Journal of Environmental Sciences Vol.16, No.2, pp.256—261, 2004

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2004)02-0256-06 **CLC number**: X14; X13 **Document code**: A

Long-term impacts of land-use change on dynamics of tropical soil carbon and nitrogen pools

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Abstract: Land-use changes, especially the conversion of native forest vegetation to cropland and plantations in tropical region, can alter soil C and N pools and N availability for plant uptake. Deforestation, followed by shifting cultivation and establishment of rubber tree plantation, is a common land-use change in Xishuangbanna, southwest China. However the influence of this kind of land-use change on soil C and N dynamics in this region remains poorly understood. This study was conducted to assess the effects of land-use change on soil C and N pools. Soil samples were collected on five adjacent plots, which belong to three land-use types including secondary forest-an acuminate banana(*Musa itinerans*) secondary forest and a male bamboo(*Dendrocalamus membranaceae*) secondary forest, shifting cultivation, and rubber tree (*Hevea brasiliensis* (H.B.K.) *Muell. Arg.*) plantation(one plot is 3-year-old, and another is 7-year-old). We measured soil bulk density (BD), pH value, moisture content and concentrations of soil organic carbon(SOC), total soil nitrogen(TSN), and inorganic N(NO_3^--N and NH_4^+-N) at 0—3, 3—20, 20—40 and 40—60 cm depths, and calculated C and N pools in 0—20, 20—40, 40—60, and 0—60 cm soil layers. Compared with the adjacent secondary forests, shifting cultivation and establishment of rubber tree plantations resulted in significant decline in concentrations and stocks of SOC and TSN in 0—20 and 0—60 cm soil layers, and increase in pH and bulk density at 0—3, 3—20, and 20—40 cm depths. Soil moisture content decreased only in 0—20 cm surface soils in shifting cultivation and plantations. The dynamics of mineral N was much more complex, which had different trends among depths and ecosystems. Compared with the secondary forests, SOC stocks in 0—20 cm surface soils in shifting cultivation and rubber tree plantations(3-year-old plantation and 7-year-old plantation) decreased by 34.0%, 33%, and 23%; and TSN stocks decreased by 32.2%, 20.4%, and 20.4%, respectively, whereas the decreases of SOC and TSN stocks in 0—60 cm soil layers were much less. The results indicated that C and N losses were mainly occurred in 0—20 cm surface soil, followed by 20—40 cm layer.

Keywords: soil organic carbon(SOC); total soil nitrogen(TSN); inorganic nitrogen; land-use change; tropical soil; Xishuangbana

Introduction

Soils play an important role in the global C and N cycles and can be a source or sink of them depending on land use and managements. The top one-meter soil on the world contains approximately 1500 Gt C(1 Gt = 10^{15} g)(Johnson, 1995; Bruce, 1999), and even relative small fluxes into and out of this pool can amount to large fluxes on a global scale. There is considerable concern that land-use change, in particular, may be leading to a depletion of soil C and consequent increases in atmosphere CO_2 (Houghton, 1999; Bruce, 1999). Detwiler (Detwiler, 1986) estimated that clearing of forest followed by cultivation results in an average 40% loss of soil C, and clearing followed by pasturing results in an average 20% loss of soil C, each within 5 years. Globally, the net contribution from change in land use accounted for about 25% all human-induced emissions of C during the 1980s, and almost this entire source was emitted from tropical countries as a result of deforestation, which accounted for about 85% of the net changes in C attributable to land use change in the 1980s(Houghton, 2001).

N_2O, the third most important greenhouse trace gas in the troposphere and one important contributor to ozone destruction in the stratosphere, has had its concentration in the atmosphere increased steadily over the last few decades. Soil is estimated to be the largest source that contributes approximately 65% of total emissions (Prather, 1995). Tropical forest soils were thought to be the probable largest single source, followed by cultivated soils(Smith, 1997). The increase in N_2O atmosphere concentration is directly associated with large-scale human interference in the N cycle (Prather, 1995) which is largely related to agriculture. As the tropical ecosystems are converted to agriculture, pasture or silviculture, there is an increasing potential for tropical soil N_2O emissions to become yet more significant(Duxbury, 1994).

