Soil Ecological Study on Shifting Cultivation in the Mountainous Area in Northern Thailand

Sota TANAKA

1998

Soil Ecological Study on Shifting Cultivation in the Mountainous Area in Northern Thailand

Sota TANAKA

1998

Acknowledgments

This work could be completed through the kind support and cooperation of many individuals and institutions in Thailand and Japan.

First of all, I am deeply grateful to my adviser, Professor of Soil Science, Kyoto Prefectural University, Dr. Koyo Yonebayashi, for his kind guidance, keen supervision, generous encouragement, and amazing perseverance during the course of this work.

I would like to express my deep gratitude to Dr. Shin'ya Funakawa, Associate Professor of Soil Science, Kyoto University, to give me a chance to embark in this work at the Graduate School of Kyoto Prefectural University. I am deeply indebted to Dr. Tomoo Hattori, Emeritus professor, Kyoto Prefectural University, for his guidance, valuable discussions and encouragement given me.

I am very thankful to Dr. Yukihiro Hayashi, Lecturer of College of Bioresource Science, Nippon University and Dr. Hideaki Hirai, Associate Professor of Faculty of Agriculture, Utsunomiya University for their support and supervision in my research in Thailand. I wish to express my sincere thanks to Dr. Tawachai Na Nagara, head of the Laboratory of Soil Physics, Department of Agriculture in Thailand and Dr. Prateep Verapattananirund, the former stuff member of the Laboratory of Soil Physics, Department of Agriculture in Thailand, for their kind assistance and arrangements in my research in Thailand. I greatly thank Dr. Narong Srisawas, Assistant Professor of Faculty of Social Sciences, Kasetsart University, Dr. Korntornt Pountprakhon and Mr. Thamanoon Kaewkongka, the stuff members of Department of Agriculture in Thailand, and Miss. Nitaya Kijtewachakul, Research Coordinator of Regional Community Forestry Training Center of Thailand for their cooperation to my research in Thailand. I also give special thanks to all of the stuff members of Department of Agriculture in Thailand, especially Mr. Botan, for their encouragement and support in Thailand. I thank the National Research Council of Thailand for allowing me to carry out my research in Thailand.

I wish to express my appreciation for the encouragement and support provided in various ways by Dr. Takaaki Honjyo, the former Associate Professor of University Forests, Kyoto Prefectural University, Dr. Kazumi Saito, Professor of Department of Biological Resource Chemistry, Kyoto Prefectural University, Dr. Hidekazu Yamada, Associate Professor of Soil Science, Kyoto Prefectural University, and Mr. Atsushi Trii, Kansai Research Center, Forestry and Forest Products Research Institute.

Appreciation is also extended to Dr. Atsuhiko Shintani, instructor of College of Engineering, Osaka Prefecture University, for his cooperation to make computational program.

I acknowledge with many thanks the encouragement and support of the former and present students of the Laboratory of Soil Science, Kyoto Prefectural University, especially Messrs. Kei Nanbu, Munehiro Ebato, and Jing Yu Dai.

I wish to give a thousand thanks to the villagers in Ban Rakpaendin, Ban Du La Poe, and Ban Huai Mak Nun for their cooperation and assistance in my field research and life in the village.

Finally, my heartfelt thanks go to my dear fiancée and my parents for their constant understanding and consoling me when I am at crucial moments.

Sota T.

CONTENTS

List of Tables

List of Figures

CHAPTER 1. Introduction

1.1 Study background

There has been a drastic decrease in forest area in the humid tropics and subtropics. In the case of Thailand, forest area declined from 2.0×10^5 to 1.4×10^5 km^2 or from 39 to 27 % of total land area between 1976 and 1991 (Royal Forest Department 1992). Particularly, the rapid decrease was observed in the mountainous area of the northern region, where the forest decline was estimated from 1.0×10^5 to 7.7×10^4 km^2 or from 60 to 45 % between 1976 to 1991. One of the main reasons for such a decrease in the forest area is thought to be the expansion of cultivation activity due to population pressure or commercialism. Fox et al. (1995) estimated that population density on agricultural lands in their study area in northern Thailand was 0.26 and 0.52 persons ha^{-1} in 1954 and 1992, respectively. For subsistence, the farmers are obligated to expand cultivation area or to cultivate their land intensively, i.e. to shorten fallow period or lengthen cropping period. These situations have caused decrease in forest area, deterioration of watersheds, and decline of soil fertility.

In the mountainous area of northern Thailand, shifting cultivation is conducted by hill peoples such as Hmong, Karen, etc., and Thai people, who migrated from low land area (Kunstadter and Chapman 1978). In general, most of them are not favored economically and politically and cannot afford a technology with high input of capital and labor for their crop production. In order to alleviate forest degradation while maintaining or improving the living standard of the farmers, it is necessary to develop alternative land use systems, which assure sustainable cultivation or crop production, if possible, with low input of capital and labor.

1.2 Study objectives

Many studies on shifting cultivation have been carried out from the viewpoints of various academic disciplines, i.e. anthropological, economical, and so on. But from soil ecological aspects, only a few researchers comprehensively reported on this subjects, as long as the author knows. For example, Nye and Greenland (1960) studied on the soils under the shifting cultivation in Africa, or Sanchez (1973) in Latin America. In Southeast Asia, Kunstadter et al. (1978) and Kyuma and Pairintra (1983) reported the soils under shifting cultivation in Thailand, while Ramakrishnan (1992) in India. Because of low fertility of Ultisols or Oxisols in the tropics, these studies tended to emphasize on fertilization effect such as addition of basic cations and P accumulated in the vegetation in fallow forest associated with the slash and burn practice and the release of N caused by the soil burning effect. However, there is still insufficient information about the soil properties to analyze the dynamics of soil fertility in cropping/fallow period in the shifting cultivation.

In order to analyze soil ecological problems involved in the present cropping systems and to offer appropriate guidelines for agricultural development in the area in future, the author conducted comparative study on soil properties and their dynamics both in Karen people's traditional cultivation system and Hmong and Thai people's more intensive upland farming system in the mountainous region of northern Thailand.

In Chapter 3, physicochemical properties and mineralogical properties of the soils are investigated with special reference to their charge characteristics in order to clarify the factors that affected the soil fertility in the area. In this chapter, it will be shown that soil acidity is considered to associate with the contents of basic cations both in the surface and subsurface soils and affect the contents of available P in the surface horizon, whereas soil organic matter is thought to determine the CEC values and to contribute to the contents of available N. In Chapter 4, the dynamics of K, Mg, and Ca, and soil acidity between the soils and aboveground biomass in fallow forest are analyzed in relation to the land use stages. The dynamics and properties of soil organic matter are studied in detail in Chapters 5, 6, and 7. In Chapter 5, decomposition rate of soil organic matter is evaluated from the results on soil respiration experiment and soil burning effect is assessed through soil incubation experiment. In Chapters 6 and 7, N mineralization process and the significance of labile pools of soil organic matter for the process are analyzed. In Chapter 8, the results in the above chapters are summarized, and the advantages in the traditional shifting cultivation system and the soil ecological problems in the present intensive cropping system are discussed. From the results in this study, the author proposes appropriate measures for the development of sustainable agriculture in the area. Moreover, the author hopes to give an assistance to improve villager's life through this study.

Chapter 2. Description of study sites

2.1 Location

This study was carried out in three village in the mountainous region of northern Thailand, Ban Du La Poe (DP village) and Ban Huai Mak Nun (HM village) in Mae Hong Son Province, and Ban Rakpaendin (RP village) in Chiang Rai Province during 1993 to 1997 (Fig. 2.1 and Table 2.1). The DP and HM villages were inhabited by Karen people. In the DP village, the traditional land use system of shifting cultivation consisting of only 1 y of cropping for upland rice and about 10 y of fallow periods was still maintained, whereas, in the HM village, the fallow period had recently been shortened to about 4 y. The RP village was inhabited by Hmong and Thai peoples. They planted upland rice or cash crops such as maize, cabbage, ginger, etc. under 2 to 5 y continuous cropping period with short fallow.

The study sites in the DP and HM villages of Karen people were either under cropping just after fallow, short fallow, or rather prolonged fallow dominated by woody species, which often reached a height of 10 to 15 m. On the other hand, the study sites of the RP village were mostly under cropping or young fallow dominated by bamboo or herbaceous species. The amounts of aboveground biomass and its nutrient contents will be presented in Chapter 4. Generally speaking, the study sites in the DP (15 to 32°; mean 26°) and HM (15 to 33°; mean: 25°) villages were located on a relatively steep slope compared to those in the RP village (8 to 25°; mean: 17°).

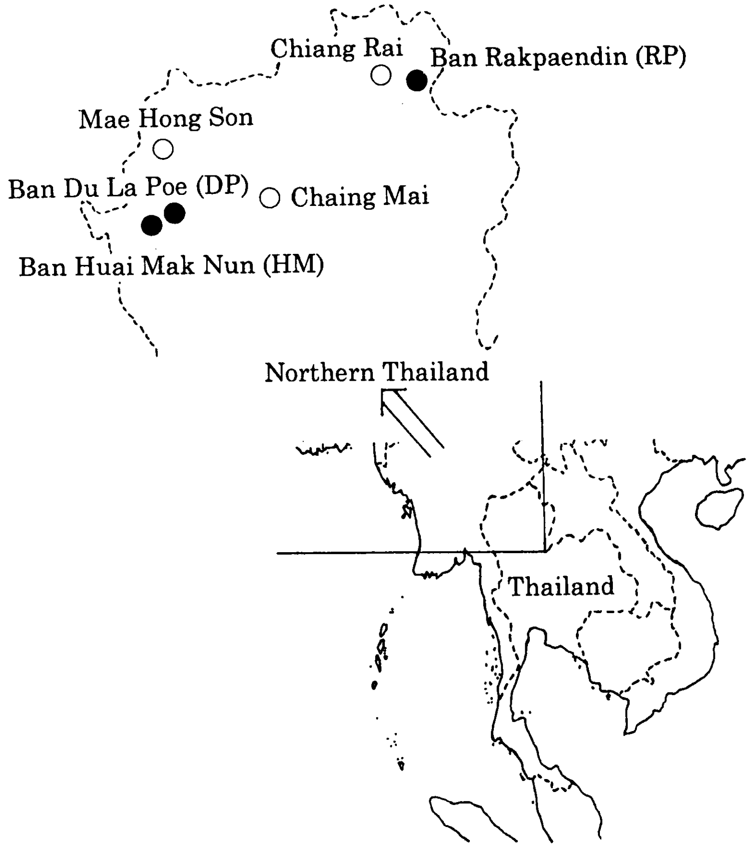


Fig. 2.1 Study sites. ○:major city, ●: village studied.

Table 2.1 Brief description of the villages studied.

Name of village	Major ethnic groups	Location	Altitude(m)	Parent materials
Ban Du La Poe (DP village)	Karen people	Mae Hong Son Prov. N 18° 24', E98° 05'	1,100-1,300	Fine-textured sedimentary rocks and granite
Ban Huai Mak Nun (HM village)	Karen people	Mae Hong Son Prov. N 18° 20', E98° 00'	700-850	Granite
Ban Rakpaendin (RP village)	Thai and Hmong people	Chiang Rai Prov. N 19° 49', E100° 22'	500-550	Paleozoic shale

2.2 Climate

Table 2.2 presents annual climatic data at Mae Hong Son (altitude: 230 m) and Chiang Rai (altitude: 420 m) cities, respectively (Office of Agricultural Economics 1989, 1993, and 1995). The mean annual temperature and rainfall from 1985 to 1994 were 26.1 and 24.6℃ and 1282 and 1631 mm at Mae Hong Son and

Chiang Rai cities, respectively. In both cities, rainfall was concentrated in the rainy season from April to November (Table 2.3; Meteorological Department 1987). Since the study sites are located on hill-slopes and their altitude ranges from 500 to 1,300 m (a.s.l.) (Table 2.1), the mean annual temperature in the study sites may be lower than the values recorded at these cites. Based on Kyuma's classification of climate in Southeast Asia (Kyuma 1972) and that of Köppen, all the villages studied were included in Group Ⅶ (Central India-Northern Indochina Region) or transitional region of Köppen's Aw and Cw. At the end of the dry season, cropping field was prepared with the slash and burn practice, and crops were seeded at the beginning of the rainy season. On the other hand, during the dry season, a shortage of rainfall limited crop growth.

Table 2.2 Annual temperature and rainfall from 1985 to 1994 at Mae Hong Son and Chiang Rai cities.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Mean
Mae Hong Son											
Temperature (℃)											
Mean	27.1	26.5	25.8	26.6	26.8	26.1	25.9	25.2	25.1	25.4	26.1
Maximum	41.5	41.1	40.8	42.4	41.9	41.1	33.6	42.5	41.3	40.0	40.6
Minimum	12.0	10.5	11.0	10.8	8.3	7.0	20.2	8.5	5.1	9.0	10.2
Rainfall (mm)	1,343	1,254	1,064	1,318	1,063	1,257	1,481	1,262	1,364	1,436	1,282
Chiang Rai											
Temperature (℃)											
Mean	24.8	24.7	24.4	25.0	25.0	25.0	24.4	24.2	24.1	24.4	24.6
Maximum	39.0	38.2	38.7	39.4	40.5	40.0	31.3	39.6	37.9	38.2	38.3
Minimum	4.8	6.0	5.9	8.3	8.0	6.8	19.1	6.5	4.2	8.9	7.7
Rainfall (mm)	1,936	1,473	1,244	1,720	1,594	1,652	1,500	1,543	1,488	2,160	1,631

Cited from Agricultural Statistics of Thailand Crop Year 1988/1989, 1992/1993, and 1994/95 (Office of Agricultural Economics 1989, 1993, and 1995).

Table 2.3 Monthly temperature and rainfall in 1987 at Mae Hong Son and Chiang Rai cities.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Mae Hong Son													
Temperature(℃)	21.1	21.8	24.8	29.2	29.9	28.5	27.2	27.4	27.2	27.2	25.9	19.7	25.8
Rainfall(mm)	14.3	0.0	20.3	84.5	70.8	99.5	209.6	227.4	161.1	60.1	116.0	0.0	1063.6
Chiang Rai													
Temperature(℃)	19.3	20.7	23.4	26.9	28.1	27.7	27.0	26.7	26.5	25.7	23.7	16.6	24.4
Rainfall(mm)	0.2	1.3	17.8	92.1	87.3	63.3	146.0	408.0	293.3	54.8	75.5	0.0	1243.6

Cited from Annual Climatological Data of Thailand (Meteorological Department 1987).

2.3 Parent materials of the soils

A larger part of residual soils in the mountainous area of northern Thailand is derived from Tertiary sedimentary rocks or igneous rocks such as granite or granodiorite (Geological Survey Division 1983). As shown in Table 2.1, the soils in the DP village were derived either from fine-textured sedimentary rocks or granite, which partly underwent metamorphism, whereas the soils in the HM village were derived from granite. The soils in the RP village were derived from Tertiary sedimentary rocks.

Chapter 3. Soil acidity and organic matter content as main factors to determine soil chemical fertility

3.1 Introduction

Because of the low fertility of Ultisols or Oxisols in the tropics and subtropics, most of studies on the soils under the shifting cultivation tended to emphasize on fertilization effect such as addition of basic cations and P from the vegetation of fallow forest associated with the slash and burn practice and increase in the inorganic N release caused by the soil burning effect. However, since the shifting cultivation in the study area is mostly performed on hill-slope under cooler climatic conditions in the upper part of mountain (higher than 500 m a.s.l.), the soil conditions in the study area are assumed to be very different from the cases in Africa (Nye and Greenland 1960), Latin America (Sanchez 1973), and northeast Thailand (Kyuma and Pairintra 1983). In order to get basic information about soil properties in the study area and to analyze the factors that affected the soil fertility under shifting cultivation, physicochemical properties and mineralogical properties of the soils were investigated with special reference to their charge characteristics.

