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Dynamics of soil and vegetation during crop and fallow period in slash-and-burn fields of northern Laos

W. Roder [a],* S. Phengchanh [b] S. Maniphone[b]

[a]International Rice Research Institute, P.O. Box 933, Manila 1099,Philippines

[b] LAO- IRRI Project, P.O. Box 600, Luang Prabang, Laos

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Abstract

Slash-and-bum rice production systems in northern Laos are undergoing dramatic changes. Increased population pressure and regulations limiting access to land have resulted in shorter fallow periods. Limited information is available on nutrient dynamics in slash-and-bum systems of Southeast Asia in general and particularly on effects of reduced fallow length. Crop and fallow effects on soil parameters and fallow vegetation were quantified in slash-and-bum fields in Luang Prabang, northern Laos from 1991 to 1994. Over the cropping season from May to October declines of 8, 7, and 3% organic C and 33, 40, and 53% extractable P. were observed for the depth. intervals of 0-3, 3-10 and 10-25 cm, respectively. Over the same period extractable K declined by 34% in the 0-3 cm interval and increased by 15 and 17% in the 3-10 and 10-25 cm intervals. The declining trend continued over the 3 year crop-fallow cycle with losses (depth 0-100 cm) of 29±7.6 t organic C ha^{-1}, 2.0 ± 1.1 t total N ha^{-1}, and 0.7+0.81 extractable K ha^{-1}. At the end of the fallow period the above ground biomass contained 100 kg N hat 5 kg P ha $^{-1}$, and 140 kg K ha^{-1}. The fallow vegetation was dominated by Chronzolaena odorata with a gradual succession towards tree and bamboo species. The nutrients in the above ground fallow vegetation represent only a small fraction of the N and C lost due to mineralization and leaching. With the present no-till system, mineralization losses are far more serious than losses due to soil erosion. Short fallows will result in a fast decline and low equilibrium of soil organic C levels, reducing the potential for rice yields and limiting farmers choice for other land use options which may become available with better market access.

Keywords: shifting cultivation; rice; soil fertility; C-loss

* Corresponding author. Present address: RNR-Research Center Bumthang, P.O. Jakar. Bhuran.

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1. Introduction

Slash-and-bum agriculture remains a dominant land use system in many parts of the tropics. Although systems vary, most slash-and-burn farmers depend on perennials to suppress weeds and recover soil fertility during the fallow period. Observers generally agree that slash-and-bum systems are sustainable with long fallows, but many caution that the systems will collapse due to insufficient restoration of soil fertility levels if fallows are reduced (Jordan, 1985; Sanchez and Logan, 1992; Warner, 1991). Accumulation of soil organic matter during the fallow period and ash deposits from the burned biomass are the main factors contributing to increased soil fertility at the end of the fallow period. The biomass of the fallow vegetation is generally a major pool for potassium. calcium and magnesium (Andriesse and Schelhaas, 1987; Jordan, 1985; Nye and Greenland,' 1960; Sanchez, 1987). However, most of the nitrogen and phosphorus, is located in the soil and the additions from the burned biomass are less important.

Mineralization of organic matter, occurring at high rates after the initial burning of die plant biornass, is an important source for N and other plant nutrients. Tulaphitak et al.(1985) estimated a loss of 13 t organic matter ha^{-1} ,in the first year after burning for slash-and-bum systems in northern Thailand. Similarly, organic matter losses of 10 ha^{-1}, during the cropping period after burning were reported from a study conducted in northern Laos (Roder et a)., I 995a). Organic matter and nutrient dynamics under shifting cultivation systems have been described for African, Asian, and South American conditions (Brubacher et at, 1989; Nakano, 1978; Nye and Greenland, 1960; Nye and Greenland, 1964; Sanchez Ct al., 1983; Tulaphitak et al., 1985; Van Reuler and Janssen, 1993a; Zinke et al., 1970) yet, quantitative data for nutrient pools are limited to information obtained by measurements taken at one point in time, and few investigations have quantified nutrient dynamics over an entire cropping and fallow cycle. Furthermore, several authors have emphasized a lack of soil fertility data relating to slash-and-burn agriculture in the hilly regions of Southeast Asia (Nalcano, 1978; Sanchez, 1976).