Nitrogen(N) along with carbon is the most complex and crucial of the elements essential for life, and plays a critical role in nutrient cycling, water, root growth, plant productivity, and environmental quality(Sainju, 2002). Concentrations of organic C and N are good indicators of soil quality and productivity due to their favorable effects on physical, chemical, and biological properties(Bauer, 1994). Soil nitrogen concentration and its availability influence world productivity directly. Although increasing attention is being given to the change of carbon in global vegetation and soils because of "greenhouse effect", the dynamics of soil nitrogen following land-use changes and the

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Foundation item: The National Natural Science Foundation of China (No. 40071085); * Corresponding author. E-mail: xghan@ns.ibcas.ac.cn relationship between soil carbon and nitrogen are two important ecological research focuses.

Xishuangbanna, covering about 1.91×10^4 km^2 of which 54.6% area is woodland, is a very important part of tropical region in China, and even in Asia(Tang, 1998). A large area of forest has been cleared and converted to plantations and cropland resulted from increasing need for food, firewood and timber since last century, which led to a decrease in contents of soil carbon and nitrogen. However, the influence of land-use change on soil C and N dynamics in this region remains poorly understood till now. To evaluate the influences of land-use change on the dynamics of soil carbon and nitrogen in this area, a series of detailed studies are needed.

The objective of our study is to determine the concentrations and pools of SOC and different forms of soil nitrogen under different land-use patterns in order to elucidate the effect of land-use change on soil carbon and nitrogen dynamics. We also aim to investigate the relationship between the dynamics of soil carbon and nitrogen after land-use change.

1 Description of the study site

The study area is located in Xishuangbanna tropical region in southwest China. This region has undergone rapid rate of deforestation during the last several decades. The primary causes of deforestation include plantation conversion, shifting cultivation, and timber harvest. And the conversions of forest to shifting cultivation and rubber tree plantation are common land-use changes in the region.

The study site, located in Guanlei, is one of the permanent sites of the Forest Ecology Research Station, Xishuangbanna Tropical Botanical Garden, the Chinese Academy of Sciences (CAS). The site (21°42′N, 101°15′E) is located at a gentle slope of 5—10°, and the altitude varies from 800 to 910 m. The mean annual temperature is 22.1℃, and annual precipitation is about 1400 mm, with a dry season from October to the next April. According to Chinese system, the soils are classified as Udic Ferrisols. The selected five adjacent plots include an acuminate banana(*Musa itinerans*) secondary forest (reforested for 20 years), a male bamboo (*Dendrocalamus membranacea*) secondary forest (reforested for 9 years), two rubber tree (*Hevea brasiliensis Muell.-Arg.*) plantations (one is 3-year-old, and another is 7-year-old) and a shifting cultivation. The plots of rubber tree plantations were for slash-and-burn agriculture for 3 years after male bamboo secondary forest had been cleared, and then established plantations 3 and 7 years ago, respectively. The cropland began to be cultivated after the acuminate banana secondary forest was clear-cut in 1995, and then for slash-and-burn agriculture till 2001.

2 Study methods

2.1 Soil sampling

Soil sampling was done after harvest of rice at the end of the dry season in April 2001. Three profiles were dug in each plot, and soil samples were taken from the following depths: 0—3, 3—20, 20—40 and 40—60 cm. Soil samples were air-dried, ground with a mortar and pestle, sieved to < 2 mm, and stored for chemical analysis. For the determination of bulk density, 3 undisturbed cores per depth were taken from 0—20 cm, 20—40 cm and 40—60 cm depths with 100 cm^3 cylinders. Bulk density and soil moisture content were measured according to the method of McLean (McLean, 1982).

2.2 Laboratory analyses

The total carbon (TC) concentration was measured by H_2SO_4-K_2CrO_7 oxidation method(Nelson, 1982). There was no detectable inorganic C in the acidic soils, so that we can regard TC as SOC. TSN concentration was determined by Auto-Kjeldahl method, utilizing Kjeltec System 1026 Distilling Unit(Sweden). Inorganic N(NO_3^--N and NH_4^+-N) was measured colorimetrically in 1 mol/L KCl soil extract solutions using a Skalar SAN^{plus} Segmented Flow Analyzer (Netherlands). Soil pH in H_2O(soil: water ratio 1:5) was determined according to the method of Culley (Culley, 2000). All the procedures were replicated three times for each soil sample.

