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A Nutrient Balance Analysis of the Sustainability of a Composite Swiddening Agroecosystem in Vietnam's Northern Mountain Region

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Abstract

This paper reports some results of the first three years of an on-going research project on nutrient balances in a composite swidden agroecosystem. In a composite swiddening system, households simultaneously cultivate both swidden fields on hill slopes and paddy fields in the valleys. The study is being carried out in Ban Tat, a small settlement of Da Bac Tay ethnic minority people in Hoa Binh Province in Vietnam's Northern Mountain Region. Nutrient inputs and outputs for a swidden field on a hill slope and a wet rice field in the valley below it were recorded and nutrient balances for each subsystem calculated. The swidden had large negative balances for N, P, and K in all years of the experiment whereas in the paddy field only K was in serious deficit. Nutrients lost from the swidden field constituted a major source of inputs into the paddy field. This suggests that the sustainability of wet rice agriculture in the valleys is heavily dependent on interactions with the hill slopes.

At the level of the composite swidden system as a whole, nutrient inputs and outputs were not in balance. Outputs of N exceeded inputs by 159 kg/ha and outputs of K exceeded inputs by 867 kg/ha. Only P showed a positive balance with inputs exceeding outputs by 220 kg/ha. Comparison of the nutrient balances for the swidden and the wet rice field revealed that the negative imbalance of nutrient inputs to outputs was much greater in the swidden field than in the paddy field. Thus, if the farmers at Ban Tat relied exclusively on swiddens to meet their food requirements, their agricultural system would be much less sustainable than it is now. This confirms the main hypothesis of this research that it is the fact that most households simultaneously cultivate both wet rice fields and swiddens that explains the relatively high sustainability of the land use system in Ban Tat.

Keywords: swidden agriculture, nutrient balance, sustainability, Da Bac Tay ethnic group, upland farming system, input-output analysis

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I Introduction

The question of whether swidden agriculture (also called shifting cultivation or slash and burn farming) is a sustainable land use in the mountains of Vietnam continues to be a hotly debated issue. Some anthropologists have asserted that swiddening is a highly sustainable and productive system under traditional conditions of land use. Bui Minh Dao [2000], for example, claims that traditional rotational swiddening in the Central Highlands of Vietnam was highly productive, giving a higher yield per labor hour than wet rice farming, and was also sustainable as long as the ratio of cultivated land to fallow land did not exceed 1 : 10. Thus, when population densities in the mountains were low (<15 persons/km^2) and the need to use land to raise cash crops limited, swidden agriculture represented a very successful adaptation. Everywhere in Vietnam's uplands, however, populations have increased well beyond the carrying capacity of traditional shifting cultivation systems. This trend has been exacerbated by the rapid expansion of the area devoted to growing of cash crops and increasingly strict government regulations that limit farmers' access to remaining areas of forest. Consequently, upland farmers have had to intensify production on their shrinking area of swidden fields and shorten the fallow period to only a few years. This has led in many areas to a loss of forest cover, rapid land degradation and serious yield declines, especially in the Northern Mountain Region (NMR).

In some parts of the NMR, however, ethnic minority farmers employ a system of composite swiddening [Rambo 1998]. This system of land use appears to be more sustainable than pure shifting cultivation systems. Composite swiddening is a unique type of agroecosystem that integrates permanent wet rice fields in the valley bottoms, rotating swidden pilots on the hill slopes, and exploitation of wild resources of the forest into a single household resource system. This system is employed by the Da Bac Tay ethnic minority people of Ban Tat (Tat Hamlet) in Hoa Binh province in the Northwestern Mountains, the study site for the research reported in this paper.

This composite system is able to support higher population densities with less environmental degradation than can pure shifting cultivation. Although the Da Bac Tay people of Ban Tat have engaged in composite swiddening for at least a century, their community retains a high level of forest cover. Between 1954 and 1999, population density increased by more than 7 times, from 10 persons/km^2 to 75 persons/km^2, yet the area covered by forest or regenerating forest vegetation decreased by only 5 percent, from 92 percent to 84 percent of the landscape [Fox *et al*. 2000: 523–525].

Based on initial field research at Ban Tat, Rambo [1998] suggested that composite swiddening was a highly sustainable form of shifting cultivation that, if it could be further improved, could offer a model for use elsewhere in the NMR. In order to experimentally verify this hypothesis and begin developing ways to improve the productivity and sustainability of this system, Hanoi Agricultural University (HAU) initiated a long-term study of nutrient balances in swidden and paddy fields in Ban Tat. Analysis of nutrient balances was seen as offering an operationally feasible method for empirically measuring system sustainability.

