields. Summing over four cropping years, nutrient losses amounted to 611.2 kg ha⁻¹ for N,

84.0 kg ha⁻¹ for P and 2358 kg ha⁻¹ for K. Certainly, at the end of the cropping period, soil fertility of swidden fields would be greatly reduced.

Changes in soil nutrient status during cropping and fallow periods

Comparisons of soil nutrients at the beginning and at the end of the year in fields representing different years of cropping revealed that, total carbon declined sharply during the first two years of rice cropping, then tended to stabilize in the subsequent two years of cassava cropping (Figure 1). Total P showed a similar trend as

total C, but extractable P as well as total and mineral N and potassium of both forms declined continuously throughout the cropping period. Also fields representing different years of cropping were different fields, the declining trend of all nutrients across fields indicated a continuous decline of soil fertility in the successive years of swidden cropping. Results of soil analyses, thus, confirm the results of nutrient balance analyses.

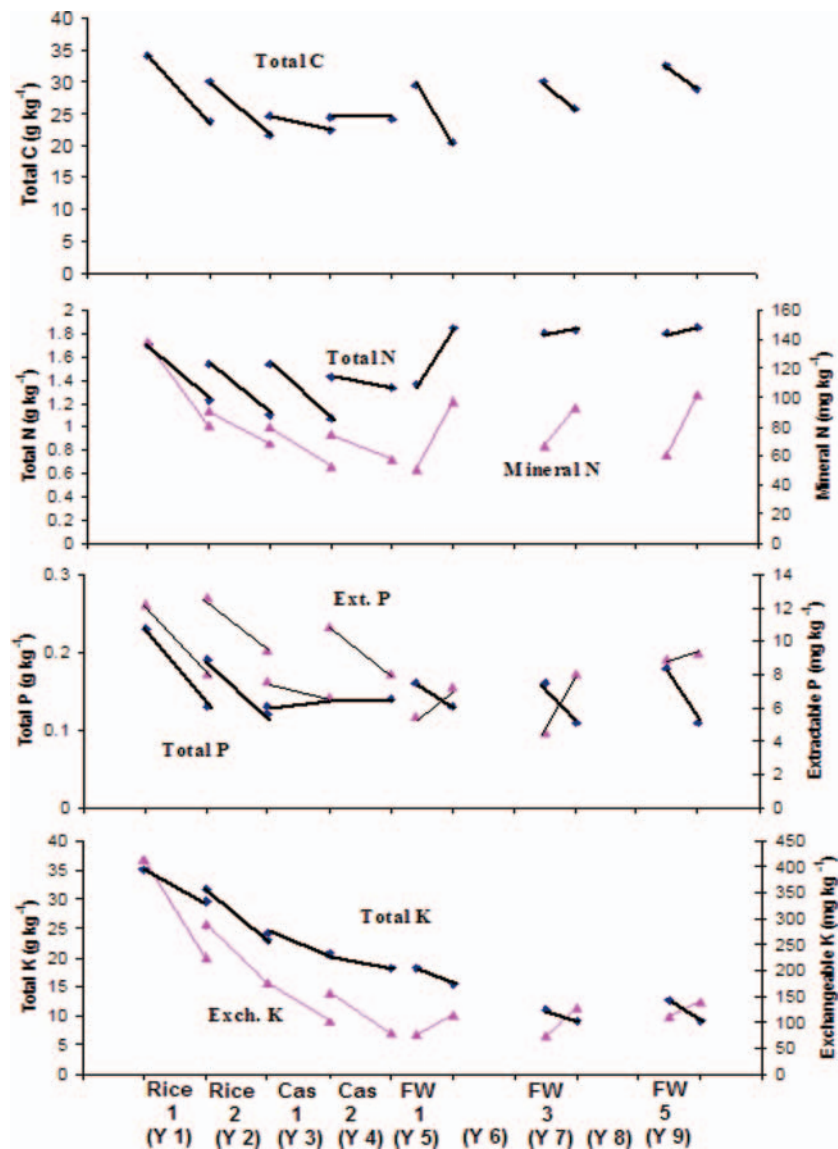


Figure 1 Changes in soil organic carbon, total and mineral N, total and extractable (Ext.) P, and total and exchangeable (Exch.) K during the cropping and fallow periods in the swidden cycle at Tat hamlet in Northern Vietnam. For each year of cropping, measurements were made at the beginning of the year before planting and at about the same time in the following year before planting the next crop, covering the entire year. For each year of fallow, measurements were made at the beginning (April) and at the end (October) of the rainy season, covering only six months. (Rice 1 and 2 = first- and second-year rice; Cas 1 and 2 = first- and second-year cassava; FW 1, 2 and 3 = first-, second-, and third-year fallow, respectively).

During the fallow period, total carbon was high at the beginning of each rainy season and sharply declined toward the season end. In contrast, both total and mineral N as well as extractable P and exchangeable K increased during the rainy season. Apparently, litter fall decomposed during the rainy season, releasing N of both forms and also extractable P and exchangeable K to the soil. The results also showed a continuous building up of C and N during the fallow period, however, both total P and K continued to decline in the successive years of fallow. The decline of these nutrient pools could be due to nutrient uptake by fallow vegetation as suggested by Tulaphitak *et al.* (1985). This is a nutrient conserving mechanism of the ecosystem as pointed out by Jordan (1985).