2.3 Statistical analyses

Statistical analyses of soil properties were performed for each parameter using analysis of variance (ANOVA) with SPSS 10.0 program. The data from the various soil depths were analysed separately. If an F-test proved significant at $P < 0.05$ level then the means of each plots were compared by least significant difference(LSD). Relationship between soil C and N pools was examined using single regression analysis with SPSS 10.0 program. All values in the tables and figures were presented as means.

3 Results

3.1 Soil pH, moisture and bulk density

3.1.1 Soil pH

Soil pH was the highest in 3—20 cm surface soil in shifting cultivation (6.02), and the lowest in acuminate bamboo secondary forest at the same depth (4.78) (Table 1). Soil pH among depths in the two secondary forests changed a little, while those in shifting cultivation and rubber tree plantations had large differences, and the ranges of pH were 5.24—6.02(shifting cultivation), 5.20—5.46(3-year-old rubber tree plantation), and 5.31—5.78 (7-year-old rubber tree plantation). Soil pH at each depth in shifting cultivation and rubber tree plantations was higher than that at the same depths in the two secondary forests, and the differences at 0—3 and 3—20 depths were significant($P < 0.05$).

3.1.2 Moisture content

Soil moisture content was the lowest at 0—3 cm depth in shifting cultivation(19.4%), and the highest at 3—20 cm depth in acuminate banana secondary forest (35.9%). Moisture content of surface soils(0—3 and 3—20 cm depths) in acuminate banana secondary forest(30.2% and 35.9%) was significantly higher than that in shifting cultivation

(19.4% and 28.3%), and only 0—3 cm surface soil moisture content in male bamboo secondary forest(27.8%) was significantly higher than the two rubber tree plantations (21.3% and 20.6%).

Table 1 Soil physical and chemical properties at 0—3, 3—20, 20—40, and 40—60 cm depths on five spots under secondary forest, shifting cultivation, and rubber tree plantation

Depth, cm	Land-use type	BD, g/cm^3	pH water	Moisture, %	SOC, g/kg	TSN, g/kg	C:N	Mineral N	
								NO_3^--N, mg/kg	NH_4^+-N, mg/ kg
0—3	Secondary forest 1	ND	5.07^{b}	30.2^{a}	34.8^{a}	2.90^{a}	12.0^{a}	10.1^{b}	64.6^{a}
	Shifting cultivation	ND	5.59^{a}	19.4^{b}	23.9^{b}	2.28^{b}	10.5^{b}	7.9^{c}	73.9^{a}
	Secondary forest 2	ND	4.99^{b}	27.8^{a}	36.0^{a}	2.82^{a}	12.8^{a}	5.4^{c}	12.6^{c}
	Plantation 1	ND	5.46^{a}	21.3^{b}	28.1^{b}	2.70^{a}	10.4^{b}	9.3^{b}	20.8^{b}
	Plantation 2	ND	5.60^{a}	20.6^{b}	24.6^{b}	2.25^{b}	10.9^{b}	12.1^{a}	20.1^{b}
3—20	Secondary forest 1	1.20^{b}	4.92^{b}	35.9^{a}	29.1^{a}	2.45^{a}	11.9	12.6^{a}	58.2^{a}
	Shifting cultivation	1.25^{ab}	6.02^{a}	28.3^{b}	18.4^{b}	1.60^{c}	11.5	8.4^{b}	50.7^{a}
	Secondary forest 2	1.17^{b}	4.78^{b}	26.7^{b}	28.9^{a}	2.28^{b}	12.7	4.9^{c}	10.4^{c}
	Plantation 1	1.28^{a}	5.45^{a}	24.2^{b}	17.7^{b}	1.67^{c}	10.6	12.7^{a}	17.7^{b}
	Plantation 2	1.30^{a}	5.78^{a}	23.4^{b}	20.2^{b}	1.66^{c}	12.2	12.9^{a}	18.6^{b}
20—40	Secondary forest 1	1.31^{ab}	4.88	34.1^{a}	17.2^{a}	1.66^{a}	10.4	11.5^{ab}	29.9^{b}
	Shifting cultivation	1.34^{ab}	5.35	26.6^{b}	13.2^{b}	1.00^{b}	13.2	9.1^{b}	98.0^{a}
	Secondary forest 2	1.29^{b}	4.86	27.7^{b}	18.4^{a}	1.57^{ab}	11.7	5.3^{c}	9.1^{c}
	Plantation 1	1.36^{a}	5.30	24.1^{b}	14.5^{b}	1.42^{ab}	10.2	11.9^{ab}	13.4^{c}
	Plantation 2	1.37^{a}	5.45	25.5^{b}	14.7^{b}	1.46^{ab}	10.1	13.2^{a}	24.8^{b}
40—60	Secondary forest 1	1.37	4.90	32.9	12.9	1.25	10.3	5.93^{c}	13.8^{c}
	Shifting cultivation	1.40	5.24	28.3	12.4	1.18	10.5	10.8^{a}	85.8^{a}
	Secondary forest 2	1.38	4.80	26.2	13.2	1.21	10.9	6.5^{c}	8.9^{c}
	Plantation 1	1.39	5.20	27.3	12.7	1.20	10.6	9.4^{b}	10.1^{c}
	Plantation 2	1.40	5.31	27.0	12.2	1.14	10.7	11.6^{a}	33.0^{b}