Slash-and-burn agriculture with upland rice as the major crop is the predominant land use system in the hilly areas of northern Laos. Over the last 20 years. average fallow periods have been reduced drastically (Roder et at, 1994). Although farmers consider labor requirements for weeding as a far more important constraint to upland rice production than soil fertility, there is a growing concern about the environmental as well as agronomic effect of reduced fallow length and there is an urgent need to quantify trends in soil fertility and weeds under the reduced fallow periods Soil nutrients and fallow vegetation were, therefore, measured in 4 slash-and-burn fields in 1991 to 1994 to document dynamics of soil fertility parameters and fallow vegetation during the cropping and the fallow cycle and to quantify major nutrient pools. The findings from this study are expected to (1) substantiate statements associating soil fertility trends with fallow period, (2) provide base line data to quantify future fertility trends, and (3) help optimize future use of land resources in the hills of Laos.

2. Materials and methods

2.1. General description of area, firming system, and monitoring sites

The studies were carried out in the Xiengnguen District in the Province of Luang Prabang in northern Laos (190N). Approximately 25% of the total upland rice area of the country is in this province. Upland rice is generally cultivated on sloping land using slash-and-bum methods without tillage and without inputs of fertilizers. Slopes can range from 0 to over 100%, but over 70% of the upland cultivation is limited to slopes in the class O~-30% (World Bank, 1995> Rice is planted in hills with the help of a dibble stick A single crop of rice is followed by fallow periods of 2-10 years.

The climate is dominated by the monsoon with a dry period from October to April and moderate to high rainfall from May to September. The average rainfall for Luang Prabang town was 1340 mm for 1961-90 and ranged from 1064 to 1406 mm in 1991-94. Sandstone, limestone, and clastic rocks of Mesozoic and Paleozoic origin are the dominant geological formations in the region (ESCAP. 1990). Other important geological formations include granite and volcanic rocks. Upland soils were classified as Orthic Acrisols (FAO/UNESCO, 1974) and are generally reddish brown and moderately acidic.

Four monitoring areas (SI -S4) of 20 X 20 m were selected and delineated in April 1991 after farmers had burned the dry, above ground biomass (Table 1). Sites 1 and 2 were located close to Ban Lorig-O and sites 3 and 4 close to Ban Phonthong. The 2 villages are about 25 km apart. Sites selected had soils representative of the region, were uniform in slope, had undergone several fallow/crop cycles, and were free of large termite mounds or large root wads. The fallow periods prior to the burning ranged from 6 to 8 years. All plots were located inside existing fields and farmers followed the same practices in the monitored plots as in the surrounding field. Rice was planted in May 1991 at densities of 8-12 hills m2 Weeding was done manually 3 times during the season. After the rice harvest in November 1991, fields were left fallow for 2 or more years The cultivators of site S1 and S2 decided to plant rice again after 2 years of fallow. The average fallow length in the district observed in a 1991 survey was 4 years (Roder et al., 1994).

Table 1
Description of slash-and-bum fields used in the study [a]

	S1	S2	S3	S4
Elevation Un)	460	450	540	520
Slope (%)	35	45	28	45
Soil type [b]	Dystric Cainbisol	Dystric Cambisol	Ferric Alisol	Ferric Alisol
Years falIow	6	6	8	8

[a] Sites were located in the Xiengrguen District. Luang Prabang Province, Laos (Si and 52 near Ran Long-O. S3 and S4 near Ban Phonthong).
[b] Soil Sorvey and Soil Classification Laboratory Dongdok. Department of Agriculture and Extension. Vientiane.

Short range variation at SI and a second location (not included in the monitoring study) was quantified in 1991 using an Oakfield core sampler (20 mm diameter) and 20 individual samples per plot (Roder et al., 1995bY Coefficients of variation for the top interval (0-3 cm) averaged over 2 sites were 10.4% for p1-I, 8.7% for total N, 20.7% for organic C, 12t% for total P. 75.8% for extractable P, and 44.8% for extractable K. Variation generally decreased with increasing depth of soil, except for soil organic C. Following this preliminary study the number of subsamples required to estimate changes of 10% at a confidence level of 95% was less than 15 for all variables measured, except for extractable P and K.