The central hypothesis of our research is that *it is the fact that most households simultaneously cultivate both wet rice fields and swiddens that explains the high evident sustainability of composite swiddening in Ban Tat*. The wet rice fields yield approximately half of the grain produced by each household with the swiddens yielding the other half. Thus, the existence of the wet rice fields reduces the pressure to clear new areas of forest or shorten the fallow period of abandoned swidden plots that, in a pure swiddening system, would quickly lead to degradation of vegetation cover and soils. At the same time, crops such as canna and ginger raised in swiddens are sold for cash used to buy rice from the market, thus reducing the need for households to be self-sufficient in grain production. This further reduces the pressure to clear additional large areas of forest for rice cultivation and thus inhibits widespread land degradation.

That the farmers of Ban Tat manage the swidden and wet rice field subsystems in ways that maintain a positive soil nutrient balance in each subsystem is a second hypothesis of our research. 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. In the case of the swiddens, the question is much more complex and must be studied over the duration of the entire multi-year cycle of cultivation and fallowing. Our study is designed to measure nutrient balances of each of the two key subsystems over the full rotational cycle of cultivation. In the present paper only data collected during the first three years are analyzed so that no conclusions can be reached about the validity of this hypothesis.

The existence of strong positive functional linkages between the swiddens and wet rice field subsystems also appears to contribute to the sustainability of the land use system as a whole. Nutrients carried into the paddy fields by run-off water from the hill slope swiddens may increase yields in the wet rice fields and livestock grazed in the fallow swiddens provide manure that is used to increase yields in the paddy fields. Developing a better understanding of these functional linkages among key sub-systems in the composite swiddening agroecosystem is one of the key objectives of this research project. Our study is designed to assess the contribution that flows of nutrients between these subsystems make to maintaining nutrient balances in the system as a whole.

II Description of the Study Site

In order to collect nutrient flow data in a controlled fashion, an experimental site was established in Ban Tat which is a small hamlet in the mountain-valley realm of the Northwestern Mountains. A stream flows through the settlement which is sited in a narrow valley surrounded by steep mountain slopes. The experimental site is located in a small watershed with the area of 3.54 ha at east longitude: 105 degrees 11' 92'' and north latitude: 20 degrees 92' 82.''

The rainy season starts in May with more solid rain in July, August and September, after which the rainfall declines until the end of the rainy season in December. Rainfall recorded from May to December was 1,756 mm in 2000, 2,262 mm in 2001 and 2,045 mm in 2002. The maximum daily rainfall recorded was 210.8 mm on September 11 and 112.6 mm on July 22 in 2001 and 80.2 mm on October 23 in 2002. On 6 days each in 2001 and 2002 there was rainfall of more than 30 mm/hr. Such heavy rainfall is the main cause of soil erosion.

The experimental site has three components: The first part is secondary forest which covers 2.47 ha, the second part is swidden (0.76 ha), and the last is the paddy field in the valley at the base of the hill slope (0.21 ha). The average slope of the hill is from 29–36 degrees.

The pattern of land-use in the watershed is forest (bamboo and trees) on the top slope and beside the swidden, the swidden and fallow swiddens with regenerating forest in the middle slope, and paddy fields in the valley. In the swidden part, the cropping pattern was as follows: in the first year (2000), it was pure upland rice. In the second year (2001), there were three treatments (types) of land use: upland rice, cassava, and fallow. In the third year (2002), there were two types of land use: agroforestry (*Melia* intermixed with cassava) and fallow. In the wet rice field two rice crops were grown per year in the spring and winter seasons. Soils at the site were sandy and extremely acid. Total nitrogen, total phosphate and available potassium, CEC, and organic carbon were all very low. The physical and chemical properties of the soil in the swidden field prior to clearing the forest and in the paddy field are shown in Table 1.