The sustainability of any system of rotational swiddening depends on soil fertility recovery during the fallow period (Nye & Greenland, 1960; Sanchez, 1976; Jordan, 1985). In this study, although there were some recovery of soil fertility during the fallow period, only total carbon and total N showed a full recovery to the initial status. The values of other nutrients at the end of the five-year fallow were much lower than the corresponding values at the beginning of the first cropping year. Although soil nutrients at the end of the five-year fallow were measured before while the initial values were measured after the fallow vegetation was cut and burned, the status of soil nutrients would not be much changed even after the fallow vegetation is cut and burned. This is because most carbon and nitrogen would be lost through burning, and much of the ash depositing on soil surface would be washed away by early rains. The remaining ash would add more P and K to the soil, but the amounts would be too small to reach the initial level at the beginning of the first cropping year.

These results, thus, indicated that five years of bush-tall grass fallow are not sufficient to fully restore the initial level of soil fertility at the beginning of the first cropping year. Zinke *et al.* (1978) reported that shifting cultivation fields in northern Thailand required at least eight to 10 years of fallow in order to maintain soil fertility. Several other studies (Kyuma *et al.*, 1985; Nye & Greenland, 1960; Tanaka *et al.*, 1997; Tulaphitak *et al.*, 1985) have also suggested this requirement of length for fallow period. The consequence of the shortening of the fallow period to five years will, thus, be a gradual decline of soil fertility in swidden fields in Tat hamlet.

Conclusions

Our results clearly showed that swidden fields are being continuously degraded in Tat hamlet. 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. Our data also showed that soil fertility was being restored during the fallow period. However, only five years of bush-tall grass fallow is not sufficient to restore soil fertility to its level at the beginning of the first cropping year. If the current practice is continued, the land will be highly degraded, making the composite swiddening unsustainable.

Under current circumstances, increasing the length of fallow period may not be possible. As soil erosion is the most important nutrient outflow during the cropping period, reducing it would slow down soil fertility depletion. Possible strategies to improve land-use sustainability would be to reduce soil erosion during the cropping period and to speed up the rate of soil fertility restoration during the fallow period. Minimum tillage, contour planting, mulching, terracing or strip cropping could be used to reduce soil erosion, but these have to be selected to fit the crops and socio-economic conditions of local farmers. Planting fast-growing leguminous trees during the fallow period has also been suggested as a means to speed up soil fertility restoration. Diversification and intensification of other components of the composite swiddening could also help reduce the pressure on swidden fields (Vien, 1998). However, in the long run, swiddening in the uplands may have to be changed to agroforestry or perennial woody trees or fruit trees to be able to achieve sustainability of land use.

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