Notes: BD—bulk density; SOC—soil organic carbon; TSN—total soil nitrogen; C: N—the ratio of SOC to TSN; ND—there were no measurements about bulk density at 0- 3 cm depth; secondary forest 1—acuminate banana secondary forest; secondary forest 2—male bamboo secondary forest; plantation 1—3-year-old rubber tree plantation; plantation 2—7-year-old rubber tree plantation, the same as those in the following tables. Within each depth, values within each column marked with the same letters are not significantly different at $P < 0.05$ (LSD)

3.1.3 Bulk density

Soil bulk density generally increased with depth on all the five spots(Table 1). Bulk density at 3—20 cm depth was the lowest in acuminate bamboo secondary forest(1.17 g/cm) and the highest in the 7-year-old rubber tree plantation(1.30 g/cm). The differences of bulk density between male bamboo secondary and two rubber tree plantations at 3—20 and 20—40 cm depths were significant($P < 0.05$). The bulk density of shifting cultivation at each depth was higher than that of acuminate banana secondary forest, but the differences were not significant. Overall, shifting cultivation and rubber tree plantations had higher soil bulk density than secondary forests.

3.2 SOC pool

SOC concentrations were the highest in 0—3 cm surface soils, and generally decreased with depth in each ecosystem (Table 1). The values ranged from 36.0 gC/kg in the male bamboo secondary forest (0—3 cm depth) to 12.2 gC/kg in the 7-year-old rubber tree plantation(40—60 cm depth). SOC concentrations at 0—3, 3—20, and 20—40 cm depths in the secondary forests were significantly higher than those in the shifting cultivation and rubber tree plantations ($P < 0.05$), while the values in 40—60 cm depth had no significant differences.

SOC stocks, like SOC concentration generally decreased with depth in all ecosystems (Table 2). SOC stocks to 60 cm depth ranged from 11.6 kgC/m^2 in the shifting cultivation to 15.2 kgC/m^2 in the male bamboo secondary forest. SOC stocks in surface soil (0—20 cm depth) ranged from 4.52 kgC/m^2 in the shifting cultivation to 6.98 kgC/m^2 in the acuminate banana secondary forest, which accounted for 39.6% to 46.5% of SOC pools to 60 cm depth. SOC pools at 0—20, 20—40 and 0—60 cm depths in secondary forests were significantly higher than those in shifting cultivation and rubber tree plantations, respectively($P < 0.05$). Compared with the acuminate banana secondary forest, SOC pools in 0—20, and 0—60 cm depths in shifting cultivation declined by 34% and 23%. And the pools in 3-year-old and 7-year-old rubber tree plantations, compared with the male bamboo secondary forest, decreased by 33%, 22% and 23%, 16%, respectively. The SOC losses after land-use changes in this study were similar with the average loss (about 22%) after conversion of forest to agricultural land(Murty, 2002). Compared with the secondary forests, SOC pools in 0—60 cm layers in shifting cultivation and two rubber tree plantations reduced at average rates of 0.57, 0.55, and 0.25 kgC/(m^2·a), respectively. But taking the accumulation of C in secondary forests into account, the rate of SOC reduction might be slower. SOC reduction rate in the 7-year-old plantation was much lower than that in the 3-year-old plantation, maybe we could deduce that SOC loss had stopped 7 years after the establishment of the plantation, and C began to accumulate in the surface soil.