Table 1 Physical and Chemical Properties of the Surface Soil

Unit	Upland Soils	Paddy Soils
Soil texture (%)		
Sand	47.50–58.20	51.20–62.70
Limon	24.50–33.00	18.00–27.90
Clay	12.10–24.40	9.40–30.80
Bulk density (gram/cm^3)	1.04–1.32	1.0–1.59
Particle density (gram/cm^3)	2.5–2.6	2.5–2.6
Acid soils: pH_{kcl}	3.61–4.03	3.73–4.42
Available of P_2O_5 (mg/100 g soils)	0.30–4.00	1.20–5.40
Available or active ion iron (mg/100 g soils)	5–42 (high)	25–100
Available N (mg/100 g soils)	7.0–8.0	4.0–5.0
Available K_2O (mg/100 g soils)	6.40–28.00	7.30–17.70
SiO_2/R_2O_3	< 2.0	< 2.0
C/N ratio	< 13.00	< 11.00
K_2O (%)	4.76–5.36	4.78–4.76
Nitrogen (%)	0.07–0.19	0.06–0.17
MgO and CaO	poor	poor
Organic matter (OC %)	0.26–1.91	0.47–1.88
CEC (less than 10 meq/100 g clay)	5.50–8.80	6.30–7.83 (low)
High in aluminum saturation (%)	22.30–33.70	7.33–13.91

III Conceptual Approach and Research Design

Analysis of soil nutrient balance is a method of assessing agroecosystem sustainability that has been widely used in Southeast Asia [Patanothai 1998]. Nutrient balance is assessed by using an input-output model [Patanothai 1996]. In order to assess the nutrient balance in the composite swiddening system, we need to measure all of the nutrient flows into and out of its swidden and paddy field components. The extent to which the soil nutrients in each subsystem are in balance is established by comparing the quantities of all the nutrient inputs into the system from external sources (e.g., nutrients carried in irrigation water flowing into the paddy field, nutrients contained in rice seed planted in the swidden) with the quantities of nutrients removed from the subsystem as outputs to other subsystems (e.g., soil eroded from the swidden to the paddy field, outflow of water from the paddy field). Only inputs from external sources and outputs from the subsystem to other subsystems are measured. Nutrients that are recycled within the system (e.g., nutrients contained in the plant biomass that are burned to clear the swidden and are retained in the form of ash; rice stubble in the paddy field that is plowed under to prepare the soil for the new crop) do not affect the balance.

Because the composite swidden agroecosystem of Ban Tat is very complex, our limited resources did not permit us to study the functioning of the total system. Instead, we have focused on its two most important subsystems from the standpoint of human subsistence requirements: the swidden subsystem on the hill-slopes and the paddy field subsystem in lower areas. These two sub-systems are functionally linked to each other by the flow of water that transfers nutrients from the swiddens on the hill slopes to wet rice fields in the valley. For each subsystem we formulated models incorporating all important inputs and outputs (Figs. 1 and 2). These models were used to design the plan for data collection at the field site in Ban Tat.

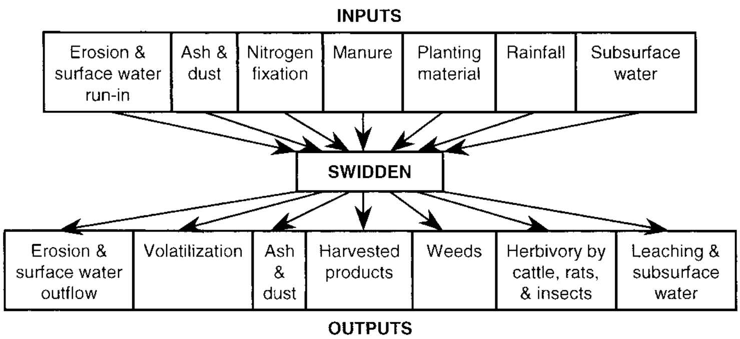

Fig. 1 Input-Output Model for the Swidden Field Subsystem

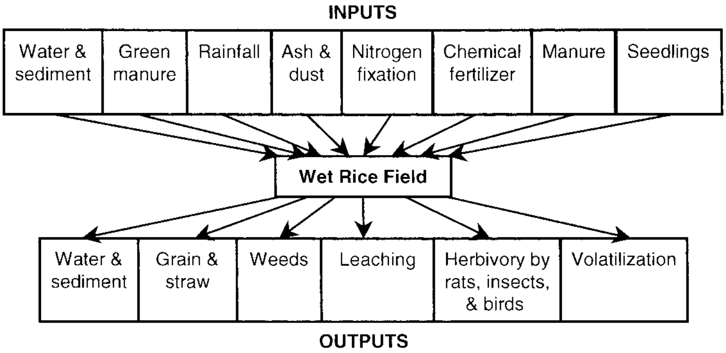

Fig. 2　Input-Output Model for the Wet Rice Field Subsystem

III–1 *The Swidden Field Subsystem*

The input-output model for the swidden subsystem is shown in Fig. 1. Key inputs and outputs in this model include:

a) Soil erosion: soil is eroded by heavy rains or strong winds. Winds blow soil in or out of the field and surface run-off from the rainfall carries soil and dissolved nutrients down the slope. In-flowing surface water from upland areas of forest also brings in soil and dissolved nutrients. In our case study, soil erosion is mostly caused by the rainfall; erosion is very small.