22. Soil sampling

Twenty subsamples per plot were collected in a grid pattern using an Oakfield core sampler (20 mm diameter). Sampling depths were 0-3, 3-10, 10-25, 25-50, 50-75, and 75-100 cm. Sampling was done in May 1991, 1992, 1993, and 1994 (S1 and S2 before burning). Additional samples from the 3 top intervals were collected from all sites after rice harvest in 1991 and from plots S1 and S2 after slashing (March), burning (May), and rice planting (May) in 1994. Soil bulk density was measured in 1994 taking 5 subsamples per site with the Oakfield core sampler.

2.3. Soil loss

Attempts were made to measure soil loss by placing 20 steel pins (80 cm) in each site before the onset of the rainy season in 1991. Due to moderate erosion, no height differences could be observed at the end of the 1991 cropping season. The method was presumed unsuitable and no further measurements were made.

2.4. Processing of soil samples and chemical analysis

Samples were air-dried and sent to the laboratory of the Lands Development Department in Bangkok for analysis of pH, organic C (Walkiey-Riack acid dichromate digestion), total N (semimicro Kjeldahl), extractable P (Bray 2), extractable K (extraction with I N NH_4OAc), Al (KCl extraction), and CEC (extraction with I NH_4OAc at pH 7, DLD, 1992; Page et al., 1982).

2.5 Plant sampling

Above ground biomass was measured at the time of rice harvest in October/November 1991 and after 1 and 2 years of fallow in December 1992 and 1993. In 1991, all plant biomass was harvested from 10 randomly placed I x I m frames- In 1992 and 1993, plant dry matter was estimated by cutting and weighing the above ground biomass from a representative area of 9 m2 adjacent to the monitoring plot. Plant material was measured separately for the most important species Dry matter was calculated based on a moisture content of 12% for the air-dried subsamples. Litter fall was measured during the second year of fallow (1993). Four wooden boxes of 0.25 X 0.25 m, with a bottom of 2 mm wire mesh screen were placed randomly in each plot and the material accumulated was removed at monthly intervals.

Plant samples for the major species from the 1991 and 1992 plant measurements (one combined sample for all the sites) were analyzed for N, K, F, and Ca content by the Soil Survey and Soil Classification Laboratory (SLC) Dongdok, Department of Agriculture and Extension (Vientiane, Laos). Nitrogen, K, P, and Ca content of different plant pans analyzed were reported earlier (Roder et al., 1995c). Litter samples were analyzed separately for each month and each site,

2.6. Presentation of results

Except for an overall budget of organic C, N, extractable F, and extractable K, all soil data are discussed relative to soil mass. Soil bulk density was measured in 1994 only. Various studies have shown that bulk density changes during the course of the fallow and cropping period but these changes are generally small (Brown and Lugo, 1990; Nye and Greenland, 1964). hi a study by Nye and Greenland (1964) with forest cover as original vegetation, burning and 2 years of cropping resulted in less than 2% change in bulk density in the top 25 cm soil interval. Authors were aware of the impact of bulk density changes on the original sample depth, but given the soil type, the relative short fallow period, and the absence of tillage, the changes are not expected to affect the results significantly.

Most studies monitoring soil or vegetation dynamics in slash and burn systems are limited to one site (Andriesse and Schelhaas, 1987; Seubert et al., 1977; Tulaphitak et at, 1985). Because of extreme variation, the results from studies encompassing more than one site are usually discussed separately for individual sites (Sanchez et at, 1983; Van Reuler and Jaussen, I 993a). In our discussion we present average data for the four sites, along with a measurement of variation. While this way of presentation does not obscure any of the trends, changes observed (even if consistent across sites) are often not significant because of the high variations between sites.