Table 2 Soil organic carbon stocks(kgC/m^2) at 0—20, 20—40, 40—60 cm depths in secondary forests, shifting cultivation, and rubber tree plantations

Land-use type	0—20 cm	20—40 cm	40—60 cm	Total
Secondary forest 1	6.98^{a}	4.52^{a}	3.52	15.02^{a}
Shifting cultivation	4.60^{b}	3.52^{c}	3.48	11.60^{b}
Secondary forest 2	6.76^{a}	4.74^{a}	3.72	15.22^{a}
Plantation 1	4.52^{b}	3.94^{b}	3.52	11.98^{b}
Plantation 2	5.22^{b}	4.02^{b}	3.42	12.66^{b}

Notes: Total—the sum of SOC stocks at 0—20, 20—40, 40—60 cm layers. Values within each column not marked with the same letter differ significantly ($P < 0.05$)

3.3 Soil N pool

3.3.1 Total soil N pool

Like SOC concentrations, TSN concentrations in 0—3 cm surface soils were the highest, and it decreased with depth in all ecosystems(Table 1). The concentrations ranged from 2.90 gN/kg in 0—3 cm surface soil in acuminate banana secondary forest to 0.97 gN/kg in 40—60 cm depth soil in shifting cultivation. TSN concentrations in 0—3, 3—20, and 20—40 cm depths in shifting cultivation were significantly lower than those in acuminate banana secondary forest, and only those in 0—3 and 3—20 cm surface soils in the rubber tree plantations were lower than those in the male bamboo secondary forest. There were no marked differences in the concentrations in 40—60 cm depth among all the five plots.

Table 3 Total soil nitrogen stocks(kgN/m^2) at 0—20, 20—40, 40—60 cm depths in secondary forests, shifting cultivation, and rubber tree plantations

Land-use type	0—20 cm	20—40 cm	40—60 cm	Total
Secondary forest 1	0.59^a	0.49^a	0.34^a	1.42^a
Shifting cultivation	0.40^b	0.27^c	0.27^b	0.94^c
Secondary forest 2	0.54^a	0.41^b	0.31^a	1.26^b
Plantation 1	0.43^b	0.39^b	0.33^a	1.15^b
Plantation 2	0.43^b	0.40^b	0.32^a	1.15^b

Notes: Total—the sum of total soil nitrogen stocks at 0—20, 20—40, 40—60 cm depths surface soils. Values within each column not marked with the same letter differ significantly($P < 0.05$)

TSN pools and concentrations had the similar trend with SOC, generally declined with depth on all plots(Table 1 and Table 2). Compared with the acuminate banana secondary forest(0.59 kgN/m^2), the TSN stocks(0.40 kgN/m^2) in the shifting cultivation(0—20 cm depth surface soil) decreased by 32.2%. While those in the rubber tree plantations all decreased by 20.4%, compared with the male bamboo secondary forest. At 20—40 cm depth, the stock in shifting cultivation was also significantly lower than that in acuminate banana secondary forest. There were no marked differences in 40—60 cm depth among all the ecosystems. Overall, compared with the secondary forest, TSN pools in 0—60 cm soil layer in shifting cultivation decreased by 33.8%, and the average reduction rate was 0.08 kgN/m^2. The soil N pools in the two plantations did not show significant changes.