3.2 Materials and methods

3.2.1 Materials

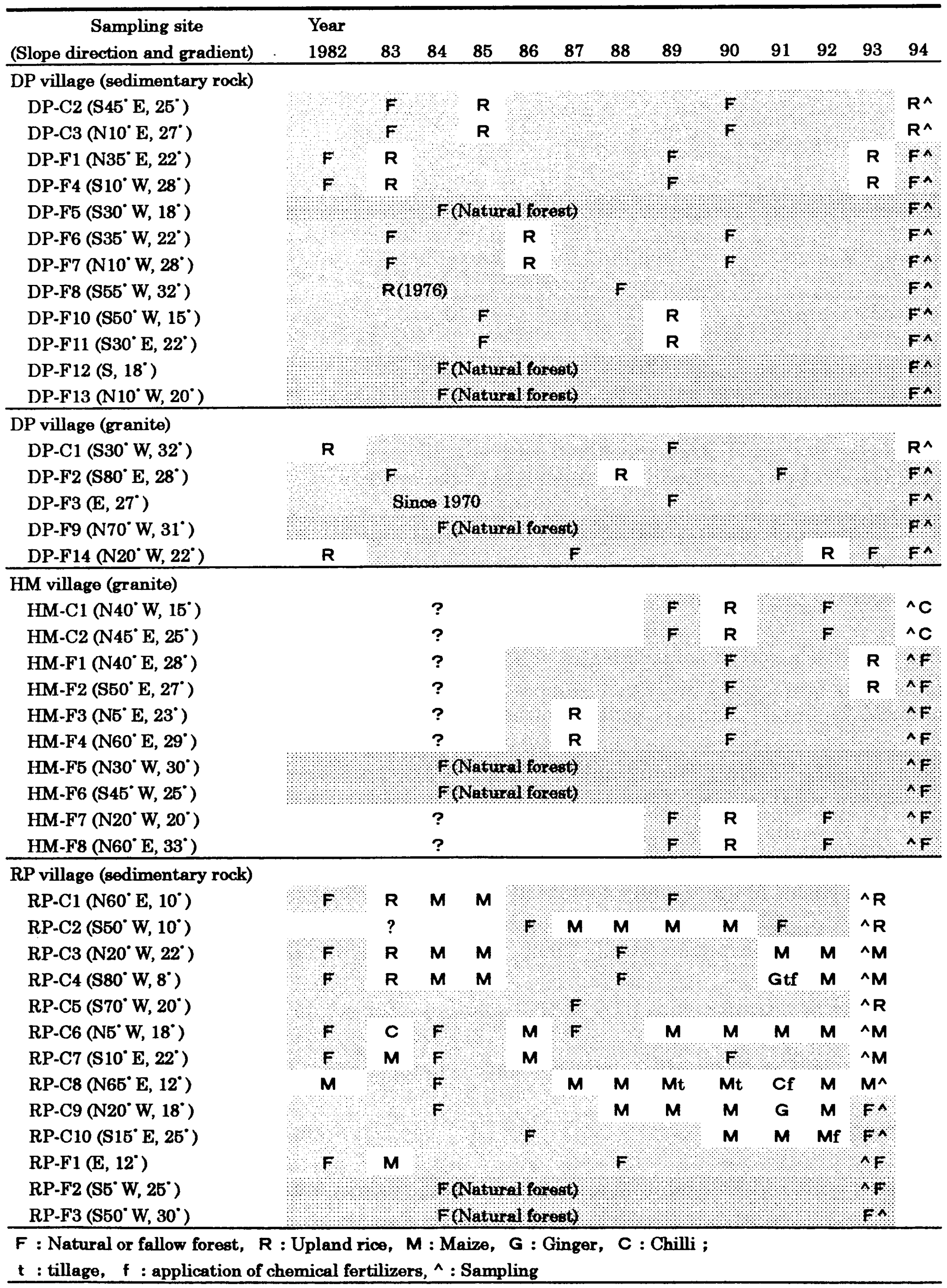
Forty sites were set up in the upper part of a convex slope under the different land use stages, including 17 sites in the DP village, 10 sites in the HM village, and 13 sites in the RP village in March, 1993 to November, 1994 (Table 3.1, Fig. 3.1). Soil samples were collected from every 10 cm depth up to 50 cm in the selected profiles and from surface 10 and 30-40 cm depths in the others. The descriptions of the profiles were presented in Appendix. Most of the soils studied were Typic Haplustults or Ustic Dystropepts in the USDA classification system (Soil Survey Staff 1992).

Table 3.1. Sampling sites.

Name of village	Number of sampling sites			Total
	Crop land (just after fallow)	Fallow forest	Natural forest	
DP (sedimentary)	2(2)	8	2	12
DP (granite)	1(1)	3	1	5
HM (granite)	2(2)	6	2	10
RP (sedimentary)	10(4)	1	2	13

3.2.2 General physicochemical properties of the soils

The soil samples collected were air-dried and passed through a 2 mm mesh sieve and the gravel content was measured. Soil pH was measured in water or 1 M KCl solution with a soil to solution ratio of 1:5 by the glass electrode method (Horiba, pH meter/M-7). Total C and N contents were determined with a NC analyzer (Sumika Chem. Anal. Service, Sumigraph NC-800). Cation exchange capacity (CEC) and contents of exchangeable bases (Na, K, Mg, and Ca) were measured after successive extraction with 1 M ammonium acetate at pH 7.0 and subsequently 10 % NaCl solutions (Thomas 1982; Muramoto et al. 1992). The amount of NH_4 replaced by Na was determined by titration with 0.01 M HCl solution after steam distillation, whereas the contents of exchangeable bases were determined by atomic absorption spectrophotometry (Shimadzu, AA-640-01, AAS). Exchangeable Al and H were extracted with 1 M KCl solution and then exchange acidity was determined by titration with 0.01 M NaOH and exchangeable Al by titration with 0.01 M HCl. The content of exchangeable H was calculated as the difference between the values of exchangeable acidity and exchangeable Al.



Sampling site (Slope direction and gradient)	Year 1982	83	84	85	86	87	88	89	90	91	92	93	94
DP village (sedimentary rock)													
DP-C2 (S45° E, 25°)		F		R					F				R^
DP-C3 (N10° E, 27°)		F		R					F				R^
DP-F1 (N35° E, 22°)	F	R						F				R	F^
DP-F4 (S10° W, 28°)	F	R						F				R	F^
DP-F5 (S30° W, 18°)			F (Natural forest)										F^
DP-F6 (S35° W, 22°)		F			R				F				F^
DP-F7 (N10° W, 28°)		F			R				F				F^
DP-F8 (S55° W, 32°)		R(1976)					F						F^
DP-F10 (S50° W, 15°)				F				R					F^
DP-F11 (S30° E, 22°)				F				R					F^
DP-F12 (S, 18°)			F (Natural forest)										F^
DP-F13 (N10° W, 20°)			F (Natural forest)										F^
DP village (granite)													
DP-C1 (S30° W, 32°)	R							F					R^
DP-F2 (S80° E, 28°)		F					R			F			F^
DP-F3 (E, 27°)		Since 1970						F					F^
DP-F9 (N70° W, 31°)			F (Natural forest)										F^
DP-F14 (N20° W, 22°)	R					F					R	F	F^
HM village (granite)													
HM-C1 (N40° W, 15°)			?					F	R		F		^C
HM-C2 (N45° E, 25°)			?					F	R		F		^C
HM-F1 (N40° E, 28°)			?						F			R	^F
HM-F2 (S50° E, 27°)			?						F			R	^F
HM-F3 (N5° E, 23°)			?			R			F				^F
HM-F4 (N60° E, 29°)			?			R			F				^F
HM-F5 (N30° W, 30°)			F (Natural forest)										^F
HM-F6 (S45° W, 25°)			F (Natural forest)										^F
HM-F7 (N20° W, 20°)			?					F	R		F		^F
HM-F8 (N60° E, 33°)			?					F	R		F		^F
RP village (sedimentary rock)													
RP-C1 (N60° E, 10°)	F	R	M	M				F				^R	
RP-C2 (S50° W, 10°)		?			F	M	M	M	M	F		^R	
RP-C3 (N20° W, 22°)	F	R	M	M			F			M	M	^M	
RP-C4 (S80° W, 8°)	F	R	M	M			F			Gtf	M	^M	
RP-C5 (S70° W, 20°)						F						^R	
RP-C6 (N5° W, 18°)	F	C	F		M	F		M	M	M	M	^M	
RP-C7 (S10° E, 22°)	F	M	F		M				F			^M	
RP-C8 (N65° E, 12°)	M		F			M	M	Mt	Mt	Cf	M	M^	
RP-C9 (N20° W, 18°)			F				M	M	M	G	M	F^	
RP-C10 (S15° E, 25°)					F				M	M	Mf	F^	
RP-F1 (E, 12°)	F	M					F					^F	
RP-F2 (S5° W, 25°)			F (Natural forest)									^F	
RP-F3 (S50° W, 30°)			F (Natural forest)									F^	

F : Natural or fallow forest, R : Upland rice, M : Maize, G : Ginger, C : Chilli ;
t : tillage, f : application of chemical fertilizers, ^ : Sampling

Fig. 3.1 Land use history at the study sites.

In order to evaluate the amount of available N, the content of $(NH_4^+ + NO_3^-)$-N mineralized during 4 weeks of aerobic incubation at 30℃ was determined by steam distillation using successive addition of MgO and Devarda's alloy after extraction with 2 M KCl solution from the soils (Keeney and Nelson 1982; Inoko 1986). The amount of available P extracted with 0.001 M H_2SO_4 and $(NH_4)_2SO_4$ solution at pH 3.0 (Truog 1930) was determined by the molybdophosphoric blue method.

Particle size distribution was determined by the pipette method. Clay minerals were identified by X-ray diffraction (XRD) analysis using Cu-K α radiation.

At selected profiles in the HM and RP villages, bulk density of the soils was determined using 100 mL core samples.

3.2.3 Charge characteristics of the soils

The charge characteristics were analyzed by the ion adsorption method for the soils at the 30-40 cm depth from DP-C1, DP-C2, DP-F7, HM-C1, and RP-F2, which were selected based on their characteristic properties in clay mineralogy (see Fig. 3.3), and surface 10 cm soils from RP-F2 and RP-C6. In addition, to evaluate the effect of organic matter on the soil charge characteristics, the surface soil sample from RP-F2 was treated with H_2O_2 to decompose organic matter and determined ion adsorption curve. Ion adsorption method employed here is described below.

The soil samples were crushed to pass through a 0.2 mm mesh sieve. In a 50 mL centrifugation tube, 2 g of soil samples were washed with 1 M NaCl solution three times and successively with 0.1 M or 0.02 M NaCl solution at pH values ranging from 4 to 8. The samples were equilibrated in the 0.1 or 0.02 M NaCl solutions at each pH for 2 d. The solution pH was adjusted to each objective pH with dilute HCl or NaCl solution, if necessary. After centrifugation, Na and Cl ions adsorbed on the soils were extracted with 0.5 M KNO_3 and then Na was determined by AAS and Cl by mercury(II) thiocyanate colorimetry at 460 nm. Content of Al ion in the extract was measured by the titration method used for the determination of exchangeable Al, because it sometimes occupied the cation exchange sites in the pH range below 5 during the equilibration (Gillman 1984; Gillman and Sumpter 1986). The amounts of Na, Al, and Cl in the occluded solution were corrected based on their concentration in the supernatant and the weight of the occluded solution. The amounts of negative charges of the soils at each pH was calculated by the sum of the amounts of adsorbed Na and Al, whereas that of positive charges was calculated based on the amount of adsorbed Cl.

3.3 Results and discussion

3.3.1 General physicochemical properties of the soils

General physicochemical properties of the soils are presented in Table 3.2. The mean, maximum, and minimum values of the general physicochemical properties of the soils are presented in Table 3.3 in relation to the villages and parent materials.

(1) Total C was considered to be mostly composed of organic carbon because of acidic conditions of the soils. The contents of total C and N in the surface 10 cm depth ranged from 11.4 to 63.3 g C kg^{-1} and from 0.7 to 4.8 g N kg^{-1}, respectively, whereas those in the 30-40 cm depth ranged from 3.5 to 25.4 g C kg^{-1} and from 0.2 to 2.0 g N kg^{-1}, respectively. The soils from the DP village generally showed higher organic matter contents than the others, presumably due to the higher altitude and longer fallow period of the DP village. According to the results from the soils under cropping or fallow in this study and by other researchers (Nakano 1978; Yoshinaga et al. 1989; Sakurai et al. 1996), as a whole, the organic matter content from the northern region of Thailand was higher than that from the other regions, where the content was mostly less than 20 g C kg^{-1} in the surface layers. Especially, in northeast Thailand, the content was often less than 10 g C kg^{-1} in the surface layers (Miura 1991; Ota et al. 1997), presumably due to sandy characteristic of the soils.

(2) The pH(H_2O) and pH(KCl) of the soils mostly ranged from 5 to 7 and from 4 to 6, respectively. It was higher in the surface 10 cm soil layers than in the 30-40 cm layers. In the surface soils, exchangeable bases such as Ca and Mg were dominant, whereas exchangeable Al was often predominant in the subsoils. Compared with the soils under tropical rain forest with an udic soil moisture regime (Ohta et al. 1993), where Al saturation usually exceeded 70 %, the acidic condition of the soils studied was not pronounced. This was thought to reflect an ustic moisture regime in *-this region or accumulation of bases by biological recycling (Wada 1986; Yoshinaga et al. 1989).

(3) CEC values varied widely, ranging from 7.3 to 27.9 cmol(+) kg^{-1} in the surface 10 cm and from 4.3 to 16.3 cmol(+) kg^{-1} at the 30-40 cm depth, respectively. Judging from the fact that the CEC values were generally higher than the sum of exchangeable cations (Na, K, Mg, Ca, and Al), i.e. effective CEC (ECEC), a certain amount of variable negative charges occurred in the soils.

(4) The clay content ranged from 11.9 to 59.3 % in the surface 10 cm soil layers and from 13.1 to 66.4 % in the 30-40 cm soil layers. In general, the soils derived from sedimentary rocks were more clayey than those from granite.

Especially, in the RP village, the clay contents in all of the soils from 30-40 cm layers exceeded 50 %. On the contrary, the content of coarse sand fraction was higher in the granite-derived soils than in the soils derived from sedimentary rocks, mainly due to the higher content of quartz grains in the former.

Figure 3.2 shows relationship between the clay content of the soils from the surface 10 cm depth and that from the 30-40 cm depth. In the DP village, there is no difference between the clay contents of the surface 10 cm soils and the 30-40 soils under cultivation or fallow, compared with the case of natural forest. On the other hand, some soils from the HM and RP villages showed lower clay contents in the surface 10 cm than that in the 30-40 cm layers, compared with the case of natural forest. This suggests the presence of relatively severe soil erosion in the field under the intensive land use with short fallow or continuous cropping, of which degree was thought to be depend on topographic conditions or land use patterns.

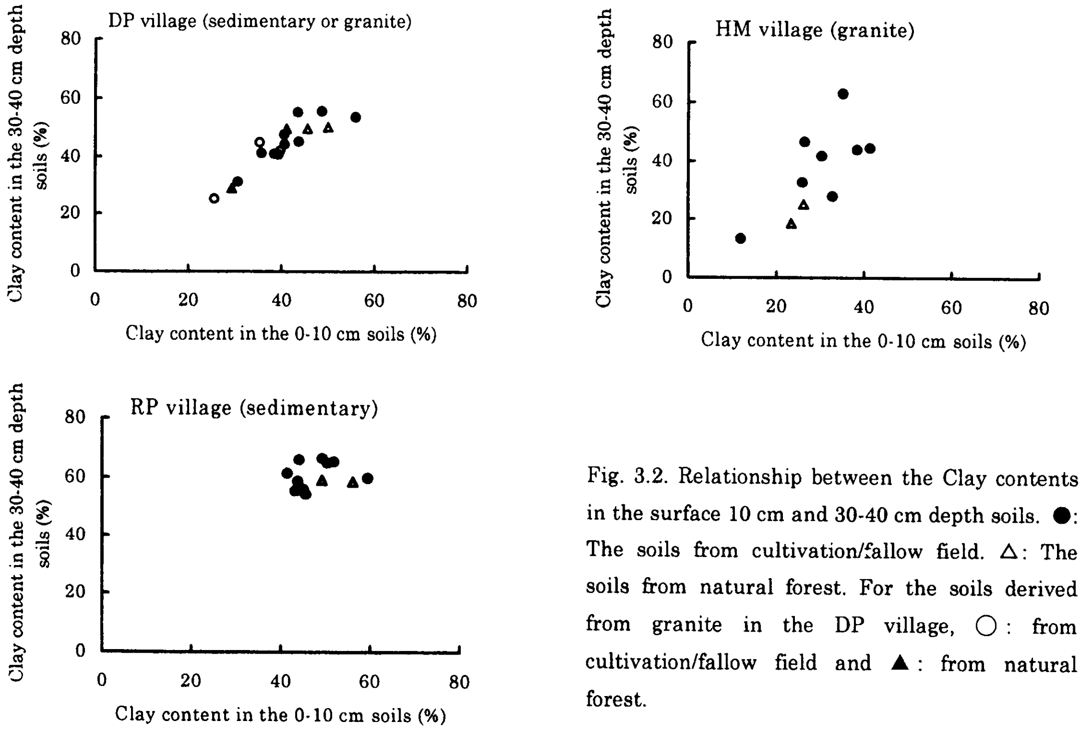


Fig. 3.2. Relationship between the Clay contents in the surface 10 cm and 30-40 cm depth soils. ●: The soils from cultivation/fallow field. △: The soils from natural forest. For the soils derived from granite in the DP village, ○: from cultivation/fallow field and ▲: from natural forest.