3. Results and discussion

3.1. Soil observations

Our observations documenting an initial increase after burning and subsequent decrease for most soil nutrient status parameters are consistent with those reported by others (Nye and Greenland, 1964; Sanchez et al., 1983; Seubert et al., 1977; Tulaphitak et al., 1985). Due to the previous depletion of soil organic C because of repeated cycles of short fallows and the limited quantities of above ground biomass present at the time of burning, the magnitude of the changes are comparatively small in our study (Table 2, Figs. 1-3). The effects of biomass burning on soil pH, and extractable nutrients are, to a large extent, the result of ash deposits (Van Reuler and Janssen, 1993b) and therefore depended on the available biomass quantity and its composition. Biomass quantities in our studies (not measured) were estimated at <25 t ha^{-1}, compared with 30-80

Table 2
Average values for soil parameters measured in four slash-and-bum fields in northern Laos after burning (A) and at the time of rice harvest (B) 1991

Parameter	Soil depth 0-3cm			Soil depth 3-10 cm			Soil depth 10-25 cm		
	Aa	B	T-test [b]	A	B	F-test	A	B	F-test
pH	5.5	5.3	023	4.7	48	0.32	4.5	4.6	0.08
Al (meq 100 g^{-1})	0.3	0.5	036	2.9	2.4	0.02	4.2	3.5	<0.01
Organic C (%)	3.3	3.0	0.20	2.3	2.1	0.20	1.6	1.5	0.66
Extractable P (mg kg^{-1}) [C]	24	16	0.06	7.9	4.7	0.09	4.3	2.0	<0.01
Extractable K bug kg^{-1})	347	229	0.06	127	146	0.09	83	97	0.22
CEC (meq 100 g^{-1})	15	16	0.29	13	13	0.22	11	12	<0.01
Exch. Mg(meq 100 g^{-1})	3.0	2.4	0.06	1.1	1.2	0.50	0-6	0.7	039
Exch.Ca(meq 100g^{-1})	3.8	4.5	0.33	11	3.0	<0.01	0-7	2A	<0.01

[a] A = sample taken after burning (May). B = sample taken at the rime of rice harvest (November).
[b] Probability level of T-test.
[c] Bray Z

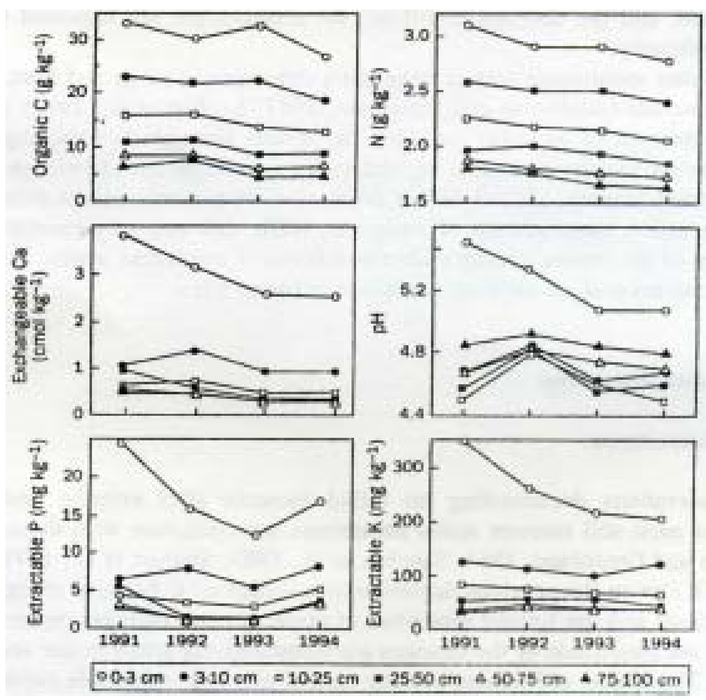

Fig 1. Average trends in selected nutrient status parameters during the cropping (1991) and fallow period (1992-94) for the depth intervals of 0-3, 3-10, 10-25. 25-50. 50-75 and 75-100 cm observed in 4 slash-and-burn fields in northern Laos (ANOVA summary in Table 3).