3.3.2 Mineral N pool

Concentrations of soil NH_4^+ -N and NO_3^- -N were strongly influenced by land use. Even in the two secondary forests, inorganic N concentrations differed greatly, which might be mainly due to restoration duration and species composition. In all the five ecosystems, mineral N was generally predominant by NH_4^+ -N, and the proportion ranged from 51.8% (40—60 depth in plantation 2) to 91.5% (20—40 cm depth in shifting cultivation) (Table 1). The trend of mineral N concentration in soil profiles was more complex than TSN. Compared with secondary forests, concentrations and stocks of NH_4^+ -N at 0—20cm depth in shifting cultivation had no notable changes, but increased significantly at 20—40, and 40—60 cm depths which might be due to N leach and accumulation in deeper soils. Like NH_4^+ -N, the concentrations and stocks of NO_3^- -N in 0—20 cm surface soils declined, but increased at 40—60 cm depth. These changes might result from the difference in nitrification rates. Unlike in shifting cultivation, compared with secondary forest, concentrations and stocks of NH_4^+ -N and NO_3^- -N all increased significantly at all depths in rubber tree plantations. At 0—60 cm depth, NH_4^+ -N stocks ranged from 7.5 gN/m^2 (plantation 2) to 63.0 gN/m^2 (shifting cultivation), and NO_3^- -N stocks ranged from 4.3 gN/m^2 (male bamboo secondary forest) to 10.2 gN/m^3 (plantation 2).

3.4 The relationship between SOC and TSN

The ratio between SOC and TSN in surface soil(0—3cm depth) declined notably after the conversion from secondary forest to shifting cultivation and plantations, but there were no same trends beneath 3 cm depth(Table 1). Murty *et al*. (Murty, 2002) reviewed the studies on the effects of land-use change on soil C and N, and found that C:N ratio both increased and decreased after conversion of forest to agricultural land, with trend depending on changes in system N. Systems with increasing soil N generally had decreasing C:N ratios, whereas systems with decreasing soil N had increasing C:N ratios. In our study, although both SOC and TSN decreased substantially, C:N ratio in 0—3 cm surface soil also decreased notably. Pools of SOC and TSN were strongly correlated with each other at 0—20, 20—40, 40—60, and 0—60 cm depths (Fig. 1). The equations for the regressions at the four depths were TSN = 0.0982 * (SOC) + 0.027, R^2 = 0.7765, P = 0.0001; TSN = 0.0967 * (SOC) + 0.0484, R^2 = 0.6205, P = 0.0003; TSN = 0.1114 * (SOC) + 0.041, R^2 = 0.7031, P = 0.0001; TSN = 0.0896 * (SOC) + 0.108, R^2 = 0.9222, P = 0.0001. TSN pool was positively correlated with SOC pool. It was concluded that losses of SOC and TSN were concomitant and the losses were in proportions after the conversion of forests to shifting cultivation and rubber tree plantations.

Table 4 Mineral N(NO_3^- -N and NH_4^+ -N) stocks (gN/m^2) at 0—20, 20—40, 40—60 cm depths in secondary forests, shifting cultivation, and rubber tree plantations

Land-use type	0—20 cm		20—40 cm		40—60 cm		Total	
	NO_3^- -N	NH_4^+ -N	NO_3^- -N	NH_4^+ -N	NO_3^- -N	NH_4^+ -N	NO_3^- -N	NH_4^+ -N
Secondary forest 1	3.0^a	14.0^a	3.0^a	7.8^b	1.6^b	3.8^c	7.6^b	25.6^b
Shifting cultivation	2.1^b	12.7^a	2.4^a	26.3^a	3.0^a	24.0^a	7.5^b	63.0^a
Secondary forest 2	1.1^b	2.4^c	1.4^b	2.3^c	1.8^b	2.8^c	4.3^c	7.5^c
Plantation 1	3.3^a	4.5^b	3.2^a	3.6^c	2.6^a	2.8^c	9.1^a	10.9^c
Plantation 2	3.4^a	4.8^b	3.6^a	6.8^b	3.2^a	9.2^b	10.2^a	20.8^b