b) Subsurface water: it runs under the surface soil layer and it carries nutrients away with it from the swidden field.

c) Nutrient leaching: nutrients are leached downward through the soil layers and then flow laterally down the slope.

d) Rainfall: rainwater contains nutrients, especially nitrogen formed by lightening.

e) Organic materials: inputs such as seeds and other planting materials.

f) Nutrients carried by dust and ash: carried in by wind from the surrounding burning fields as well as lost through convection during burning.

g) Nutrients in fertilizer, green manure, and night soil: when transplanting or tending to crops, farmers may apply a variety of fertilizers.

h) Output of nutrients by harvesting plants: such as grains, roots, and other plant parts.

i) Weeds: they are an output when farmers pile them outside the edge of the field but are often recycled in the swidden fields.

j) Plant consumption by cattle, rats, and insects: herbivores may remove nutrients when they eat the plants but deposit their wastes outside of the field.

k) Nitrogen fixation by leguminous plants (usually weeds) and microorganisms.

l) Volatilization: the loss of nutrients into the atmosphere in gaseous form. This output is expected to be very small in the swidden field.

III–2 *The Wet Rice Field Subsystem*

The input-output model for the wet rice field subsystem is presented in Fig. 2. Nutrient inputs and outputs for the wet rice field subsystem include the following:

Inputs

a) Water and sediment that comes from the swidden fields through irrigation and flooding
b) Green manure brought into the field by farmers
c) Rainfall
d) Ash and dust brought in by the winds from the surrounding areas
e) Nitrogen fixation by plants in the field
f) Chemical fertilizers
g) Manure brought in by the farmers
h) Transplanted seedlings

Outputs

a) Water and sediment that flow out of the field in drainage and during flooding
b) Grain and straw taken out after harvesting
c) Weeds that are taken out at weeding time
d) Leaching of the soil
e) Herbivory by rats, insects, birds
f) Volatilization

IV Methodology

In order to measure nutrient flows in the research site, we set up 6 run-off plots in the swidden land and 3 run-off plots in the secondary forest for measuring nutrients lost through erosion on the second and the first part respectively. We set-up 8 waters samplers for calculating leaching of nutrients at 3 different depths on the first and second parts, and 6 sets of lysimeters and some weirs in and at the border of the paddy field for calculating changes in nutrients in the paddy field. An automatic rain gauge was set up to record rainfall and collect rainwater for nutrient measurement. Because the quantity of nutrients in the rain water was found to be small (10 kg/ha/yr), measurement was done only in the first year of the experiment.

Data on nutrient flows relating to crop management were collected by interviewing farmers about the quantities of inputs and outputs from their fields and collecting samples of plant materials for chemical analysis. Removal of nutrients by herbivores was estimated by comparison of the biomass of sample plots protected with wire mesh screening with unprotected plots in the field.

V Assessment of Nutrient Balances

Nutrient balances were calculated for the swidden in each of the first two years of cultivation, both for the rice treatment in years 1 and 2, and the cassava treatment in year 2. For the third year of the experiment, a nutrient balance was calculated for the entire hill slope area in the watershed including the fallow swidden, the third year cassava treatment, and the secondary forest on the upper slopes. For the wet rice field, nutrient balances were calculated for the first and second years of the experiment. Finally, the overall nutrient balance of the composite swidden system over a three-year period was calculated.

V–1 *Nutrient Balance of the Rice Swidden Field*

Data collected on the nutrient inputs and outputs of nitrogen, phosphorous and potassium for hill rice in the swidden field in 2000 and 2001 are presented in Table 2.

As Table 2 shows, the nutrients contained in seedlings and rainfall are the only major inputs into the subsystem. The farmers never apply fertilizer to the rice in the swidden field. Thus, nutrient inputs are very small, with N (around 11 kg) the most significant. The outputs are much larger with burning and erosion and leaching the major factors. Consequently, nutrient balance values for N, P, K in both years are all highly negative. The N deficit in 2000 was over 174 kg, primarily due to losses when the swidden was burned, and almost 123 kg in 2001, mostly because of erosion and leaching. The P balance was less unfavorable, with a deficit of 21 kg in 2000, with most loss caused by burning, and 16 kg in 2001, largely as a result of erosion and leaching. The deficit of K was 390 kg in 2000 and 725 kg in 2001, with erosion and leaching the main cause in both years.