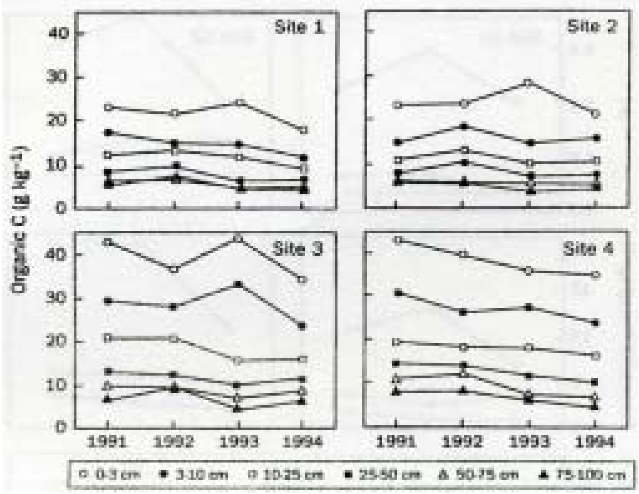

Fig. 1 Trends in organic C during the cropping (1991) and fallow period (1992-94) for the depth intervals of 0-3, 3-lO. 10-25. 25-50, 50-75 and 75-100 cm observed in 4 slash-and-bum fields (sites 1-4) in northern Laos (ANOVA summary in Table 3)

reported by Andriesse and Schelhaas (1987), 160-180 by Greenland and Kowal (1960), and 194 t h^{-1} by Kyuma et al. (1985). Because of ash deposit and the effect of heat, the most dramatic changes in the upper soil layers occur at the time of burning and the period immediately after burning (Sanchez et al., 1983; Seubert et al., 1977; Tulaphitak et al, 1985). In our study, this effect was observed at the end of the monitoring period when two sites were changed to rice after a fallow period of 2 years.

3.1.1. Cropping period (1991)

From the time of planting in May to rice harvest in October, organic C and extractable P decreased in all 3 depths monitored, although high variation precluded significance for organic C (Table 2). Extractable K decreased by 34% in the top interval (0-3 cm) and ‘increased by 15% and 17% in the 3-10 and 10-25 cm soil intervals. Similarly, the downward movement of elements released from above ground biomass burning resulted in an increase of pH. CEC, and exchangeable Ca in the 10-25 cm depth interval. The rainfall from May to September was 947 mm and leaching is likely to occur.

3.1.2. Fallow period (1991-1994)

The most important observation is the continuous downward trend over the entire cropping and fallow period in the soil N and organic C contents (Figs. 1 and 2, Table 3) with substantial losses of C and N to the atmosphere. On average, losses over the period or 3 years represented 20% of the total soil organic C and 8% of the nitrogen content in the 1 m profile (Table 4). While the loss in the initial year occurred largely in the top soil layer, it was more significant at lower layers in the following years. Sites 3 and 4 had a substantially higher level of organic C but the trends were similar for all sites (Fig.

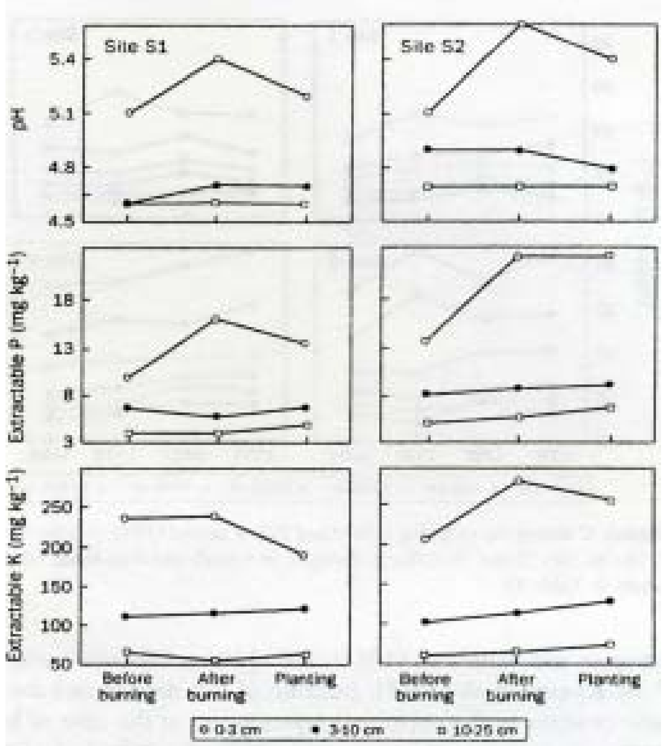

Fig. 3. Changes in pH, extractable P and extractable K observed at two slash-and-born fields (sites 1 and 2) in northern Laos from samples collected before burning (March), after burning (April) and at the time of rice planting (May).