Notes: Total—the sum of mineral N stocks at 0—20, 20—40, 40—60 cm depths. Values within each column not marked with the same letter differ significantly($P < 0.05$)

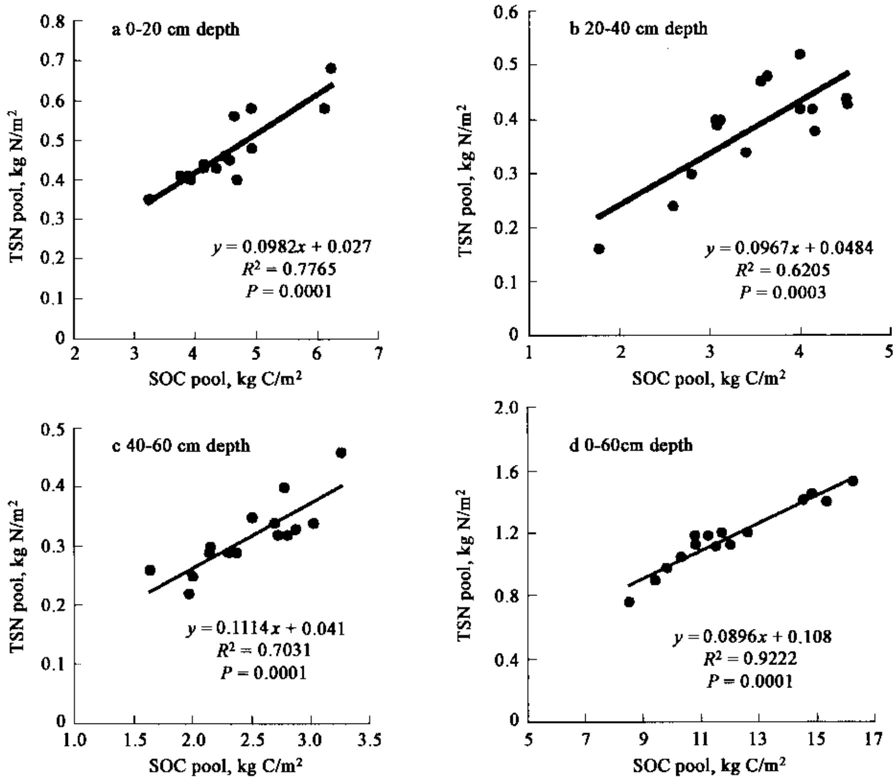

Fig. 1 Linear regressions between the SOC pools(kgC/m^2) and TSN pools(kgC/m^2) at 0—20, 20—40, 40—60, and 0—60 cm depths in the secondary forests, shifting cultivation, and rubber tree plantations ($n = 15$)

4 Discussion

4.1 Effects of land-use change on the dynamics of SOC

Deforestation, followed by shifting cultivation or establishment of plantations changes soil physical, chemical and biological properties due to changes in the quantity and quality of organic carbon inputs to the soil, nutrients inputs and losses, and stimulation of decomposition through soil disturbance. On the other hand, changes in soil properties also influence the dynamics of soil C and N. The conversion generally leads to a reduction of soil carbon. Most losses occurred within a few years and the magnitude varies with previous vegetation, climate, soil type, management practices and time since the conversion. The C dynamics in soil after conversion of forest to cropland to a great extent depends on agricultural managements such as residue management, crop rotation, tillage, and fertilization. Tree types and precipitation had effects on soil carbon after the conversion of forest to plantations. Planting broadleaf trees had little effect on soil carbon, but planting conifer trees significantly reduce soil carbon by 15%. Carbon was released only in the areas with precipitation > 1500 mm. Besides tree types and precipitation, plantation age also had significant effects on soil carbon stocks(Guo, 2002).