3.2 Clay mineralogy of the soils

X-ray diffractograms of the representative samples are shown in Fig. 3.3. Clay mineral composition of the soils was characterized by various degrees of mixture of kaolin minerals and clay mica, with a certain amount of 2:1-2:1:1 intergrade minerals. Compared with Ultisols, Oxisols, Alfisols, etc. previously reported in Thailand (Ogawa et al. 1981; Inoue 1986; Yoshinaga et al. 1989) or with Ultisols in Indonesia (Ohta, et al. 1992), in which kaolin minerals generally predominated, the soils studied seemed relatively rich in 2:1 clay minerals. Only two profiles out of 40, DP-C1 and DP-F9, contained a significant amount of smectite.

Figure 3.4 is a scattergram of the percentage of clay content in the fine earth fraction (<2 mm) and the ratio of peak area at 1.0 nm to that at 0.7 nm in the XRD spectrum of K saturated clay sample after heating at 350℃ (I_{10}/I_7 (K350)), which is considered to give a relative amount of 2:1 clay minerals to 1:1 kaolin minerals because most of the 1.4 nm minerals had collapsed to around 1.0 nm after K saturation and heating at 350℃. According to Fig. 3.4, all the soils contained significant amounts of 2:1 clay minerals. The soils from the RP village showed a higher clay content with a relatively high content of 2:1 clay minerals than the others. On the contrary, the soils derived from granite were characterized by a relatively coarse texture.

Figure 3.4 also shows the decreasing trend in the (I_{10}/I_7 (K350)) ratio with the increase of the clay content in the granite-derived soils, suggesting that kaolin minerals had been formed the through weathering process of granite. Nonetheless, the correlation between the ratio of (I_{10}/I_7 (K350)) and CEC/clay in the subsoils was not significant (Fig. 3.5), indicating that the increase in the content of 2:1 clay minerals did not always result in the increase in the CEC of the soils. This fact suggests that the contribution of mica minerals to CEC was much more pronounced than that of kaolin minerals even among the soils with low mica contents.

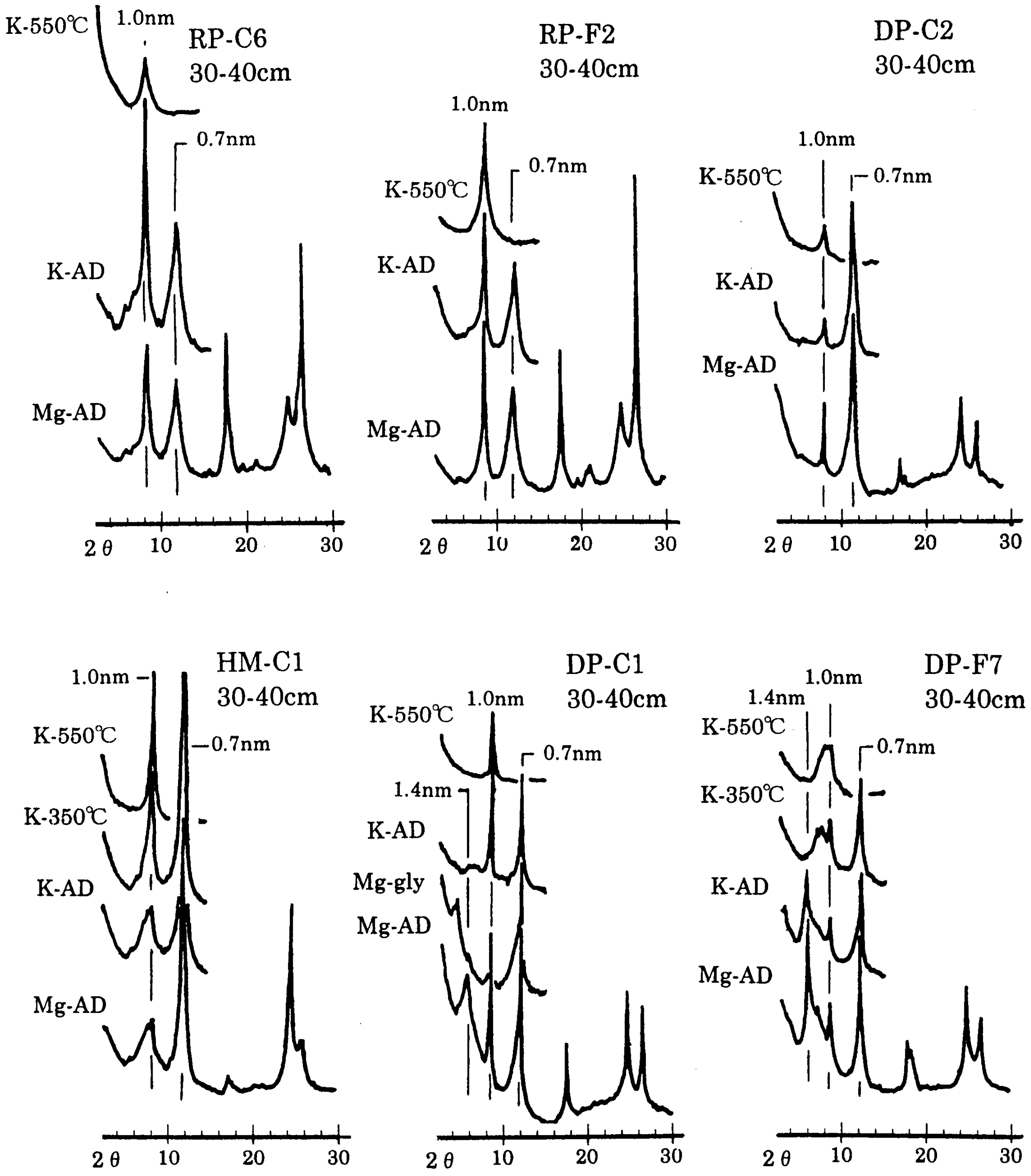


Fig. 3.3 X-ray (Cu-Kα) diffractograms of parallel oriented clay specimens from the representative soil profile. Mg-AD: Mg saturation and air-drying, Mg-Gly: Mg saturation followed by glycerol solvation, K-AD: K saturation and air-drying, K-350: K saturation and heating at 350℃, K-550: K saturation and heating at 550℃.

The general occurrence of mica minerals indicated that weathering of the soils in the study area had not been appreciable, presumably due to their location on a relatively steep slope and successive supply of new materials for soil formation. On the other hand, the soils in northeast Thailand are characterized by the clay mineral composition dominated by kaolin minerals and low nutrient holding capacity because the soils derived from Mesozoic sandstone or siltstone and this area located mainly on plateaus with gentle slope (Miura 1991).

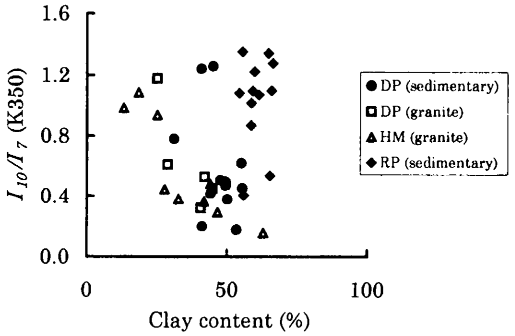


Fig. 3.4. Scattergram of the clay content and I_{10}/I_7 (K350) in the 30-40 depth soils.

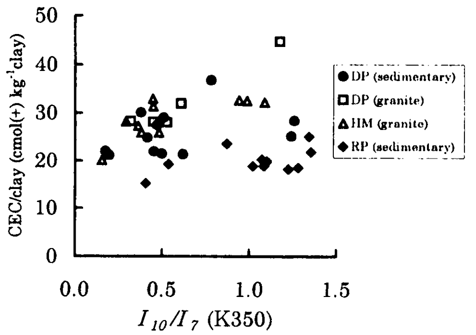


Fig. 3.5 Scatterglam of the I_{10}/I_7 (K350) and CEC/clay in the 30-40cm depth soils.

3.3.3 Charge characteristics of the soils in relation to cation retention

To investigate the effect of clay mineral composition or organic matter content on the charge characteristics on the soils, negative and positive charges in the pH range of 4 to 8 were measured by the ion adsorption method for selected soil samples (Fig. 3.6A-E).

Figure 3.6A-D shows the surface negative charges of the selected soils at different pH values, which were determined in the 0.02 or 0.1 M NaCl solution. The clay fraction of the soils from DP-C2, HM-C1, and RP-F2 was mainly composed of kaolin minerals and clay mica, whereas that from DP-C1 and DP-F7 contained a certain amount of smectite and 2:1-2:1:1 intergrade minerals, respectively, in addition to kaolin minerals and clay mica (Fig. 3.3). The total C content of the samples was almost within the same range (from 11.3 to 12.8 g C kg^{-1}), except for the case of HM-C1(18.0 g C kg^{-1}). The clay content of the samples ranged from 43 to 63 %.

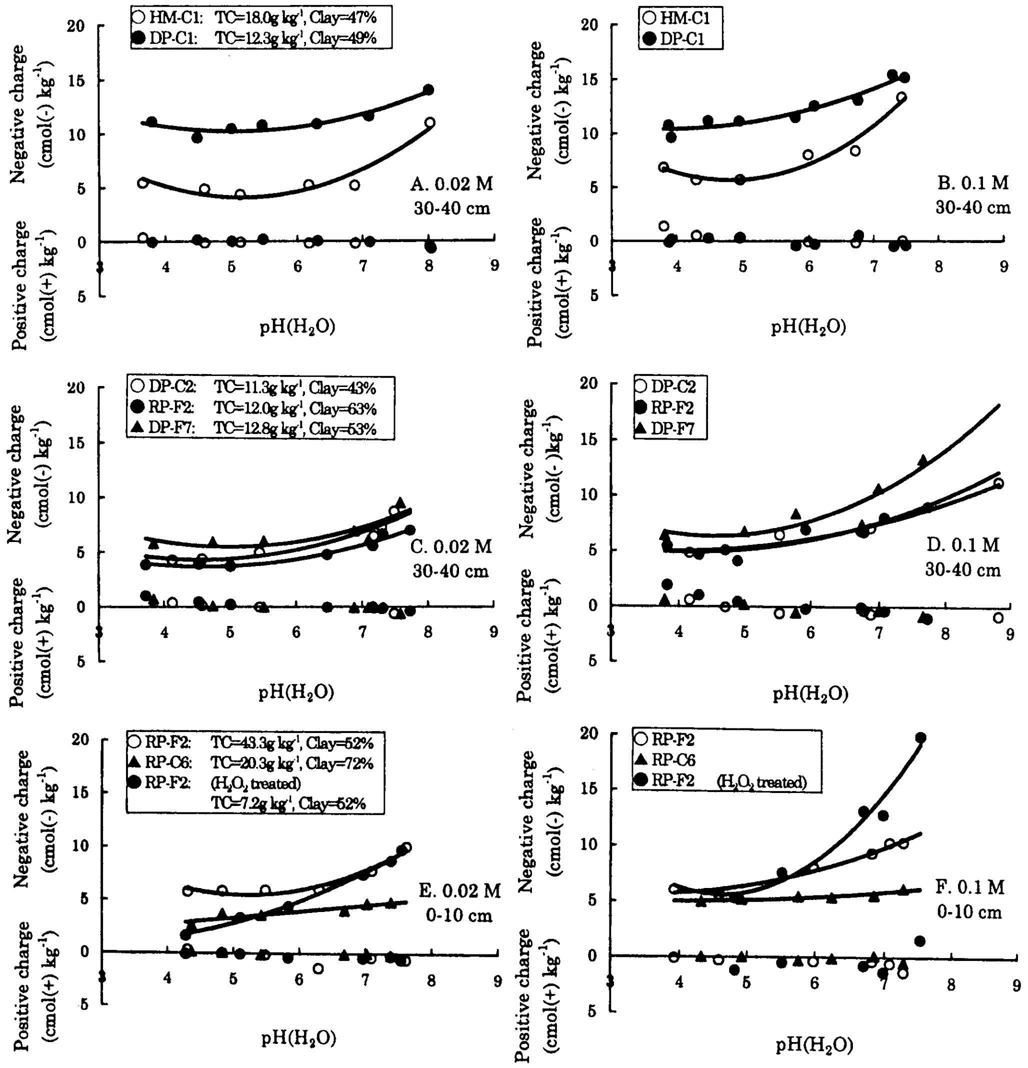


Fig. 3.6. Charge characteristics of the selected soil samples determined by the ion adsorption method.

The positive charges were scarcely detected, i.e. less than 1 cmol(+) kg^{-1} even in the pH around 4. The positive charges associated with sesquioxides were not significant for the soils studied compared to those reported for weathered tropical soils (Van Raij and Peech 1972).

In general, the soils showed almost constant negative charges at the pH below 6, suggesting that permanent negative charges predominated in this pH range. Because the amount of negative charges in the 0.1 M NaCl solution was slightly larger than that in the 0.02 M solution, a small amount of concentration-dependent surface charges may have occurred. Thus most of the subsoils were characterized by the predominance of permanent negative charges with some amount of variable ones, which was consistent with the report on Ultisols in Thailand by Wada and Wada (1985). Among the soil samples, the amount of negative charges in the DP-C1 soils was apparently larger than in the others, presumably because of the existence of smectite. The relatively large proportion of pH-dependent variable negative charges observed in the HM-C1 soil could be attributed to the higher content of organic matter in this sample than in the other soils.

On the other hand, in the soils from the surface 10 cm layer, the proportion of variable negative charges increased as the content of organic matter increased, suggesting the contribution of organic matter to the cation retention of the soils through the dissociation of acidic functional groups, especially in the higher pH above 6 (Fig. 3.6E, F).

It was concluded that the soils examined were dominated by permanent negative charges in the pH range below 6, whereas the amount of variable negative charges increased especially in the pH range above 6, which was determined by the organic matter content.

3.4 Soil acidity and organic matter content as main factors to determine soil chemical fertility in the study area

3.4.1 Cation retention of the surface 10 cm depth soils

Figure 3.7 shows a highly positive correlation between the total C content and CEC in the surface 10 cm soils (R^2=0.79). This suggests that capacity to retain basic cations was primarily determined by the organic matter content in spite of the significant variations observed in the soil texture or clay mineralogy. On the other hand, there is no significant relation between the clay content and CEC in the surface soils.

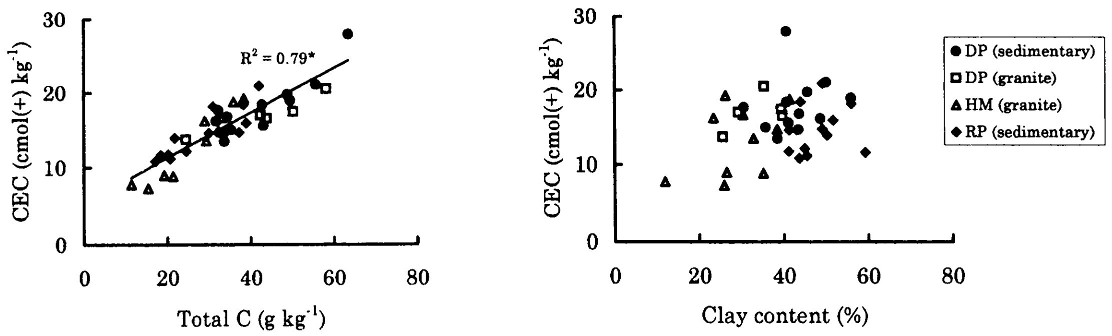


Fig. 3.7. Relationship between total C or clay content and CEC of the surface 10 cm depth soils.