V–2 *Nutrient Balance of the Cassava Swidden Field*

Data on inputs and outputs of nutrients to the part of the swidden plot with the cassava treatment in the second year of cultivation is presented in Table 3.

Table 2 Nutrient Balance for Rice Swidden (kg/ha)

Input	2000			2001		
	N	P	K	N	P	K
Seedlings	0.46	0.10	0.10	1.00	0.10	0.30
Rainfall	10.00	0.00	0.00	10.00	0.00	0.00
Total	10.46	0.10	0.10	11.00	0.10	0.30
Output						
Erosion, surface outflow, and leaching	31.91	3.75	298.37	88.40	9.18	718.01
Burning	130.08	13.38	76.90	24.87	6.24	2.46
Harvesting	9.87	4.13	11.68	7.00	0.90	1.90
Herbivory	2.60	0.22	2.66	2.60	0.22	2.66
Total	174.46	21.48	389.61	122.87	16.54	725.03
Overall balance	–164.00	–21.38	–389.51	–111.87	–16.44	–724.73

In comparison to the second year rice swidden, the cassava treatment, although having negative balances for all nutrients, suffered somewhat lower losses of N and K than did rice in the same year. One factor, although only a minor one, is that cassava was not eaten by herbivores. The most important causes of nutrient loss from the cassava were erosion, run-off and leaching. Removal of nutrients in the harvested tubers was a relatively minor output.

V–3 *Nutrient Balance of the Hill Slope Component*

In the third year (2002), input and output data were collected for the entire hill slope in the experimental watershed. Erosion and run-off water from the entire hill slope flow into the paddy field. Cassava was planted on 14 percent of the total area, natural fallow covered 8 percent, and secondary forest covered 74 percent. Inputs and outputs for all three land use types have been combined into a single balance of nutrients for the hill slope component of the watershed (Table 4).

Nutrient inputs and outputs for the hill slope were very low although there were negative balances for all nutrients. However, losses were from 5 to 10 times less than from the cultivated swidden in the first and second years. Most nutrient losses were the result of erosion, run-off and leaching from the relatively small area in the watershed under cultivation or in the early stages of fallow. Clearly, secondary forest is a superior land use in terms of preventing erosion losses of nutrients from sloping lands.

Table 3 Nutrient Balance for Cassava Treatment of the Swidden Field in the Second Year (2001)

(kg/ha)

Input	N	P	K
Planting material	4.10	0.50	6.10
Rainfall	10.00	0.00	0.00
Total	14.10	0.50	6.10
Output			
Erosion, surface water outflow, and leaching	72.69	9.19	613.09
Burning	24.87	6.24	2.46
Harvesting	17.30	2.20	25.50
Total	114.86	17.63	641.05
Overall balance	–100.76	–17.13	–634.95

Table 4 Nutrient Balance for the Hill Slope Land Component in the Third Year (2002)

(kg/ha)

Input	N	P	K
Crop management	0.006	0.002	0.002
Rainfall	10.000	0	0
Total	10.006	0.002	0.002
Output			
Harvesting	2.105	0.464	2.167
Erosion, run-off, leaching	27.889	1.854	81.560
Total	29.994	2.318	83.727
Overall balance	–20.204	–2.316	–87.725

V–4 *Nutrient Balance of the Wet Rice Field*

Table 5 presents input and output data for the experimental wet rice field for 2000 and 2001.

Nutrient inputs and outputs for the wet rice field were relatively close to being in balance. Nitrogen was in deficit by 13 kg/ha in 2000 but had a small positive balance (11 kg) in 2001. Values for phosphorous were positive for both years while potassium was in deficit in both 2002 and 2001. Nutrients brought into the subsystem by water flowing off of the hill slope make a major contribution to achieving balance for N and K.

V–5 *Overall Nutrient Balance for the Composite Swidden System*

By combining data on nutrient inputs and outputs for three years for the swidden and secondary forest on the hill slope and the wet rice field in the valley of our experimental watershed we were able to calculate the overall nutrient balance for the composite swiddening system (Table 6). Nutrient inputs occur through crop management (introduction of planting materials and application of fertilizer) and rainfall. Outputs occur through harvesting, loss to herbivores, and run-off of water out of the wet rice field. It should be remembered that in the case of our site, nutrient outputs from the hill slope in the form of erosion and leaching constitute inputs to the wet rice field so they are not included in the calculation as a loss or gain for the total system.