2) with total C losses over the 25 t ha^{-1} for site 1, 13 for site 2, 26 for site 3, and 49 for site 4.

Zinke et al.(1970) and Nakano (1978) have shown that total N and C in slash-and-bum systems in northern Thailand reached their lowest levels in the middle of the fallow period of 4-5 years. Tulaphitak et al. (1985) reported organic matter loses, of' 8.8% annually and estimated that 240 kg N, 20 kg P, and 80 kg K would be released during the first year after burning due to the mineralization of soil organic matter. Estimates of P, K, Mg, and Ca are probably influenced by organic matter mineralization. Cations released through mineralization may reduce or magnify changes expected due to leaching. Soil pH and extractable bases showed a fast decline in the topmost soil layer in the first year after burning, with a simultaneous increase in the lower soil. layers. Extractable P and K increased towards the end of the fallow period. But even when accounting for the K stored in the vegetation, the overall balance for K is still negative (Tables 4 and'6).

Many observations on soil changes under slash-and-bum agriculture were limited to measurements in the upper 0-15 or 0-30 cm top layer, (Nye and Greenland. 1964; Sanchez et a!., 1983; Tulaphitak et al., 1985). Brown and Lugo (1990) have shown that

Table 3
Summary cable for ANOVA of soil parameters (mean values arc shown in Fig. 2) observed in four slash-and-bum fields in northern Laos during 1991-94

	pH	Exchangeable Ca	Total N	Organic C	Extractable P	Extractable K
0-3 *cm*						
PR> F [a]	0.02	0.08	NS	0.02	0.10	0.09
Contrast [b]	(1) <0.01	(1) 0.02	-	(3) 0.04	(2) 0.06	(1) 0.02
CV (%)	14	22.7	7.9	78	310	28.5
.3-10 *cm*						
PR>F	0.07	NS	NS	010	NS	NS
Contrast	(3) 0.02	-	-	(1)0.04	-	-
CV (%)	23	32.3	6.1	10.9	24.3	16.0
10-25 *cm*						
PR> F	0.01	NS	NS	0.01	<aci	NS
Contrast	(3) 0.04	-	-	(1) <001	(2) <0,01	-
CV (%)	2.4	35.7	64	8.4	20.5	25.6
25-50 *cm*						
PR>F	0.02	0.05	0.10	<0.01	0:10	003
Contrast	(3) <0.01	(1) 0.02	(1) 0.05	(3) 0.01	(2) 0.03	(2) <0.01
CV (%)	23	32.8	3.9	9.3	833	11.6
50-75 *cm*						
PR>F	NS	NS	0.04	<0.01	<0.01	0.01
Contrast	-	-	(1) <0.01	(3)<0.02	(2)<0.01	(3) 0.04
CV (90	2.8	41.0	3.6	12.9	36.3	10.0
75-100*cm*						
PR> F	NS	NS	0.08	<0.01	<0.01	0.03
Contrast	-	-.	(1) 0.02	(3) <0,01	(2) <0.01	(2) 0.02
CV (90	2.0	36.5	5.6	14.3	20.8	7.5

[a] PR > F for change of parameter over time.
[b] Orthogonal contrasts, only PR> F value given for the highest order still significant: numbers indicate (1) linear, (2) quadratic, and (3) cubic

Table 4
Average organic C, nitrogen. P and K changes from the lime of planting (May 1991) to the end of the fallow period (May 1994) observed in four slash-and-burn fields in northern Laos

Depth	Organic C		Nitrogen		Extractable P		Extractable K	
	(t ha-1)	(%)	(t ha-1)	(%)	(kg ha-1)	(%)	(kg ha-1)	(%)
0-25 cm	9+2.6 a	18	0.57±0.44	9	04±16	0.2	606±628	20
25-50cm	7±2.3	18	0.31 ±0.21	5	5.9±7.6	3.3	290± 192	17
50-75cm	7±2.2	24	048±0.14	8	(+)b0.5±2.3	(+)0.4	(4)50±53	(+)4
75-100cm	6-4-23	26	0.59±0.27	9	(4)3.0±1.3	(+)3.3	(+)165±102	(+)14
Total (0-100 cm)	29±74	20	1.96±1.1	8	2.8±13.7	0.5	681±766	9.4

a Mean ± standard error.
b Accumulation of element.