Figure 3.8 shows that the content of exchangeable bases was higher in the soils with higher pH. In the soils with a pH value below 6, the ECEC of the soils was low and its value was almost similar to each other, compared to that in higher pH range. The effect of variable negative charges on cation retention seemed to be limited in the pH value below 6. Therefore, exchangeable bases and Al were considered to coexist on the cation exchangeable sites derived from permanent negative charges and the proportion of the exchangeable bases to the exchangeable cations increased in the soils with higher pH. On the other hand, in the pH above 6, the increase in the amount of the variable negative charges led to a clear increase in the retention of exchangeable bases. Thus, the contents of exchangeable bases directly reflected the soil pH under field conditions.

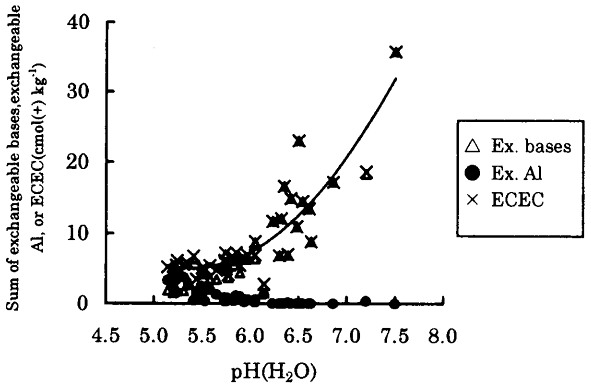


Fig. 3.8. Relationship between pH(H_2O) and sum of exchangeable bases, content of exchangeable Al, or ECEC in the soils from the surface 10cm depth.

3.4.2 Cation retention of the 30-40 cm depth soils

Unlike the results from the surface 10 cm soils, the soils from the 30-40 cm depth have a positive correlation between CEC and clay content (Fig. 3.9; R^2=0.46). Thus, the soil texture largely determined the capacity for cation retention in the soils from 30-40 cm depth. In general, the granite-derived soils showed the higher content of quartz grains, lower content of clay, and lower CEC value than the soils derived from fine-textured sedimentary rocks.

Since in the 30-40 cm soils, pH(H_2O) value ranged from 5 to 6 and ECEC did not substantially changed associating with the pH (Fig. 3.10), it was considered that the contribution of variable negative charges to cation retention was limited and that exchangeable bases and Al competed for permanent negative charge sites of the soils. Because Al saturation increased with the decrease in pH, soil acidity could be a good indicator for the composition of exchangeable cations and, hence, the capacity of the subsoils to supply exchangeable bases to plants.

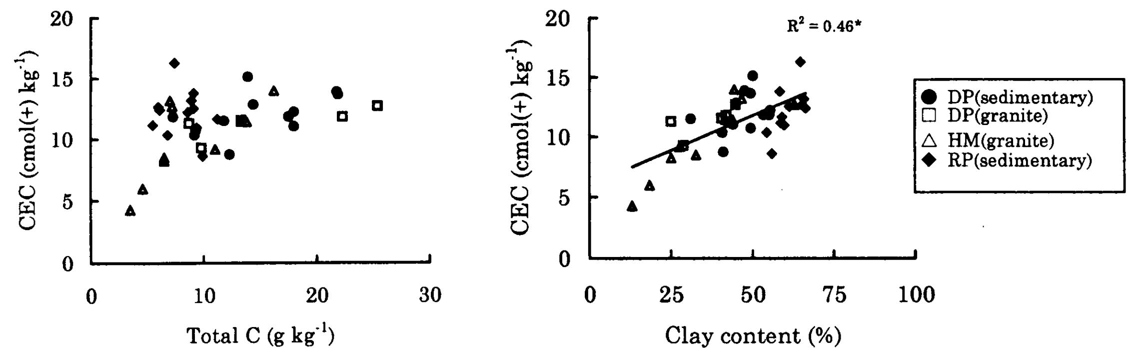


Fig. 3.9. Relationship between total C or clay content and CEC of the 30-40 cm depth soils.

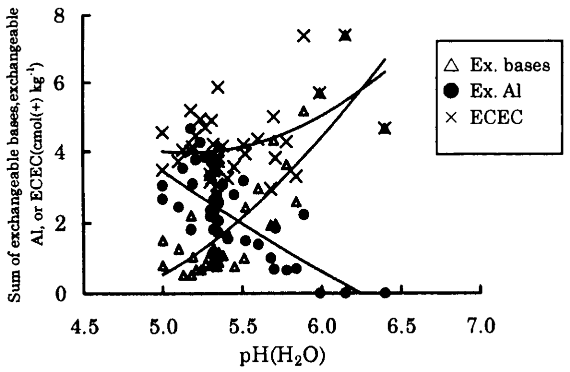


Fig. 3.10. Relationship between pH(H$_2$O) and sum of exchangeable bases, content of exchangeable Al, or ECEC in the soils from the surface 30-40cm depth.

3.4.3 Available P and N in the surface 10 cm depth soils

Figures 3.11 and 3.12 show the relationship between the soil pH and content of available P and that between the contents of organic matter and available N, respectively. The increase in the content of available F in the high pH region may be due to the increase in the content of Ca-bonded phosphate. On the other hand, the content of available N increased with the increase in the content of organic matter, presumably as its components.

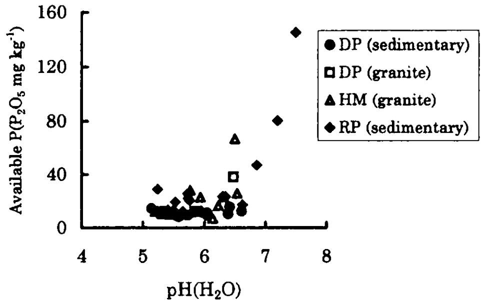


Fig. 3.11. Relationship between pH(H$_2$O) and the content of available P in the surface 10 cm depth soils.

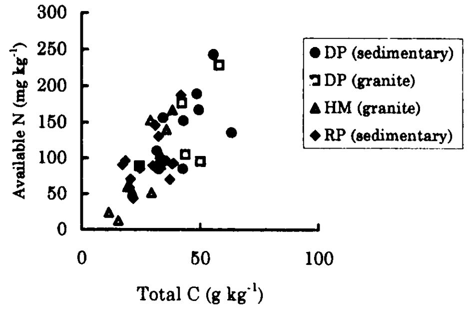


Fig. 3.12. Relationship between the contents of total C and available N in the surface 10 cm depth soils.

3.4.4 Relationship between the factors determining soil fertility and land use

Figures 3.13 and 3.14 gives a scattergram of the total C content and pH(H$_2$O) in the surface 10 cm soils and that of the clay content and Al saturation in the soils at the 30-40 cm depth, respectively. The surface 10 cm soils under fallow forest were mostly acidic with pH value lower than 6, whereas those after the slash and burn practice generally showed higher pH value than 5.8 with total C content lower than 40 g kg^{-1} (Fig. 3.13). Figure 3.14 exhibits that Al saturation was lower in the subsoils after the slash and burn practice than under fallow forest. Therefore, the acidic nature of the soils under fallow forest was ameliorated by ash input along with the slash and burn practice in shifting cultivation, accompanied with the decomposition of organic matter in the surface soils. In addition, the surface 10 cm soils in the DP village were characterized by higher contents of organic matter than 35 g C kg^{-1} (Fig. 3.13). This could be attributed to the more supply of organic matter from fallow vegetation during longer period in the DP village (Chapter 5) in addition to the lower temperature in the DP village (approximately 1,200 m altitude) than in the others. Figure 3.14 also shows that the clay contents in the soils derived from granite in the DP and HM villages were lower than in those derived from fine-textured sedimentary rocks in the DP and RP villages.

Thus the soil acidity both in the surface soils and the subsoils, organic matter content in the surface soils, and clay content in the subsoils could be used as indicators reflecting the fertility status of the soils under shifting cultivation in the area. In the following chapters, the former two properties will be analyzed in more detail in relation to the land use stages in shifting cultivation because they depend largely on soil management.

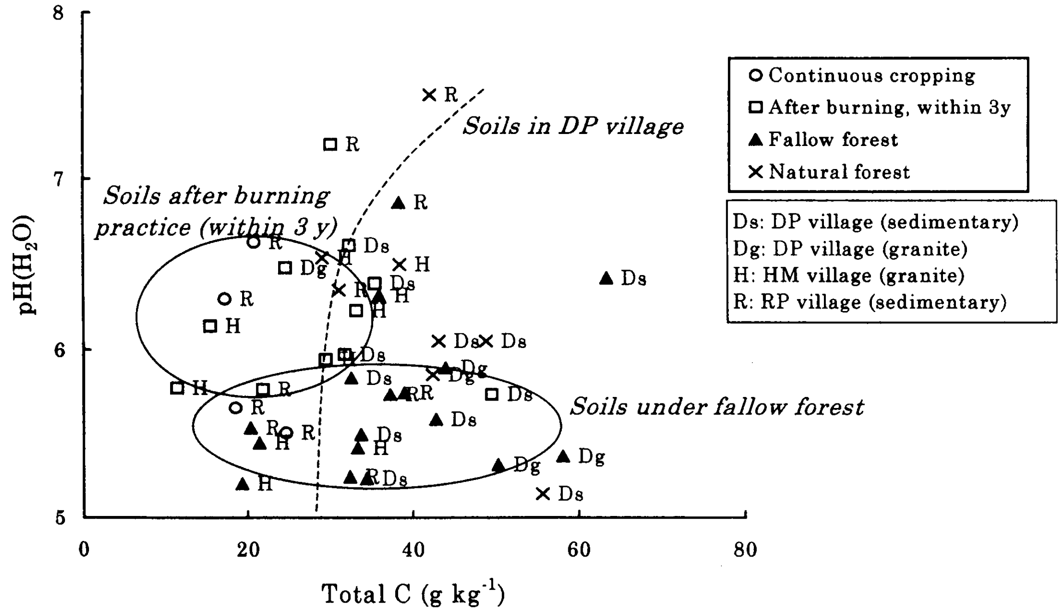


Fig. 3.13. Scattergram of the total C content and pH(H_2O) in the soils from the surface 10cm depth.

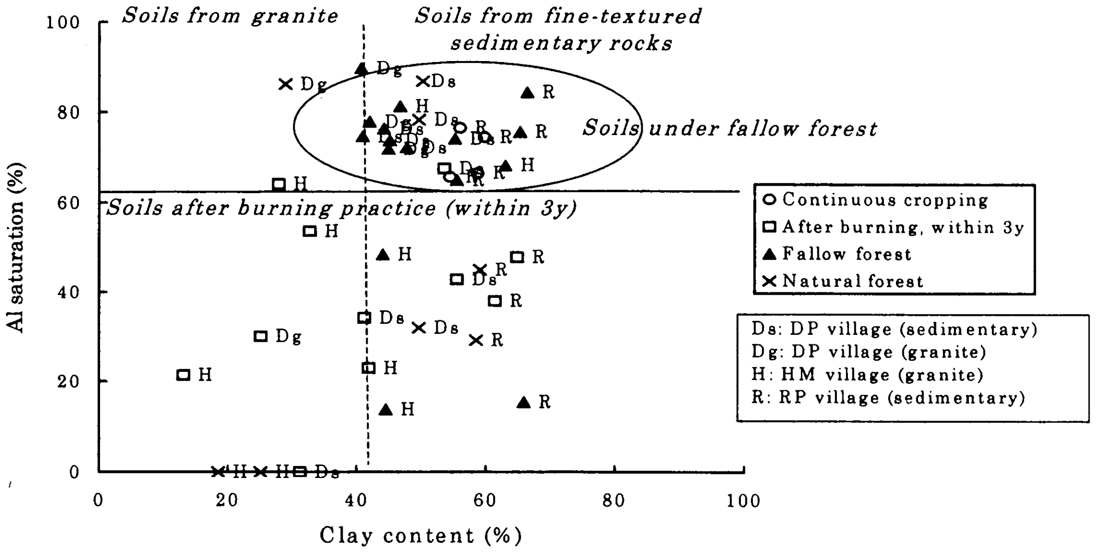


Fig. 3.14. Scattergram of the clay content and Al saturation in the soils from the 30-40 cm depth.

Table 3.2. General physicochemical properties of the soils.

Site and depth(cm)	pH H_2O	pH KCl	CEC[a]	Exchangeable cations[a] Na	K	Mg	Ca	Al	H	Sum of ex. bases[a]	Effective CEC[a]	Al Saturation
				(cmol(+) kg^{-1})								(%)
DP village (Du La Poe; derived from fine textured sedimentary rocks)												
DP−C2 (1st year of cultivation after 8 year's fallow)												
0-10	6.4	5.0	15.0	0.02	0.83	2.36	3.76	0.14	0.34	6.97	7.11	2.0
10-20	5.9	4.6	12.4	0.02	0.70	1.14	1.86	0.73	0.58	3.72	4.45	16.4
20-30	5.6	4.5	9.4	0.02	0.34	0.71	1.07	1.27	0.80	2.14	3.41	37.2
30-40	5.7	4.5	8.7	0.02	0.26	0.69	0.96	1.01	0.50	1.94	2.95	34.3
40-50	5.7	4.6	9.3	0.02	0.22	0.64	0.91	1.10	0.55	1.78	2.88	38.1
DP−C3 (1st year of cultivation after 8 year's fallow)												
0-10	5.7	4.6	18.9	0.04	0.31	1.70	3.17	0.88	0.46	5.21	6.09	14.4
30-40	5.3	4.4	11.8	0.02	0.09	0.37	0.51	2.07	0.70	0.99	3.06	67.7
DP−F1 (1st year of fallow forest after cultivation)												
0-10	6.0	4.5	16.2	0.04	1.04	1.94	3.38	0.59	0.56	6.40	6.99	8.4
10-20	5.6	4.2						1.91	0.79			
20-30	5.5	4.2						1.41	0.72			
30-40	5.3	4.2	12.2	0.04	0.51	0.66	1.19	1.81	1.11	2.40	4.21	43.0
40-50	5.4	4.3						1.69	1.09			
DP−F4 (1st year of fallow forest after cultivation)												
0-10	6.6	5.5	17.7	0.03	0.92	3.22	9.34	0.00	0.24	13.51	13.51	0.0
30-40	6.2	4.8	11.5	0.04	0.59	1.84	4.93	0.00	0.40	7.40	7.40	0.0
DP−F10 (5th year of fallow forest)												
0-10	6.4	5.3	27.9	0.03	0.84	3.80	10.26	0.00	0.30	14.93	14.93	0.0
30-40	5.3	4.2	13.9	0.05	0.30	0.37	0.35	2.77	1.01	1.06	3.83	72.3
DP−F11 (5th year of fallow forest)												
0-10	5.6	4.3	18.3	0.04	0.31	1.48	1.69	1.98	0.78	3.52	5.50	36.0
10-20	5.4	4.3						2.46	0.63			
20-30	5.3	4.3						2.32	0.67			
30-40	5.3	4.2	11.0	0.02	0.20	0.34	0.25	2.64	0.81	0.82	3.46	76.4
40-50	5.3	4.2						2.59	0.69			
DP−F6 (8th year of fallow forest)												
0-10	5.8	4.6	14.7	0.07	0.71	2.24	3.14	0.41	0.58	6.16	6.57	6.2
10-20	5.6	4.2						1.51	0.49			
20-30	5.4	4.2						2.59	0.15			
30-40	5.4	4.2	11.8	0.02	0.37	0.38	0.14	2.60	0.69	0.91	3.51	74.2
40-50	5.4	4.2						2.66	0.61			
DP−F7 (8th year of fallow forest)												
0-10	5.2	4.0	16.8	0.03	0.62	1.17	0.32	3.42	1.22	2.14	5.56	61.5
30-40	5.4	4.1	12.8	0.02	0.40	0.63	0.04	3.07	1.20	1.09	4.16	73.8
DP−F8 (17th year of fallow forest)												
0-10	5.5	4.2	13.4	0.02	0.69	0.73	0.43	2.51	0.92	1.88	4.39	57.2
10-20	5.7	4.1	11.1	0.02	0.47	0.29	0.22	2.44	0.38	1.01	3.45	70.8
20-30	5.2	4.0	11.5	0.02	0.41	0.19	0.15	2.69	0.51	0.77	3.46	77.7
30-40	5.3	4.1	10.3	0.03	0.43	0.19	0.15	2.36	0.76	0.80	3.15	74.7
40-50	5.4	4.1	10.5	0.02	0.44	0.19	0.11	2.86	0.41	0.76	3.62	79.0
DP−F5 (natural forest)												
0-10	6.1	4.9	19.7	0.03	1.13	2.67	4.91	0.16	0.43	8.74	8.90	1.8
10-20	5.8	4.6	15.9	0.02	0.72	1.71	2.53	0.76	0.46	4.97	5.73	13.2
20-30	5.7	4.5	13.8	0.02	0.65	1.27	1.73	1.04	0.56	3.67	4.71	22.1
30-40	5.6	4.4	13.6	0.02	0.57	1.01	1.35	1.40	0.69	2.95	4.35	32.1
40-50	5.6	4.4	14.4	0.02	0.48	0.91	1.37	1.49	0.48	2.78	4.28	34.9
DP−F12 (natural forest)												
0-10	6.1	4.6	15.5	0.02	0.82	2.53	3.04	0.61	0.62	6.41	7.02	8.7
10-20	5.6	4.2	11.2	0.02	0.58	0.66	0.47	2.18	0.46	1.73	3.91	55.7
20-30	5.4	4.1	10.5	0.03	0.48	0.22	0.14	2.79	0.56	0.87	3.65	76.3
30-40	5.5	4.1	10.7	0.02	0.39	0.20	0.16	2.79	0.70	0.77	3.56	78.4
40-50	5.5	4.2	12.5	0.02	0.42	0.21	0.21	2.81	0.47	0.86	3.67	76.6
DP−F13 (natural forest)												
0-10	5.1	4.0	21.0	0.04	0.44	0.70	0.75	3.35	1.80	1.93	5.28	63.4
30-40	5.1	4.1	15.1	0.03	0.23	0.20	0.07	3.52	1.84	0.53	4.05	86.9