Nye and Greenland(Nye, 1960) reviewed a broad range of tropical studies of the impacts of shifting cultivation on soil properties. They concluded that cultivation is likely to cause deterioration of soil physical conditions and reduce nutrient status and humus content. Davidson and Ackerman (Davidson, 1993) reviewed a series of research on changes in soil carbon following cultivation of previously untilled soils. Most studies showed a decline in soil carbon after cultivation, with the average decline of about 30%. Murty (Murty, 2002) reviewed the literature to assess changes in soil C upon conversion of forests to agricultural land, and found the same result. Our results were generally consistent with their conclusions. However, Nye and Greenland(Nye, 1960) reported that soil C increased 49% on a site where banana was included as part of a regular crop rotation sequence. This increase was attributed to the large litter input from the banana leaves. When soil is cultivated, decomposition is enhanced because disturbance or tillage physically fragments and redistributes residues. Consequently, soil C is rapidly oxidized to CO_2 and lost to the atmosphere(Ellert, 1996). Intensive tillage can increase decomposition rates, while no tillage minimizes soil erosion and carbon loss(Juo, 1979; Bruce, 1999).

To sum up, magnitude of carbon loss after the conversion depends on previous history of land use, agricultural managements, and many natural conditions such as temperature, precipitation, and soil type. In addition, loss of soil carbon after conversion of forest to cropland varies significantly with soil sampling depth. The conversion has no influence on soil carbon stocks beyond 60 cm depth, but it significantly reduced carbon above 60 cm depth (Guo, 2002).

4.2 Effects of land-use change on the dynamics of soil N

Land-use change influences soil N pools. Our results showed that conversion of forest to shifting cultivation and rubber tree plantation greatly decreased total soil nitrogen in surface soils, especially in 0—20 cm depth layer. Murty's review(Murty, 2002) showed that the average loss of soil N was 15% after forests were converted to cultivated land, and

C:N ratio decreased. He also found that the loss of C exceeded that of N. Hajabbasi (Hajabbasi, 1997) reported that the deforestation and subsequently tillage practices resulted in almost 50% decrease in organic matter and total nitrogen. In our study, the loss of total soil N was mainly occurred in surface soils, and the highest loss was about 32% in shifting cultivation. Soil N had no notable changes beyond 40 cm depth.

Inorganic N pools and rates of N transformation in soils are often accurate indexes of the impacts of deforestation and land use on site fertility (Vitousek, 1988). In addition, soil N availability, along with soil water content, are primary determinants of trace gases such as nitrous oxide (N_2O) in tropical soils (Davidson, 2000). Magnitude of soil inorganic N pool depends on some biological processes such as mineralization, mineral adsorption, nitrification, and denitrification. Changes in factors influencing these processes such as temperature, precipitation, and microbial activity all can affect inorganic N. In addition, land managements (such as tillage, fertilization) also have great effect. Concentrations of NO_3^--N and NH_4^+-N generally increased in soils following slash-and-burn events along land-use gradient and decreased with increasing land use. Increasing land use resulted in marked declines in NO_3^--N pools relative to NH_4^+-N pools (Hughes, 2002). In our study, NO_3^--N concentration in surface soil in shifting cultivation decreased significantly, which was consistent with their previous results. But NO_3^--N concentration in plantations increased significantly compared with secondary forest. Our results regarding inorganic N represent one-time measures taken during dry season. Consequently, results should be interpreted with some caution.

With widely differing trends reported for different circumstances, there still remains much uncertainty regarding to the magnitudes and causes in soil C and N changes following land-use change. Overall, the main reasons for C and N changes include soil erosion, nutrients inputs and losses, and microbial decomposition. Change in anyone soil physical, chemical, and biological parameter (such as soil pH, temperature, moisture, microbial biomass, etc.) related to these processes will influence soil C and N cycles. Changes in soil C and N were strongly correlated after the conversion of forest to shifting cultivation and plantations, but the relationship was much more complex. A conclusion that applied to land-use changes is that changes in soil C are associated with concomitant changes in soil N (Johnson, 1992).

Acknowledgements: The authors would like to thank Sha Liqing, Fu Xianhui, Wang Hong and Li Qingjun, from Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences (CAS), for their assistance in soil sampling. We wish to thank Mrs. Zhang Shumin and Yu Fenglan for their help in laboratory analysis, and we also thank Mr. Cai Ruiguo and Liu Fangchun from Shandong Agricultural University for their help in soil sample analysis.

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(Received for review January 2, 2003. Accepted February 14, 2003)