Table 5
Average above ground biomass in four slash-and-burn fields in northern Laos during the rice crop (1991) and cwn subsequent years of fallow (1992-93)

Species	Plant biomass (t ha^{-1})		
	1991	1992	1993
Chronwloena odorala	0.23 ± 0.07[a]	4.8 ± 0.7	4.5 ± 1.4
Lygodiurn flexuoswn	0.14 ± 0.03	0.6 ± 0.4	0.1 ± 0.05
Orhcrbroad leaf species	0.17±0.03	0.5±0,3	1.3t0.9
Grasses	0,03±0,02	0.1 ±0.1	0.2±0.1
Bamboo	0.24±0,15	2.1± 1.7	4.0±2.0
Tree species	0.51 ±0.11	1.5±0.9	5.3±1.4
Total [C]	1-4±0-13	9.8±1.1	15.5±1.9

[a] Mean ± standard error.
[b] Not available.
[c] Rice grain harvested, and rice stem in 1991 was 1.1 and 1.2 t/ha.

changes in soil C and N occurred throughout the profile. While N and organic matter losses at depths below 30 cm may have limited agronomic significance they are important for the overall C and N cycle, especially the C contribution to the atmosphere.

3.1.3. Effect of burning (1994)

At two sites the vegetation was slashed and burned in early 1994 and rice was planted in May. Soil samples taken before and after burning did show the distinct burning effects manifested by an initial increase and subsequent drop for pH and extractable bases as shown by others (Fig. 3). The magnitude was, however, small when compared to other studies (Nye and Greenland, 1964, Sanchez et al, 1983; Tulaphitak et al., 1985) and no response to burning was observed for N and organic C content. This poor response is largely due to the short fallow and low biomass quantities as discussed above.

3.2. Plant observations

The average above ground biomass at four monitoring sites was 1.4 t ha $^{-1}$ at rice harvest in 1991 and increased to 9.8 t ha>' at the end of 1992 (1 year fallow) and 15.5 t ha $^{-1}$, in 1993. At rice harvest, tree and bamboo species contributed 61% to the total biomass (Table 5). Their development is, however, too slow to fill the gap left after the rice harvest, and after the first year of fallow, tree and bamboo species contributed only 37% of the biomass. *Chromolaena odorara*, the most important weed and fallow species contributed 16% to the total above ground biomass in 1991, 49 in 4992, and 29 in 1993. With progressing fallow period, bamboo and tree species gradually replace *C. odorata* (Roder et al., 1995c). *Chromolaena odorata* introduced in the 1950s has become the most important weed and fallow species in most slash-and-bum areas of the country. The contribution of grass species to the weed and fallow biomass is generally small, and

Table 6
Average N, P. K, and Ca stored in the above ground vegetation [a] observed in four slash-and-burn fields in northern Laos during the rice crop (1991) and two subsequent years of fallow (1992-93)

	C. odorata	Others	Bamboo	Tree	Rice straw	Total
N (kg ha^{-1})						
1991	0.9	1.5	1.0	2.2	3.5	92
1992	32.6	5.5	12.6	9.8		60.5
1993	30.1	7.9	24,0	34.5		97.0
P(kg ha^{-1})						
1991	04	0.4	0.2	0.8	1.0	2.7
1992	2.4	0.8	0.4	0.3		3.9
1993	2.3	0.6	0.8	1.1		4.6
K (kg ha^{-1})						
1991	0.6	0.7	1.0	0.6	2.5	5.4
1992	52.8	4.7	27.1	7.7		92.2
1993	49.5	9.2	51.6	27.0		137
Ca (kg ha^{-1})						
1991	1.1	1.8	0.7	5.9	4.0	13.5
1992	14.4	41	2.9	5.4		26.9
1993	13.5	4.9	5.6	19.1		43.1

[a] Calculated based on N, P. K, and Ca conrern of average plant samples from 1991 and 1992 measurements. Content for 1992 measurements, reported for individual plant parts by Roder et al. (1995c) were used to calculate 1993 quantities.

in contrast with some other slash-and-bum systems in Asia, *Imperata cylindrica.* although present, is rarely dominant.