[a] Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	Total C[a]	Total N[a]	Available N[a]	Available P_2O_5[a]	Bulk density	Particle size distribution C.sand	F.sand	Silt	Clay	Gravel content	CEC /clay	I10/I7 at K350
	(g kg^{-1})		(mg kg^{-1})		(g cm^{-3})	(%)					(cmol(+) kg^{-1}clay)	
DP village (Du La Poe; derived from fine textured sedimentary rocks)												
DP−C2 (1st year of cultivation after 8 years fallow)												
0-10	35.3	2.4	96	10		9.1	28.1	27.1	35.7	2.0	41.9	0.3
10-20	24.3	1.8				4.6	29.6	25.5	40.2	2.3	30.9	
20-30	15.3	1.2				4.3	27.9	27.0	40.8	1.9	23.2	
30-40	12.3	0.9				3.7	30.3	24.9	41.2	2.7	21.2	0.2
40-50	12.2	1.0				3.1	28.8	26.1	41.9	1.9	22.2	
DP−C3 (1st year of cultivation after 8 years fallow)												
0-10	49.4	3.2	167	9		7.5	14.4	22.2	55.9	4.6	33.8	0.2
30-40	17.5	1.2				10.2	14.5	21.8	53.5	1.9	22.0	0.2
DP−F1 (1st year of fallow forest after cultivation)												
0-10	31.7	2.5	110	11		7.6	19.1	24.6	48.7	1.5	33.2	1.0
10-20	26.5	2.2				8.7	19.7	24.0	47.6	1.2		
20-30	26.0	2.2				7.3	21.2	24.1	47.4	0.5		
30-40	18.0	1.6				6.2	18.4	19.9	55.5	0.7	22.0	0.5
40-50	17.8	1.5				5.3	17.7	25.5	51.5	0.5		
DP−F4 (1st year of fallow forest after cultivation)												
0-10	32.2	2.6	89	12		18.4	24.2	26.8	30.6	16.0	57.7	1.0
30-40	11.8	1.0				21.7	22.9	24.2	31.2	22.1	36.8	0.8
DP−F10 (5th year of fallow forest)												
0-10	63.3	4.8	136	16		11.3	23.6	24.5	40.6	5.9	68.6	0.8
30-40	21.8	1.7				7.2	24.4	20.7	47.7	5.7	29.1	0.5
DP−F11 (5th year of fallow forest)												
0-10	42.7	3.2	85	8		11.5	26.6	21.2	40.7	5.7	45.1	0.6
10-20	31.9	2.5				10.9	29.9	14.2	45.0	8.6		
20-30	22.2	1.8				9.2	30.8	12.5	47.5	8.0		
30-40	18.0	1.4				5.4	28.3	22.1	44.2	8.0	24.9	0.4
40-50	17.5	1.3				13.8	32.0	10.6	43.6	7.5		
DP−F6 (8th year of fallow forest)												
0-10	32.5	2.0	84	12		8.8	25.8	21.9	43.5	5.4	33.7	1.0
10-20	14.0	1.1				7.7	10.6	23.1	58.6	2.7		
20-30	9.0	0.8				5.3	20.4	18.5	55.8	3.5		
30-40	7.3	0.6				5.4	19.0	20.4	55.2	1.8	21.4	0.6
40-50	6.0	0.6				5.4	19.1	17.4	58.1	1.0		
DP−F7 (8th year of fallow forest)												
0-10	34.4	2.2	156	12		12.8	19.4	24.0	43.7	7.1	38.4	1.5
30-40	14.4	0.9				14.2	16.2	24.5	45.1	10.6	28.4	1.3
DP−F8 (17th year of fallow forest)												
0-10	33.7	2.3	97	10		13.3	23.5	24.7	38.5	8.3	34.9	1.8
10-20	16.1	1.2				11.1	22.2	24.6	42.1	11.8	26.5	
20-30	10.7	0.9				11.7	19.7	26.3	42.3	9.1	27.2	
30-40	9.2	0.8				9.9	23.5	25.7	40.9	17.8	25.2	1.2
40-50	5.8	0.6				10.1	16.8	29.0	44.1	26.9	23.9	
DP−F5 (natural forest)												
0-10	48.7	3.7	189	9		13.8	20.1	20.5	45.6	14.9	43.2	0.5
10-20	30.4	2.4				12.4	21.4	24.7	41.4	29.4	38.3	
20-30	25.3	2.0				12.3	21.4	15.1	51.2	21.8	27.0	
30-40	21.9	1.7				14.5	19.4	16.5	49.6	23.2	27.5	0.5
40-50	21.6	1.6				15.7	19.3	14.6	50.5	20.8	28.5	
DP−F12 (natural forest)												
0-10	43.0	2.7	152	12		7.1	24.9	27.0	41.1	1.3	37.8	0.5
10-20	17.0	1.1				6.1	20.3	29.1	44.5	8.7	25.3	
20-30	12.0	0.8				4.8	20.8	26.0	48.4	2.3	21.8	
30-40	9.3	0.7				3.1	20.2	27.0	49.6	1.4	21.5	0.5
40-50	9.5	0.7				4.5	18.5	24.9	52.1	1.4	24.1	
DP−F13 (natural forest)												
0-10	55.6	3.6	243	15		4.2	20.1	25.7	50.0	0.6	42.0	0.4
30-40	13.9	1.0				4.2	21.8	23.8	50.2	0.8	30.1	0.4

[a] Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	pH H_2O	pH KCl	CEC[a]	Exchangeable cations[a] Na	K	Mg	Ca	Al	H	Sum of ex. bases[a]	Effective CEC[a]	Al Saturation
			------------------------			(cmol(+) kg^{-1})				----------------------------		(%)
DP village (Du La Poe; derived from granite)												
DP−C1 (1st year of cultivation after 11 years fallow)												
0-10	6.5	5.3	13.7	0.03	1.39	4.34	5.25	0.00	0.26	11.01	11.01	0.0
10-20	5.8	4.4	13.2	0.02	0.85	2.26	2.03	2.21	1.41	5.17	7.38	30.0
20-30	5.7	4.4	12.3	0.02	0.75	1.89	1.78	2.22	0.67	4.44	6.67	33.4
30-40	5.9	4.3	11.3	0.02	0.77	2.25	2.12	2.23	0.76	5.16	7.38	30.1
40-50	5.9	4.4	11.4	0.01	0.78	2.27	1.97	2.29	0.57	5.03	7.31	31.3
DP−F14 (2nd year of fallow forest)												
0-10	5.3	4.2	17.4	0.03	0.63	0.68	0.50	3.79	0.88	1.84	5.63	67.3
10-20	5.2	4.2						3.86	0.63			
20-30	5.2	4.2						4.36	0.25			
30-40	5.2	4.1	11.5	0.01	0.33	0.15	0.04	4.66	0.84	0.53	5.19	89.7
40-50	5.2	4.1						4.68	0.68			
DP−F2 (6th year of fallow forest)												
0-10	5.9	4.6	16.5	0.03	0.81	1.75	1.85	1.06	0.48	4.43	5.49	19.3
10-20	5.5	4.4						2.21	0.88			
20-30	5.4	4.4						2.16	1.09			
30-40	5.3	4.4	11.8	0.02	0.42	0.15	0.18	2.73	0.78	0.77	3.50	77.9
40-50	5.4	4.3						2.82	0.96			
DP−F3 (more than 25 years of fallow forest)												
0-10	5.4	4.3	20.4	0.03	0.61	1.21	1.28	2.62	0.64	3.13	5.75	45.6
10-20	5.5	4.4						2.49	0.91			
20-30	5.4	4.4						2.20	1.13			
30-40	5.3	4.4	12.6	0.05	0.34	0.35	0.16	2.33	0.71	0.91	3.24	71.9
40-50	5.3	4.4						2.35	0.47			
DP−F9 (natural forest)												
0-10	5.9	4.5	17.0	0.03	0.67	2.01	3.50	1.16	0.44	6.20	7.36	15.8
10-20	5.3	4.2	13.7	0.03	0.52	0.72	0.72	3.32	0.79	1.98	5.30	62.6
20-30	5.3	4.3	9.8	0.02	0.35	0.49	0.49	3.86	0.66	1.34	5.21	74.2
30-40	5.2	4.3	9.2	0.04	0.32	0.27	0.05	4.26	1.59	0.68	4.94	86.2
40-50	5.3	4.3	10.3	0.03	0.34	0.29	0.09	4.25	0.64	0.75	5.00	85.0

[a]Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	Total C[a]	Total N[a]	Available N[a]	Available P_2O_5[a]	Bulk density	Particle size distribution C.sand	F.sand	Silt	Clay	Gravel content	CEC /clay (cmol(+) kg^{-1}clay)	I10/I7 at K350
	(g kg^{-1})		(mg kg^{-1})		(g cm^{-3})	---------------		(%)	---------------			
DP village (Du La Poe; derived from granite)												
DP−C1 (1st year of cultivation after 11 years fallow)												
0-10	24.5	2.1	89	38		48.7	13.0	12.6	25.6	11.7	53.5	1.3
10-20	16.8	1.6				38.5	16.6	14.6	30.3	8.2	43.6	
20-30	11.4	1.0				46.7	13.6	12.6	27.2	17.7	45.2	
30-40	8.7	0.8				51.3	10.7	12.9	25.1	21.5	44.8	1.2
40-50	10.6	1.0				44.3	15.0	14.3	26.4	19.9	43.2	
DP−F14 (2nd year of fallow forest)												
0-10	50.2	3.4	95	10		40.6	8.8	11.2	39.4	10.0	44.2	0.4
10-20	26.3	1.9				36.6	11.4	11.9	40.0	12.4		
20-30	17.6	1.4				34.2	12.1	13.8	40.0	12.6		
30-40	13.3	1.1				34.3	11.5	13.5	40.7	15.0	28.3	0.3
40-50	11.8	1.0				37.4	9.0	13.9	39.7	20.5		
DP−F2 (6th year of fallow forest)												
0-10	43.8	3.3	105	12		38.7	7.9	13.7	39.7	6.3	41.6	0.7
10-20	29.1	2.4				38.0	9.8	9.3	42.9	9.1		
20-30	25.3	2.0				39.4	12.6	8.7	39.2	11.4		
30-40	22.3	1.6				35.6	8.1	14.2	42.0	10.0	28.0	0.5
40-50	18.5	1.4				34.2	7.9	12.8	45.1	8.9		
DP−F3 (more than 25 years of fallow forest)												
0-10	58.0	4.3	228	12		31.9	7.3	25.5	35.3	7.7	57.9	0.3
10-20	41.1	3.3				35.1	11.1	15.7	38.2	6.7		
20-30	32.2	2.5				33.6	8.5	16.9	40.9	9.3		
30-40	25.4	2.0				28.0	9.8	17.4	44.9	12.6	28.2	0.4
40-50	22.9	1.8				31.1	10.8	7.6	50.5	18.5		
DP−F9 (natural forest)												
0-10	42.3	3.3	176	12		46.9	9.2	14.6	29.3	10.1	57.9	0.5
10-20	23.3	2.0				41.0	10.9	14.5	33.6	10.9	40.7	
20-30	16.7	1.4				48.1	8.9	13.8	29.2	13.2	33.5	
30-40	9.8	0.8				40.6	14.1	16.5	28.9	16.9	32.0	0.6
40-50	9.2	0.8				49.9	10.5	14.8	24.8	9.0	41.5	

[a]Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	pH H_2O	pH KCl	CEC[a]	Exchangeable cations[a] Na	K	Mg	Ca	Al	H	Sum of ex. bases[a]	Effective CEC[a]	Al Saturation (%)
				(cmol(+) kg^{-1})								
HM village (Huai Mak Nun; derived from granite)												
HM−C1 (1st year of cultivation after 3 year's fallow)												
0-10	5.9	4.6	13.5	0.03	0.77	2.74	2.78	0.22	0.44	6.30	6.52	3.4
10-20	5.6	4.3	11.4	0.02	0.38	0.81	0.79	1.84	0.51	2.00	3.84	47.9
20-30	5.4	4.1	10.2	0.03	0.29	0.52	0.30	2.36	0.44	1.14	3.50	67.5
30-40	5.3	4.1	9.2	0.03	0.25	0.77	0.22	2.28	0.51	1.27	3.55	64.2
40-50	5.5	4.1	8.2	0.02	0.25	0.76	0.25	1.97	0.41	1.27	3.24	60.7
70+	5.4	4.7	7.2	0.02	0.21	1.00	0.26	1.96	0.42	1.49	3.45	56.9
HM−C2 (1st year of cultivation after 3 year's fallow)												
0-10	6.2	5.2	16.7	0.03	0.82	4.10	6.78	0.00	0.19	11.73	11.73	0.0
30-40	5.3	4.2	11.4	0.02	0.26	1.61	1.88	1.13	0.31	3.77	4.90	23.1
HM−F1 (1st year of fallow forest after 1 year's of cultivation)												
0-10	6.1	4.2	7.3	0.02	0.34	0.97	0.17	1.33	0.59	1.51	2.84	46.9
10-20	5.5	4.1						1.87	0.49			
20-30	5.3	4.0						1.91	0.64			
30-40	5.4	4.0	8.5	0.02	0.28	1.43	0.05	2.06	0.70	1.78	3.84	53.7
40-50	5.3	4.0						2.06	0.60			
HM−F2 (1st year of fallow forest after 1 year's of cultivation)												
0-10	5.8	4.2	7.8	0.03	0.30	1.70	1.67	0.46	0.28	3.70	4.16	11.1
30-40	5.8	4.1	4.3	0.02	0.18	1.80	0.59	0.71	0.34	2.59	3.30	21.5
HM−F7 (4th year of fallow forest)												
0-10	6.3	5.2	18.7	0.04	1.24	5.53	5.29	0.00	0.25	12.09	12.09	0.0
10-20	6.1	4.7						0.42	0.32			
20-30	5.8	4.4						0.50	0.12			
30-40	5.7	4.4	14.0	0.02	0.74	2.02	1.53	0.69	0.33	4.31	5.00	13.8
40-50	5.7	4.3						0.98	0.44			
70+	5.7	4.4						0.70	0.60			
HM−F8 (4th year of fallow forest)												
0-10	5.4	4.2	14.7	0.02	0.73	3.13	2.54	0.47	0.28	6.42	6.89	6.8
30-40	5.7	4.5	11.4	0.03	0.63	1.04	0.27	1.85	0.73	1.97	3.82	48.5
HM−F3 (7th year of fallow forest)												
0-10	5.2	4.0	9.0	0.02	0.56	0.71	0.26	2.26	0.63	1.55	3.81	59.3
10-20	5.1	4.0	8.9	0.02	0.42	0.20	0.05	3.14	0.64	0.69	3.83	82.0
20-30	5.2	4.0	7.8	0.02	0.41	0.13	0.04	3.16	0.74	0.60	3.76	84.1
30-40	5.3	3.9	13.2	0.02	0.46	0.36	0.04	3.82	0.94	0.88	4.70	81.3
40-50	5.4	3.9	12.9	0.02	0.49	0.16	0.03	4.34	0.97	0.71	5.05	85.9
70+	5.2	3.9	13.4	0.03	0.43	0.17	0.03	3.39	0.38	0.67	4.06	83.5
HM−F4 (7th year of fallow forest)												
0-10	5.4	4.3	8.9	0.03	0.51	0.91	0.46	1.58	0.41	1.90	3.48	45.4
30-40	5.4	4.1	12.7	0.02	0.45	0.51	0.19	2.54	1.19	1.18	3.72	68.3
HM−F5 (natural forest)												
0-10	6.5	5.8	19.2	0.03	0.84	7.12	15.03	0.00	0.26	23.03	23.03	0.0
10-20	6.3	5.3	11.2	0.02	0.58	2.04	6.03	0.00	0.18	8.67	8.67	0.0
20-30	6.0	4.7	8.5	0.03	0.59	1.68	3.77	0.00	0.19	6.06	6.06	0.0
30-40	6.0	4.5	8.2	0.03	0.59	1.79	3.29	0.00	0.26	5.69	5.69	0.0
40-50	5.9	4.4	7.9	0.02	0.51	1.41	2.93	0.12	0.19	4.87	4.99	2.4
70+	5.8	4.3	7.9	0.02	0.46	1.20	3.09	0.13	0.27	4.77	4.90	2.7
HM−F6 (natural forest)												
0-10	6.5	5.8	16.2	0.02	0.51	3.58	10.40	0.00	0.12	14.52	14.52	0.0
30-40	6.4	4.8	6.0	0.01	0.19	1.46	2.99	0.00	0.16	4.66	4.66	0.0