For the three-year period, the system shows an overall positive balance of phosphorous (220 kg/ha) but quite large deficiencies of nitrogen (159 kg/ha) and, especially, potassium (867 kg/ha). Most of the gains of P in the system come from excessive application of chemical fertilizer in the paddy field (Table 5). Losses of N and K occur mainly in the harvest and as the result of water flowing out of the wet rice field. Some of these nutrient losses become inputs into lower-lying paddy fields and some are lost into the river, especially at times when the wet rice fields overflow due to flooding caused by heavy rains. The deficiency of N could be made good through a relatively small increase in the rate of application of chemical fertilizer. It may be more difficult to compensate for loss of potassium. Farmers in Ban Tat do not currently apply chemical fertilizer containing K.

Table 5 Nutrient Balance of the Wet Rice Field (kg/ha)

Input	2000			2001		
	N	P	K	N	P	K
Seedlings	1.95	0.63	1.87	1.10	0.20	0.30
Rainfall	10.00	0.00	0.00	10.00	0.00	0.00
Organic fertilizer	9.90	7.42	71.78	0.00	0.00	0.00
Chemical fertilizer	38.30	65.56	0.00	115.00	98.00	0.00
Water inflow	97.33	9.68	337.98	227.23	25.23	379.90
Total	157.48	83.29	411.63	353.33	123.43	380.20
Output						
Harvesting	95.65	30.56	109.73	70.40	17.70	41.00
Herbivores	4.70	2.10	6.89	4.70	2.10	6.89
Water outflow	70.19	8.81	337.35	267.27	22.34	391.52
Total	170.54	41.47	453.97	342.37	42.14	439.41
Overall balance	–13.06	41.82	–42.34	10.96	81.29	–59.21

Table 6 Overall Nutrient Balance of the Composite Swidden System for 3 Years (kg/ha)

Input	N	P	K
Crop management (hill slope)	1.57	1.22	2.22
Crop management (wet rice field)	291.40	322.00	124.80
Rainfall	30.00	0	0
Total	322.97	323.22	127.02
Output			
Harvesting (hill slope)	27.84	3.72	39.74
Harvesting (wet rice field)	267.80	78.20	335.20
Outflow of wet rice field	186.73	21.39	618.60
Total	482.37	103.31	993.54
Overall balance	–159.40	+ 219.91	–866.52

VI Conclusion and Discussion

Nutrient balance analysis reveals that the composite swidden system as it is currently managed by the farmers in Ban Tat is not fully in balance. Nutrient losses from the swidden subsystem are much higher than inputs, largely as a result of burning and erosion and because the farmers do not apply any fertilizer to swidden fields. This might be taken to suggest that swiddening is unsustainable but, because swidden agriculture involves a multi-year cycle of cultivation and fallow, it will be necessary to collect nutrient input and output data for an entire cycle before it will be possible to calculate a final nutrient balance for this subsystem.

For the paddy field, K was in deficit but N and P were essentially in balance. This balance was achieved only because a large share of the nutrients lost from the swidden become inputs into the wet rice field. Nutrients from water flowing off the hill slope into the paddy field supplied more than 60 percent of the nitrogen inputs and more than 80 percent of potassium inputs to this subsystem in the first year of the experiment, and 64 percent and 100 percent in the second year. This finding suggests that assessment of the sustainability of the wet rice subsystem in composite swiddening must take account of interactions between the swiddens and the paddy fields within the watershed.

At the level of the composite swidden system as a whole, nutrient inputs and outputs are not in balance. Over the three-year period for which data have been analyzed, outputs of N exceeded inputs by 159 kg/ha and outputs of K exceeded inputs by 867 kg/ha. Only P shows a positive balance with inputs exceeding outputs by 103 kg/ha. Thus, under current management practices, the composite swidden system may not be sustainable in the long-term at least if current management practices remain unchanged.

Comparison of the nutrient balances for the swidden and the wet rice field reveals that the negative imbalance of nutrient inputs to outputs is much greater in the swidden field than in the paddy field. Thus, if the farmers at Ban Tat did not practice composite swiddening but instead relied exclusively on swiddens to meet their food requirements, their agriculture would be much less sustainable than it is now. This confirms the main hypothesis that it is the fact that most households simultaneously cultivate both wet rice fields and swiddens that explains the relatively high evident sustainability of the land use system in Ban Tat.

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