The nutrient quantities stored in the above ground biomass were modest for P. but substantial for K (Table 6). Upon burning, most of the P, K, and Ca present in the plant biomass are expected to become available for the crops. In addition to the nutrients present in he above ground biomass, there is a gradual accumulation in the topsoil through litter fall. The total litter quantity produced during the second year of fallow was 1.2 t ha^{-1}, with peak of litter fall occurring towards the end of the dry season, when *Chromolaena odorata* sheds its leaves (Table 7, Fig. 4). The amounts of plant nutrients

Table 7
Average biomass and N, P, and K content of litter collected in four slash-and-bum fields in northern Laos during the second year of fallow (1993)

Parameter	
Dry matter(t ha^{-1})	1.2±0.07[a]
N(kg ha^{-1})	16±1.9
P (kg $^{-1}$)	1.6±0.1
K(kg $^{-1}$)	5.0±0.3

[a] Mean ± standard error.

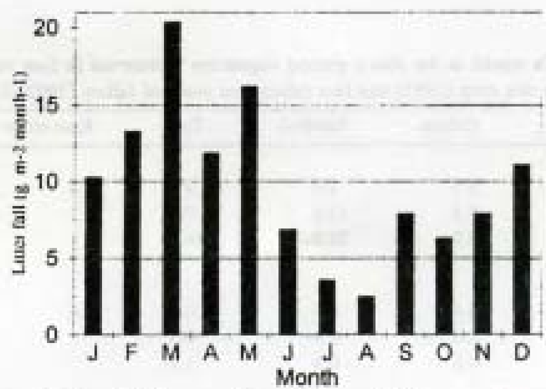

Fig. 4. Average monthly litter fall (means of 4 sites) observed in the second year of fallow (1993).

added through the litter are modest and the N and K quantities of litter and above ground biomass combined are much lower compared to those lost from the soil.

4. Summary and conclusions

The sail pools of organic C and total N were reduced substantially during the cropping and the short fallow period- Only a small proportion of the over 28 t of organic C and 2 t of N losses can be attributed to erosion. Soil loss during the cropping period was too low to be measured by the pin method. In a separate study, carried out under similar conditions, soil loss over the cropping period ranged from 0.3 to 30 t ha^{-1} accounting for about 10% of the N and C losses (Roder et al., 1995a).

The fallow period of 2 years was too short to reverse the downward trend and soil organic C and N levels are expected. to decrease further with subsequent cropping-fallow cycles until an equilibrium has been reached. Similarly, the fallow periods of 10-15 years reported during the 1950s were not sufficient to restore soil organic C to levels present before burning. The C pools present at the beginning of the study were therefore undoubtedly very different when compared to the soil under natural. vegetation. Brown - and Lugo (1990) suggested that the time for recovery of soil C during succession would be about 40—50 years. The amount of C, N, and K present in the above ground plant biomass represent only about 20, 5, and 20% of the quantities lost from the soil pool during the short fallow period. Any discussion on the contribution of slash-and-bum agriculture towards the atmospheric C needs .to include the C-dynamics of the soil pool. The C released from the soil through mineralization after burning is generally higher than the C released from the burning of the above ground biomass.

The reduction in fallow period has substantially increased the labor requirement for weeding and farmers generally attribute more importance to effects of fallow on weeds than upon soil fertility (Roder et al., 1995a). in recent studies, soil organic matter has shown only a weak or no association with rice yield, while fallow length has no effect at all. The absence of a measurable correlation between yield decline and changes in soil fertility parameters in slash-and-bum fields has been reported by Sanchez (1976) and Nakano (1978). They suggested that too much emphasis should not be placed on the recovery of fertility in the fallow period. The importance of organic C for the maintenance of soil physical, chemical, and biological properties is, however, well established and a decline below a critical limit will lead to yield declines. Studies with additional N-fertilizer inputs have already demonstrated substantial yield increases, indicating that the mineralization of soil organic matter is insufficient to provide the N requirements of the rice crop. Furthermore, the tremendous reduction in soil organic C levels will strongly limit the farmers' choice for other land use options which may become available with better access to markets.

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