[a]Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	Total C[a]	Total N[a]	Available N[a]	Available P_2O_5[a]	Bulk density	Particle size distribution C.sand	F.sand	Silt	Clay	Gravel content	CEC /clay	I10/I7 at K350
	(g kg^{-1})		(mg kg^{-1})		(g cm^{-3})			(%)			(cmol(+) kg^{-1}clay)	
HM village (Huai Mak Nun; derived from granite)												
HM−C1 (1st year of cultivation after 3 years fallow)												
0-10	29.4	2.3	52	23	1.1	43.3	10.1	13.8	32.8	3.5	41.1	0.9
10-20	23.4	1.8			1.0	39.7	11.4	14.9	34.1	4.7	33.3	
20-30	16.1	1.2			1.1	38.2	10.7	16.5	34.6	4.2	29.5	
30-40	11.0	0.8			1.4	41.1	11.5	19.7	27.8	7.0	32.9	0.4
40-50	11.9	0.9				40.0	13.1	19.2	27.7	9.3	29.6	
70+	7.6	0.6				38.8	13.7	17.8	29.8	10.5	24.1	
HM−C2 (1st year of cultivation after 3 years fallow)												
0-10	33.1	2.6	106	17		36.4	16.6	16.6	30.4	4.0	54.8	0.5
30-40	13.3	1.1				36.5	11.4	10.3	41.8	3.7	27.3	0.4
HM−F1 (1st year of fallow forest after 1 year of cultivation)												
0-10	15.4	1.1	13	7	1.3	49.9	13.7	10.5	25.9	10.8	28.2	0.5
10-20	9.4	0.7				46.5	13.0	14.7	25.8	18.5		
20-30	6.2	0.5				46.3	9.7	9.1	34.8	19.7		
30-40	6.5	0.6			1.5	39.8	12.3	15.1	32.7	15.4	25.9	0.4
40-50	6.2	0.5				36.6	12.7	16.6	34.2	11.6		
HM−F2 (1st year of fallow forest after 1 year of cultivation)												
0-10	11.4	0.7	24	28		57.0	17.0	14.1	11.9	18.7	65.5	0.6
30-40	3.5	0.2				62.7	15.9	8.3	13.1	25.9	32.6	1.0
HM−F7 (4th year of fallow forest)												
0-10	35.8	3.0	140	23		34.3	10.6	13.7	41.4	4.6	45.2	0.5
10-20	24.7	2.1				36.4	10.3	11.4	41.9	6.3		
20-30	20.9	1.7				33.3	10.1	12.1	44.5	6.1		
30-40	16.2	1.2				33.3	10.1	12.1	44.5	9.0	31.4	0.4
40-50	13.4	1.1				28.2	10.4	9.8	51.7	13.6		
70+	8.9	0.8				31.0	7.7	9.6	51.7	17.6		
HM−F8 (4th year of fallow forest)												
0-10	33.3	2.1	90	14		42.0	8.8	10.8	38.4	2.5	38.3	0.2
30-40	13.8	1.0				36.7	10.4	8.9	44.0	3.0	25.9	0.5
HM−F3 (7th year of fallow forest)												
0-10	19.3	1.2	60	12	1.4	47.3	14.3	11.9	26.5	7.0	33.9	0.3
10-20	15.8	0.9				52.8	9.9	13.5	23.8	10.3	37.4	
20-30	8.5	0.6				43.1	15.3	15.8	25.8	19.5	30.2	
30-40	7.0	0.5			1.4	35.8	9.2	8.3	46.7	11.5	28.2	0.3
40-50	6.4	0.5				29.4	9.3	9.3	52.1	8.2	24.8	
70+	5.8	0.5				31.4	7.7	9.6	51.2	5.6	26.2	
HM−F4 (7th year of fallow forest)												
0-10	21.4	1.1	52	10		53.3	0.9	10.6	35.2	11.7	25.2	0.2
30-40	7.2	0.6				27.0	1.4	8.5	63.0	7.0	20.1	0.2
HM−F5 (natural forest)												
0-10	38.3	3.3	167	67	1.1	54.9	13.6	5.3	26.2	3.5	73.3	1.0
10-20	15.8	1.7				52.3	14.5	7.1	26.1	5.7	42.8	
20-30	8.7	0.9				52.4	13.8	10.2	23.6	4.0	36.1	
30-40	6.5	0.7			1.5	50.7	14.7	9.5	25.1	3.1	32.7	0.9
40-50	4.9	0.5				55.4	11.5	9.8	23.4	2.5	33.7	
70+	3.4	0.4				52.2	13.4	12.1	22.3	2.4	35.6	
HM−F6 (natural forest)												
0-10	29.0	2.8	153	26		52.6	12.1	12.0	23.4	6.8	69.3	0.9
30-40	4.6	0.5				59.9	11.9	9.7	18.5	12.2	32.3	1.1

[a]Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	pH H_2O	pH KCl	CEC[a]	Exchangeable cations[a] Na	K	Mg	Ca	Al	H	Sum of ex. bases[a]	Effective CEC[a]	Al Saturation (%)
				(cmol(+) kg^{-1})								(%)
RP village (Rakpaendin; derived from Paleozoic shale)												
RP−C8 (7th year of cultivation after 4 year's fallow)												
0-10	5.5	4.3	12.1	0.03	0.26	1.65	2.27	0.87	0.77	4.22	5.09	17.1
10-20	5.3	4.2	11.6	0.03	0.12	0.57	1.22	2.09	0.82	1.94	4.03	51.9
20-30	5.3	4.2	8.8	0.03	0.11	0.34	0.57	2.45	0.92	1.05	3.50	69.9
30-40	5.0	4.2	8.6	0.03	0.10	0.26	0.43	2.67	0.80	0.81	3.48	76.7
40-50	4.9	4.2	8.4	0.02	0.08	0.17	0.30	2.65	0.77	0.57	3.22	82.3
50-60	4.9	4.2	8.3	0.02	0.09	0.20	0.35	2.69	0.85	0.66	3.35	80.2
RP−C6 (5th year of cultivation after 2 year's fallow)												
0-10	5.7	4.3	11.6	0.02	0.38	1.24	1.84	1.34	0.41	3.47	4.81	27.9
10-20	5.2	4.2	11.3	0.02	0.18	0.70	0.81	2.21	0.56	1.71	3.92	56.4
20-30	5.1	4.1	11.3	0.02	0.17	0.30	0.44	2.92	0.66	0.93	3.85	75.9
30-40	5.2	4.2	10.9	0.03	0.16	0.41	0.45	3.09	0.49	1.05	4.14	74.6
40-50	5.4	4.2	11.8	0.02	0.13	0.38	0.40	3.39	0.03	0.93	4.32	78.4
RP−C9 (1st year of fallow forest after 5 year's of cultivation)												
0-10	6.3	5.2	10.8	0.04	0.78	1.64	4.48	0.00	0.20	6.93	6.93	0.0
10-20	5.5	4.2	7.9	0.02	0.23	0.87	1.82	1.44	0.59	2.93	4.37	33.0
20-30	5.2	4.2	7.8	0.02	0.21	0.63	0.85	2.52	0.81	1.70	4.22	59.7
30-40	5.0	4.1	11.1	0.01	0.26	0.63	0.62	3.04	1.09	1.52	4.56	66.7
40-50	4.7	4.2	11.5	0.02	0.15	0.59	0.25	3.65	0.97	1.01	4.66	78.4
50-60	5.0	4.2	11.9	0.02	0.13	0.66	0.32	3.40	1.10	1.14	4.54	74.9
RP−C3 (3rd year of cultivation after 5 year's fallow)												
0-10	7.2	6.6	14.6	0.02	0.91	3.75	13.67	0.35	0.19	18.36	18.71	1.9
10-20	6.5	5.0	11.8	0.03	0.47	2.43	3.70	0.24	0.21	6.63	6.87	3.5
20-30	5.6	4.3	10.5	0.03	0.19	1.54	0.93	0.69	0.31	2.70	3.39	20.4
30-40	5.5	4.4	12.5	0.02	0.19	1.28	0.95	1.50	0.53	2.44	3.94	38.1
40-50	5.4	4.2	13.0	0.01	0.17	0.72	0.40	2.33	0.86	1.30	3.63	64.2
50-60	5.0	4.0	12.5	0.05	0.17	0.42	0.19	2.61	0.06	0.83	3.44	75.9
RP−C4 (3rd year of cultivation after 5 year's fallow)												
0-10	5.8	4.4	13.9	0.02	0.34	3.05	1.37	0.82	0.24	4.77	5.59	14.7
10-20	5.7	4.4	13.4	0.03	0.27	2.65	1.13	0.96	0.26	4.08	5.04	19.1
20-30	5.5	4.2	9.7	0.04	0.20	1.32	0.22	1.42	0.43	1.78	3.20	44.4
30-40	5.4	4.2	16.3	0.02	0.22	1.25	0.19	1.55	0.67	1.69	3.24	47.9
40-50	5.5	4.3	14.4	0.02	0.17	1.15	0.33	1.49	0.34	1.66	3.16	47.4
RP−C10 (1st year of fallow after 3 year's of cultivation)												
0-10	6.6	5.8	11.1	0.02	0.78	2.33	5.78	0.00	0.12	8.91	8.91	0.0
10-20	5.6	4.4	7.8	0.03	0.29	0.92	1.22	1.40	0.48	2.47	3.87	36.2
20-30	5.2	4.3	8.4	0.03	0.30	0.94	1.26	2.06	0.62	2.53	4.59	44.9
30-40	5.1	4.2	10.3	0.03	0.14	0.63	0.47	2.45	0.77	1.27	3.72	65.8
40-50	5.4	4.2	9.6	0.03	0.13	0.45	0.24	3.20	1.06	0.86	4.06	78.8
RP−C2 (1st year of cultivation after 2 year's fallow)												
0-10	5.5	4.3	11.7	0.02	0.49	1.14	3.01	0.36	0.24	4.67	5.03	7.2
10-20	5.2	4.2						1.44	0.40			
20-30	5.3	4.2	11.7	0.01	0.21	0.48	0.61	2.37	0.41	1.31	3.68	64.4
RP−C7 (1st year of cultivation after 6 years of fallow)												
0-10	6.9	5.9	18.4	0.02	0.58	3.72	12.92	0.00	0.12	17.24	17.24	0.0
10-20	6.5	5.1	12.2	0.02	0.24	2.26	4.07	0.00	0.19	6.59	6.59	0.0
20-30	5.9	4.7	9.8	0.02	0.20	1.50	2.62	0.16	0.29	4.34	4.50	3.6
30-40	5.8	4.5	13.2	0.03	0.16	1.26	2.16	0.66	0.20	3.62	4.28	15.4
40-50	5.6	4.4	11.2	0.02	0.14	1.21	1.79	0.82	0.52	3.16	3.98	20.6
50-60	5.2	4.2	11.3	0.02	0.13	0.92	0.95	1.05	0.99	2.02	3.07	34.2
RP−C1 (1st year of cultivation after 7 years of fallow)												
0-10	5.7	4.5	15.9	0.03	0.62	2.38	4.00	0.31	0.45	7.03	7.35	4.3
10-20	5.2	4.1	11.1	0.02	0.35	0.31	0.50	2.90	0.78	1.18	4.08	71.1
20-30	5.3	4.1	9.6	0.02	0.17	0.24	0.41	3.37	0.65	0.84	4.21	80.1
30-40	5.5	4.2	12.6	0.02	0.13	0.27	0.60	3.17	0.78	1.02	4.19	75.7
40-50	5.4	4.3	12.2	0.02	0.13	0.26	0.94	2.32	0.59	1.34	3.66	63.4
50-60	5.4	4.3	12.2	0.02	0.09	0.15	0.51	2.72	0.50	0.77	3.50	77.9
60-70	5.0	4.0	15.1	0.02	0.09	0.11	0.35	2.59	0.53	0.58	3.16	81.8

[a] Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	Total C[a]	Total N[a]	Available N[a]	Available P_2O_5[a]	Bulk density	Particle size distribution C.sand	F.sand	Silt	Clay	Gravel content	CEC /clay (cmol(+) kg^{-1}clay)	I10/I7 at K350
	(g kg^{-1})		(mg kg^{-1})		(g cm^{-3})	(%)						
RP village (Rakpaendin; derived from Paleozoic shale)												
RP−C8 (7th year of cultivation after 4 year's fallow)												
0-10	24.6	1.9	85	13	1.1	12.2	26.3	16.6	45.0	3.4	27.0	0.6
10-20	17.7	1.5			1.3	6.7	24.8	12.8	55.7	2.5	20.9	
20-30	12.4	1.2				7.4	22.3	11.5	58.8	2.9	14.9	
30-40	9.9	1.0			1.2	7.0	22.5	14.5	56.0	3.5	15.3	0.4
40-50	8.7	0.9				9.5	21.7	15.0	53.8	5.2	15.7	
50-60	9.6	1.0				9.4	21.4	12.6	56.6	3.5	14.7	
RP−C6 (5th year of cultivation after 2 year's fallow)												
0-10	18.5	1.7	97	13	1.1	13.7	10.6	16.3	59.3	8.0	19.6	1.3
10-20	13.0	1.4			1.2	14.2	11.9	18.5	55.3	20.1	20.4	
20-30	10.1	1.1			1.2	13.3	12.0	15.7	59.0	13.2	19.2	
30-40	9.4	1.1			1.3	11.0	11.5	17.6	59.8	18.0	18.3	1.2
40-50	7.3	1.0			1.3	14.3	12.8	20.5	52.3	34.7	22.6	
RP−C9 (1st year of fallow forest after 5 year's cultivation)												
0-10	17.2	1.6	90	24	1.2	20.3	18.1	17.8	43.7	6.6	24.8	1.6
10-20	8.8	1.0			1.3	15.8	16.4	22.0	45.8	5.9	17.3	
20-30	6.8	0.8			1.3	14.0	14.0	19.0	53.0	4.9	14.8	
30-40	5.5	0.8			1.4	16.1	10.6	14.6	58.7	6.2	19.0	1.0
40-50	4.3	0.7				14.8	10.5	20.3	54.4	3.7	21.1	
50-60	4.3	0.7				12.5	10.2	17.4	60.0	6.0	19.9	
RP−C3 (3rd year of cultivation after 5 year's fallow)												
0-10	30.0	1.7	90	80	1.1	17.4	18.8	22.4	41.3	9.3	35.3	1.4
10-20	17.6	1.3			1.3	13.4	18.8	21.5	46.2	6.4	25.5	
20-30	11.0	1.0			1.3	12.6	18.8	17.5	51.0	13.7	20.6	
30-40	9.1	0.9			1.3	6.0	15.7	16.9	61.4	4.5	20.3	1.1
40-50	8.8	0.9			1.4	9.2	9.4	19.4	62.0	3.7	20.9	
50-60	8.0	0.8				9.6	19.0	15.6	55.7	7.5	22.5	
RP−C4 (3rd year of cultivation after 5 year's fallow)												
0-10	21.8	1.5	44	21	1.0	9.3	17.2	23.1	50.3	2.9	27.7	1.8
10-20	21.9	1.4			1.2	8.7	16.4	22.6	52.3	2.2	25.7	
20-30	10.7	1.0			1.4	6.7	11.8	19.8	61.7	0.4	15.7	
30-40	7.4	0.8			1.4	5.5	9.9	19.8	64.8	0.8	25.1	1.3
40-50	5.8	0.7			1.3	4.9	9.7	17.8	67.6	0.9	21.4	
RP−C10 (1st year of fallow forest after 3 year's cultivation)												
0-10	20.7	1.8	71	17	1.3	13.7	25.1	15.8	45.5	9.5	24.5	1.5
10-20	11.7	1.2			1.3	10.0	19.7	18.2	52.1	22.0	15.0	
20-30	9.3	1.0			1.3	9.5	20.4	18.4	51.7	15.1	16.3	
30-40	6.8	0.9			1.4	13.2	16.2	16.1	54.4	31.6	19.0	1.1
40-50	5.6	0.8				9.3	12.4	13.4	64.8	25.6	14.8	
RP−C2 (1st year of cultivation after 2 year's fallow)												
0-10	20.3	1.7	59	19	1.1	18.1	18.8	21.8	41.2	3.4	28.5	1.3
10-20	8.7	0.9			1.2	12.0	13.7	18.4	55.9	11.8		
20-30	7.2	0.9			1.4	10.3	12.8	14.4	62.5	7.9	18.7	
RP−C7 (1st year of cultivation after 7 years of fallow)												
0-10	38.2	2.8	92	47	1.1	6.0	17.7	32.3	44.0	3.4	41.7	1.4
10-20	15.8	1.5			1.2	9.8	14.6	25.5	50.1	2.3	24 3	
20-30	10.8	1.2			1.1	7.4	13.7	17.5	61.4	6.3	15.9	
30-40	8.9	1.0			1.2	4.9	10.3	18.9	65.9	3.6	20.0	1.1
40-50	7.4	0.9			1.2	5.2	10.4	14.5	69.9	3.0	16.0	
50-60	6.4	0.9			1.3	5.9	9.9	20.1	64.1	2.5	17.7	
RP−C1 (1st year of cultivation after 7 years of fallow)												
0-10	38.9	2.3	93	22	1.2	11.4	20.1	16.8	51.7	0.2	30.8	1.7
10-20	12.9	1.1			1.3	6.3	19.6	14.8	59.4	0.1	18.7	
20-30	8.8	0.9			1.3	10.9	16.4	14.3	58.3	0.0	16.5	
30-40	6.0	0.7			1.4	3.8	14.2	16.6	65.3	0.1	19.4	0.5
40-50	6.0	0.7			1.4	5.3	12.1	20.7	61.9	0.1	19.7	
50-60	4.6	0.6			1.4	5.0	9.2	11.3	74.5	0.1	16.4	
60-70	4.1	0.6			1.4	13.5	12.6	11.4	62.5	0.2	24.1	

[a] Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	pH H_2O	pH KCl	CEC[a]	Exchangeable cations[a] Na	K	Mg	Ca	Al	H	Sum of ex. bases[a]	Effective CEC[a]	Al Saturation
				(cmol(+) kg^{-1})								(%)
RP village (Rakpaendin; derived from Paleozoic shale)												
R P − F 1 (10 years of fallow forest)												
0-10	5.2	4.2	14.8	0.02	0.33	1.60	2.69	1.58	0.60	4.64	6.22	25.4
10-20	4.9	4.0	11.1	0.05	0.18	0.49	0.40	3.24	0.63	1.12	4.36	74.3
20-30	5.1	4.1	10.5	0.02	0.12	0.34	0.32	3.95	0.41	0.80	4.75	83.1
30-40	5.2	4.2	12.4	0.02	0.10	0.30	0.27	3.76	0.50	0.69	4.45	84.5
40-50	5.3	4.2	15.1	0.01	0.08	0.16	0.15	3.41	0.51	0.40	3.81	89.4
50-60	5.2	4.1	15.4	0.01	0.09	0.13	0.17	3.17	0.97	0.41	3.58	88.7
R P − C 5 (1st year of cultivation after long fallow)												
0-10	5.7	4.4	14.6	0.02	0.49	2.73	2.46	0.59	0.33	5.71	6.30	9.4
10-20	5.5	4.2	11.2	0.01	0.29	1.65	0.52	1.49	0.48	2.47	3.96	37.6
20-30	5.5	4.1	9.5	0.02	0.13	0.84	0.15	1.84	0.45	1.13	2.97	61.9
30-40	5.3	4.2	12.2	0.01	0.16	0.88	0.12	2.18	0.34	1.17	3.35	65.1
40-50	5.3	4.1	12.4	0.01	0.15	0.95	0.15	2.06	0.63	1.27	3.33	62.0
50-60	5.3	4.1	14.3	0.01	0.16	0.97	0.25	1.75	0.79	1.39	3.14	55.8
R P − F 2 (natural forest)												
0-10	7.5	7.1	20.9	0.02	0.90	6.03	28.87	0.00	0.29	35.83	35.83	0.0
10-20	6.4	5.6	16.5	0.02	0.65	2.58	4.88	0.00	0.15	8.13	8.13	0.0
20-30	5.2	4.4	10.5	0.02	0.29	2.08	1.51	0.44	0.22	3.90	4.34	10.1
30-40	5.2	4.2	11.6	0.02	0.10	1.63	0.45	1.81	0.45	2.20	4.01	45.1
40-50	5.1	4.2	10.6	0.02	0.08	0.99	0.30	2.26	0.66	1.39	3.65	61.9
50-60	5.1	4.1	13.7	0.02	0.08	0.83	0.20	2.37	0.74	1.13	3.50	67.7
R P − F 3 (natural forest)												
0-10	6.4	5.8	18.1	0.02	0.58	6.40	9.65	0.00	0.16	16.65	16.65	0.0
10-20	5.4	4.4						0.95	0.47			
20-30	5.7	4.4						0.70	0.52			
30-40	5.4	4.2	13.8	0.02	0.23	3.05	0.84	1.72	0.65	4.14	5.86	29.3
40-50	5.3	4.2						1.75	0.84			
50-60	5.3	4.3						2.16	0.59			

[a]Oven dried-basis.

Table 3.2. continued.

Site and depth(cm)	Total C[a]	Total N[a]	Available N[a]	Available P_2O_5[a]	Bulk density	Particle size distribution C.sand	F.sand	Silt	Clay	Gravel content	CEC /clay	I10/I7 at K350
	(g kg^{-1})		(mg kg^{-1})		(g cm^{-3})			(%)			(cmol(+) kg^{-1}clay)	
RP village (Rakpaendin; derived from Paleozoic shale)												
R P − F 1 (10 years of fallow forest)												
0-10	32.4	2.0	130	29	1.2	6.2	24.0	20.7	49.1	0.1	30.1	1.0
10-20	14.2	1.3			1.4	7.6	20.1	20.6	51.7	0.3	21.5	
20-30	10.4	1.0			1.4	6.8	16.2	16.1	60.9	0.3	17.3	
30-40	6.1	0.8			1.3	4.8	13.5	15.3	66.4	0.1	18.6	1.3
40-50	4.8	0.7			1.3	3.6	12.6	22.9	60.9	0.2	24.7	
50-60	4.3	0.7				4.5	13.4	16.3	65.8	0.2	23.4	
R P − C 5 (1st year of cultivation after long fallow)												
0-10	37.2	1.8	70	26	1.1	17.3	17.5	22.2	43.1	4.3	33.9	1.5
10-20	15.5	1.4			1.2	14.6	20.7	23.3	41.4	10.1	27.0	
20-30	9.9	1.0			1.4	7.2	18.2	20.3	54.3	16.0	17.6	
30-40	8.6	0.9			1.4	8.5	16.5	19.6	55.5	8.9	21.9	1.4
40-50	6.3	0.7			1.5	10.2	14.4	17.7	57.7	1.5	21.5	
50-60	5.7	0.7			1.4	10.4	15.3	10.2	64.1	4.0	22.3	
R P − F 2 (natural forest)												
0-10	41.9	3.3	187	145	0.8	7.0	11.6	32.3	49.1	0.6	42.5	1.2
10-20	20.0	1.9			1.2	6.5	8.4	31.2	53.9	7.0	30.7	
20-30	13.1	1.4			1.3	8.2	9.8	29.6	52.4	13.1	20.0	
30-40	11.2	1.2			1.3	6.1	9.8	25.0	59.1	6.9	19.7	1.1
40-50	10.7	1.2			1.3	6.8	13.3	28.8	51.1	7.1	20.8	
50-60	11.4	1.1			1.3	8.3	11.1	27.6	53.0	6.9	25.8	
R P − F 3 (natural forest)												
0-10	31.0	3.0	146	24	1.0	5.1	6.1	32.8	56.0	0.7	32.4	0.9
10-20	14.3	1.6			1.1	5.6	7.5	31.6	55.3	2.7		
20-30	12.5	1.4			1.1	6.9	3.5	31.7	57.8	4.4		
30-40	9.1	1.2			1.1	5.2	8.8	27.5	58.5	5.9	23.6	0.9
40-50	7.7	1.1				7.2	6.2	30.0	56.6	8.6		
50-60	6.5	1.0				6.4	6.4	28.7	58.4	27.2		

[a]Oven dried-basis.

Table 3.3. General physicochemical properties of the surface 10 cm and 30-40 cm depth soils.

	DP village (sedimentary) median (max.-min.)	DP village (granite) median (max.-min.)	HM village (granite) median (max.-min.)	RP village (sedimentary) median (max.-min.)
0-10 cm soil	12 profiles	5 profiles	10 profiles	13 profiles
pH(H_2O)	5.9 (5.1-6.6)	5.9 (5.3-6.5)	6.0 (5.2-6.5)	5.8 (5.2-7.5)
pH(KCl)	4.6 (4.0-5.5)	4.5 (4.2-5.3)	4.5 (4.0-5.8)	4.5 (4.2-7.1)
CEC(cmol(+) kg^{-1})[a]	17.2 (13.4-27.9)	17.0 (13.7-20.4)	14.1 (7.3-19.2)	14.6 (10.8-20.9)
Exch.K (cmol(+) kg^{-1})[a]	0.76 (0.31-1.13)	0.67 (0.61-1.39)	0.64 (0.30-1.24)	0.58 (0.26-0.91)
Exch.Mg (cmol(+) kg^{-1})[a]	2.09 (0.70-3.80)	1.75 (0.68-4.34)	2.93 (0.71-7.12)	2.38 (1.14-6.40)
Exch.Ca (cmol(+) kg^{-1})[a]	3.15 (0.32-10.26)	1.85 (0.50-5.25)	2.66 (0.17-15.03)	4.00 (1.37-28.87)
Exch.Al (cmol(+) kg^{-1})[a]	0.60 (0.00-3.42)	1.16 (0.00-3.79)	0.34 (0.00-2.26)	0.35 (0.00-1.58)
Sum of exch. Bases (cmol(+) kg^{-1})[a]	6.28 (1.88-14.93)	4.43 (1.84-11.01)	6.36 (1.51-23.03)	6.93 (3.47-35.83)
ECEC (cmol(+) kg^{-1})[a]	6.78 (4.39-14.93)	5.75 (5.49-11.01)	6.71 (2.84-23.03)	6.93 (4.81-35.83)
Al saturation (%)	8.6 (0.0-63.4)	19.3 (0.0-67.3)	5.1 (0.0-59.3)	4.3 (0.0-27.9)
Total C (g kg^{-1})[a]	39.0 (31.7-63.3)	43.8 (24.5-58.0)	29.2 (11.4-38.3)	30.0 (17.2-41.9)
Total N (g kg^{-1})[a]	2.7 (2.0-4.8)	3.3 (2.1-4.3)	2.2 (0.7-3.3)	1.8 (1.5-3.3)
Available N (mg kg^{-1})[a]	123 (84-243)	105 (89-229)	75 (13-167)	90 (44-187)
Available P_2O_5 (mg kg^{-1})[a]	12 (8-16)	13 (10-38)	20 (7-67)	24 (13-145)
Coarse sand (%)	10.2 (4.2-18.4)	40.6 (31.9-48.7)	48.6 (34.3-57.0)	12.2 (5.1-20.3)
Fine sand (%)	23.6 (14.4-28.1)	8.8 (7.3-13.0)	12.9 (0.9-17.0)	18.1 (6.1-26.3)
Silt (%)	24.6 (20.5-27.1)	13.7 (11.2-25.5)	12.0 (5.3-16.6)	21.8 (15.8-32.8)
Clay (%)	42.3 (30.6-55.9)	35.3 (25.6-39.7)	28.5 (11.9-41.4)	45.5 (41.2-59.3)
Gravel content (%)	5.6 (0.6-16.0)	10.0 (6.3-11.7)	5.7 (2.5-18.7)	3.4 (0.1-9.5)
30-40 cm soil	12 profiles	5 profiles	10 profiles	12 profiles
pH(H_2O)	5.3 (5.1-6.2)	5.3 (5.2-5.9)	5.5 (5.3-6.4)	5.3 (5.0-5.8)
pH(KCl)	4.2 (4.1-4.8)	4.3 (4.1-4.4)	4.2 (3.9-4.8)	4.2 (4.1-4.5)
CEC(cmol(+) kg^{-1})[a]	11.8 (8.7-15.1)	11.5 (9.3-12.6)	10.3 (4.3-14.0)	12.3 (8.6-16.3)
Exch.K (cmol(+) kg^{-1})[a]	0.38 (0.09-0.59)	0.34 (0.32-0.77)	0.36 (0.18-0.74)	0.16 (0.10-0.26)
Exch.Mg (cmol(+) kg^{-1})[a]	0.38 (0.19-1.84)	0.27 (0.15-2.25)	1.45 (0.36-2.02)	0.76 (0.26-3.05)
Exch.Ca (cmol(+) kg^{-1})[a]	0.30 (0.04-4.93)	0.16 (0.04-2.12)	0.43 (0.04-3.29)	0.46 (0.12-2.16)
Exch.Al (cmol(+) kg^{-1})[a]	2.48 (0.00-3.52)	2.73 (2.23-4.66)	1.49 (0.00-3.82)	2.32 (0.66-3.76)
Sum of exch. Bases (cmol(+) kg^{-1})[a]	1.02 (0.53-7.40)	0.77 (0.53-5.16)	2.28 (0.88-5.69)	1.40 (0.69-4.14)
ECEC (cmol(+) kg^{-1})[a]	3.69 (2.95-7.40)	4.94 (3.24-7.38)	4.25 (3.30-5.69)	4.08 (3.24-5.86)
Al saturation (%)	73.1 (0.0-86.9)	77.9 (30.1-89.7)	35.8 (0.0-81.3)	65.4 (15.4-84.5)
Total C (g kg^{-1})[a]	14.2 (7.3-21.9)	13.3 (8.7-25.4)	7.1 (3.5-16.2)	8.8 (5.5-11.2)
Total N (g kg^{-1})[a]	1.0 (0.6-1.7)	1.1 (0.8-2.0)	0.7 (0.2-1.2)	0.9 (0.7-1.2)
Coarse sand (%)	6.7 (3.1-21.7)	35.6 (28.0-51.3)	38.3 (27.0-62.7)	6.1 (3.8-16.1)
Fine sand (%)	21.0 (14.5-30.3)	10.7 (8.1-14.1)	11.5 (1.4-15.9)	12.5 (8.8-22.5)
Silt (%)	23.0 (16.5-27.0)	14.2 (12.9-17.4)	9.6 (8.3-19.7)	17.3 (14.5-27.5)
Clay (%)	48.7 (31.2-55.5)	40.7 (25.1-44.9)	37.3 (13.1-63.0)	59.5 (54.4-66.4)
Gravel content (%)	4.2 (0.7-23.2)	15.0 (10.0-21.5)	8.0 (3.0-25.9)	5.2 (0.1-31.6)

[a] oven-dried basis.

Chapter 4. Dynamics of K, Mg, and Ca, and soil acidity in relation to land use under shifting cultivation

4.1 Introduction

Many researchers reported nutrient input to soil surface through the slash and burn practice and changes in nutrient contents of the soils before and after onset of the rainy season (Zinke et al. 1978; Kyuma et al. 1985; Andriesse and Schelhaas 1987a ; Ramakrishnan 1992). However, because these studies tended to focus on the fertilizer effect of the ash associated with the slash and burning practice, reaction between the soils and the ash, dynamics of soil fertility in the cropping/fallow rotation systems under shifting cultivation, or significance of the slash and burning and fallow in soil ecological systems are not still clear

In Chapter 3, it is considered that the soil acidity was closely related to the content of exchangeable bases both in the surface and subsurface soils and affected the content of available P in the surface soils. In this chapter, dynamics of K, Mg, and Ca both in the soils and aboveground biomass in fallow forest and soil acidity are studied with special reference to the significance of the ash input to soil surface and of fallow under shifting cultivation.

4.2 Materials and methods

4.2.1 Soil samples

Soil samples were collected from the 0-10 and 30-40 cm layers at 40 sites including 17 sites in the DP village, 10 sites in the HM village, and 13 sites in the RP village (the same sites to those in Chapter 3). The soil samples were air-dried and passed through a 2 mm mesh sieve for the following chemical analysis.

Soil pH(H_2O), the contents of exchangeable bases (Na, K, Mg, and Ca), Al and H in the soils were determined. The analytical methods employed here were described in Chapter 3.

The contents of total K, Mg, and Ca were determined for the selected soils, as follows (Lim and Jackson 1982 with modification): Fifty milligrams of the sample were used after appropriate grinding. Organic matter was decomposed by a mixture of HNO_3 and $HClO_4$ in Teflon beaker with heating. Silicate in the sample was decomposed completely by successive addition of HF solution. After decomposition, the residue was dissolved into 6 M HCl and the contents of K, Mg, and Ca in the solution were determined by atomic absorption spectrophotometry (AAS)(Shimadzu, AA-640-01).

4.2.2 Aboveground biomass samples

In order to estimate the alkalinity and amounts of inorganic bases (K, Mg, and Ca) which were expected to be released to the soil surface through ash input from fallow vegetation by the slash and burn practice, samples of the aboveground part of the fallow vegetation (aboveground biomass) were collected from the selected plots during different periods of fallow in 1996 in the DP and RP villages (see Table 4.2). The sampling was conducted in a 7 × 7 or 10 × 10 m^2 plot. In the DP village, the stem parts of tree species with a diameter larger than about 10 cm were excluded from estimation because villagers usually kept them to secure the sprouting in the next fallow period. Soil samples were also collected from every 10 cm depth down to 50 cm for the comparison of the nutrient stocks both in the aboveground biomass and the soil.

Samples of the aboveground biomass was pulverized and weighed after

drying at 70 ℃ for 48 h. A 500 mg aliquot of the sample was completely burned at 550℃ for 5 h after preburning with a gas burner. The ash of the sample was dissolved into 10 mL of 6 M HCl and the contents of Na, K, Mg, and Ca were determined by AAS. The titratable alkalinity was determined by back titration with 0.1 M NaOH solution after the addition of 10 mL of 0.1 M HCl solution, using bromocresol green as the indicator.

4.2.3 Soil solution samples

In order to evaluate the dynamics of inorganic bases and N contained in the ash from the aboveground biomass, the composition of the soil solution collected from RP-C1, C3, C5, and F1 were analyzed by the porous cup method during the cropping season of 1993, that is, from immediately after burning in April for RP-C3 and C5 and from May for RP-C1 and F1 until harvest in October. The soil solution was collected at 20 and 40 cm depths in triplicates.

The concentration of K in the solution was determined by AAS while those of Ca and Mg by ICP-AES (Nippon Jarrell, ICAP-750). The concentration of inorganic N was determined by titration with 0.01 M HCl after steam distillation with the addition of MgO and Devarda's alloy (Keeny and Nelson 1982).

4.3 Results and discussion

4.3.1 Composition of exchangeable cations in relation to land use

Since the composition of exchangeable cations was given in detail in Chapter 3, it will be summarized here: Among the exchangeable bases, Mg and Ca were generally predominant and K occurred as trace. Al often accounted for a larger part of exchangeable cations. Soil acidity was considered to be one of the important factors that affected the soil chemical fertility in relation to the cation retention of the soils. It was also suggested that the soil acidity fluctuated along with land use.

In order to analyze the dynamics of acidity and exchangeable bases in the soils under shifting cultivation in more detail, pH(H_2O) in the surface 0-10 cm soil layers and Al saturation in the 30-40 cm soil layers were plotted against the land use stages as indicated in Figs. 4.1 and 4.2, respectively. Although the data presented here varied widely, they can be summarized as follows:

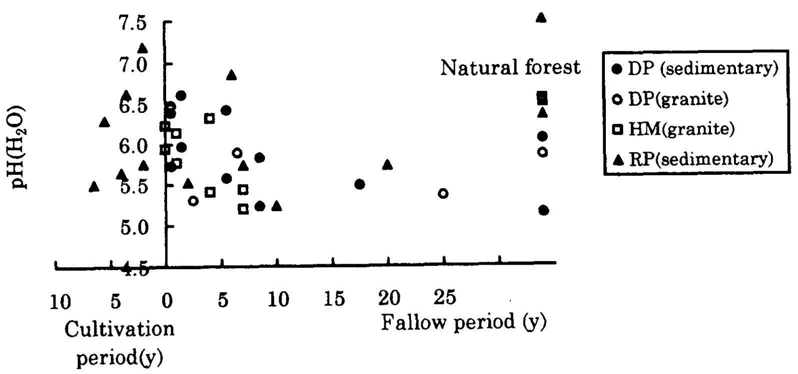


Fig. 4.1. Relationship between the land use and pH(H_2O) in the surface 10 cm layers.

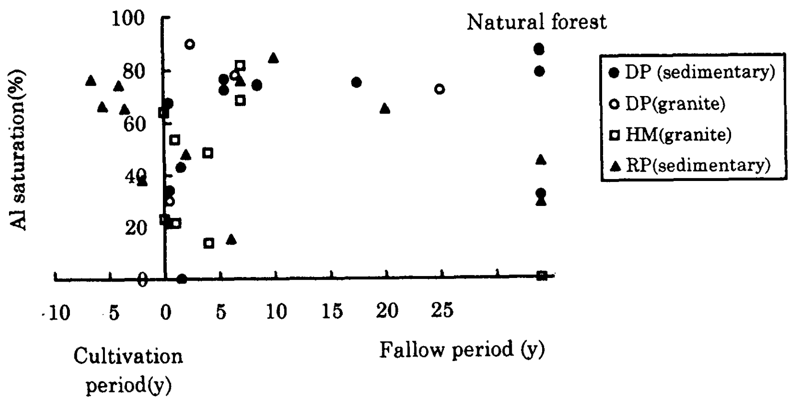


Fig. 4.2. Relationship between the land use and Al saturation in the 30-40 cm layers.

1) In the fallow fields for more than 5 y, the pH(H_2O) in the 0-10 cm soil layers was generally less than 6 and the Al saturation in the 30-40 cm soil layers was mostly as high as 70 %. Hence, the soils during these fallow periods were very acidic and poor in exchangeable bases regardless of the difference in the soil parent materials, compared to the soils under cropping or fallow fields within 3 y after the slash and burn practice.

2) In both fallow and cropping fields within 3 y after the slash and burn practice, the Al saturation of the subsoils was mostly 20 to 50 %. It was considered that the high acidity observed in the soils under fallow forest was alleviated by ash input with high alkalinity.

3) In the fields under continuous cropping for more than 4 y after the slash and burn practice, the Al saturation in the subsoils increased to values higher than 60 %. Soil acidification was enhanced at least in the subsoils at this stage.

4.3.2 Forms of Ca, K, and Mg in the soils

Table 4.1 shows the contents of total and exchangeable K, Mg, and Ca and mineralogical properties in the selected soils. The ratio of peak area at 1.0 nm to that of 0.7 nm in the XRD spectrum of K saturated clay samples after heating at 350 ℃ is considered to give a relative amount of 2:1 clay minerals to 1:1 kaolin minerals (Chapter 3).

Fig. 4.3 gives relationship between the contents of total and exchangeable Ca in the soils. Most of Ca in the soils occurred in an exchangeable form irrespective of the difference in the parent materials. Ca was more abundant in the surface soils than in the subsoils, suggesting a biological concentration under forest vegetation during fallow period.

Table 4.1. Contents of total and exchangeable K, Mg, and Ca and mineralogy of the selected soils from the surface 10 cm and 30-40 cm layers.

Village Site	Depth (cm)	Total K	Total Mg	Total Ca	Exchangeable K	Exchangeable Mg	Exchangeable Ca	Clay (%)	I10/I7**
				(cmol(+) kg^{-1})*					
Ban Du La Poe (sedimentary)									
DPF4	0-10	52.0	39.0	8.0	0.92	3.22	9.34	30.6	1.0
	30-40	54.6	39.9	3.9	0.59	1.84	4.93	31.2	0.8
DPF5	0-10	33.5	30.8	3.3	1.13	2.67	4.91	45.6	0.5
	30-40	33.5	32.0	0.8	0.57	1.01	1.35	49.6	0.5
DPF11	0-10	26.7	23.7	1.9	0.31	1.48	1.69	40.7	0.6
	30-40	28.9	22.8	0.5	0.20	0.34	0.25	44.2	0.4
Ban Du La Poe (granite)									
DPC1	0-10	65.3	30.3	3.9	1.39	4.34	5.25	25.6	1.3
	30-40	68.5	31.5	2.4	0.77	2.25	2.12	25.1	1.2
DPF3	0-10	34.2	18.1	1.1	0.61	1.21	1.28	35.3	0.3
	30-40	38.8	19.1	0.1	0.34	0.35	0.16	44.9	0.4
DPF9	0-10	94.7	29.0	3.6	0.67	2.01	3.50	29.3	0.5
	30-40	101.0	26.9	0.1	0.32	0.27	0.05	28.9	0.6
Ban Hoe Mak kun (granite)									
HMF2	0-10	142.2	19.5	1.5	0.30	1.70	1.67	11.9	0.6
	30-40	143.0	19.9	0.7	0.18	1.80	0.59	13.1	1.0
HMF5	0-10	99.4	40.4	10.9	0.84	7.12	15.03	26.2	1.0
	30-40	117.6	46.6	3.6	0.59	1.79	3.29	25.1	0.9
HMF7	0-10	62.6	63.8	6.9	1.24	5.53	5.00	41.4	0.5
	30-40	61.2	71.2	3.4	0.74	2.02	1.53	44.5	0.4
Ban Rakpaendin (sedimentary)									
RPC1	0-10	45.3	26.6	3.6	0.62	2.38	4.00	51.7	1.7
	30-40	58.4	33.6	0.8	0.13	0.27	0.60	65.3	0.5
RPC3	0-10	48.4	32.0	12.6	0.91	3.75	13.67	41.3	1.4
RPC7	0-10	55.7	32.2	10.0	0.58	3.72	12.92	44.0	1.4
	30-40	64.5	34.0	1.7	0.16	1.26	2.16	65.9	1.1
RPF2	0-10	62.0	34.7	28.6	0.90	6.03	28.87	49.1	1.2
	30-40	71.4	34.4	0.4	0.10	1.63	0.45	59.1	1.1

*110℃ oven dried basis. **The ratio of peak area at 1.0 nm to that at 0.7 nm in the XRD spectrum of K saturated clay sample after heating at 350℃.

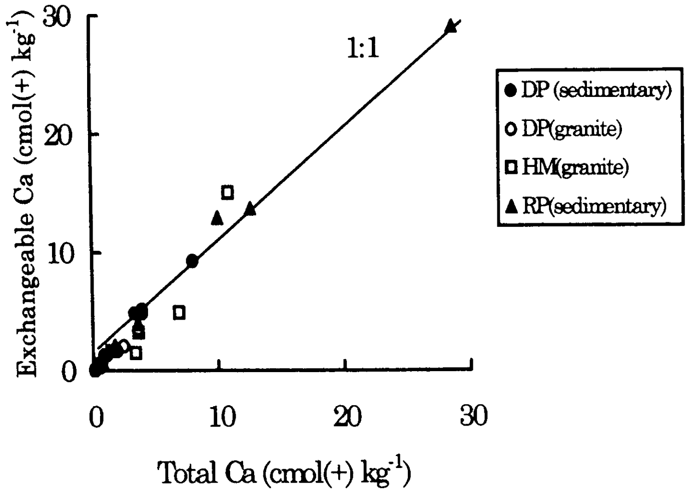


Fig. 4.3. Scattergram of the contents of total and exchangeable Ca in the soils

Figure 4.4 shows a scattergram between the clay content and content of total K in the soils. The total K content which ranged from 20 to 140 cmol(+) kg^{-1} was much higher than the content of exchangeable K (0.1 to 1.4 cmol(+) kg^{-1})(Table 4.1). The content of total K in the granite-derived soils decreased with the increase in the clay content, while that in the soils derived from sedimentary rocks did not show any significant relationship with the clay content. Among the granite-derived soils, a negative correlation between the clay content and the relative amount of mica to kaolin minerals in the clay fraction was observed (Chapter 3). Therefore, the soils were considered to have released K from mica minerals in the course of the weathering process associated with clay formation. The fairly large amount of K absorbed by the fallow vegetation at RP-96 (Table 4.2), compared to the content of exchangeable K in the soils, suggesting a gradual release of non-exchangeable K from soil minerals. The large amount of non-exchangeable K in the soils was considered to be a source of K supply for plant growth, at least under certain conditions, as summarized by Black (1968).

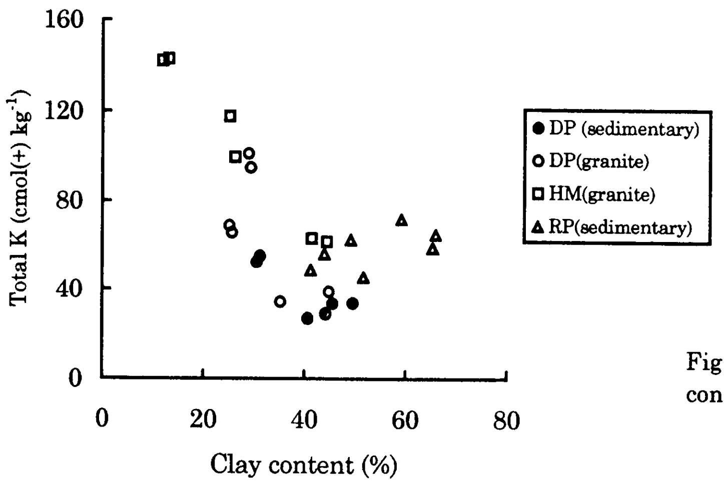


Fig. 4.4. Scattergram of the clay content and total K in the soils.

The content of total Mg in the soils ranged from 20 to 80 cmol(+) kg^{-1} and was much higher than that of exchangeable Mg (0.3 to 7.1 cmol(+) kg^{-1}), suggesting that the soils studied had a large pool for the supply of Mg other than the significant amount of exchangeable Mg. However, there was no relationship between the content of total Mg and the content of clay or exchangeable Mg.

Most of Ca occurred in an exchangeable form in the surface soils, in contrast to K and Mg, for which there was a large pool in the soil minerals in addition to the exchangeable forms. These findings indicated that Ca was likely to be readily depleted from the ecosystem under the process of soil acidification, especially in the cultivated fields, as discussed below.

4.3.3 Amount of aboveground biomass and nutrient content

Figure 4.5 shows the amount of the aboveground biomass in relation to the duration of fallow period. In the RP village, herbaceous species were dominant in the first year of fallow and bamboo species grew up very rapidly within the initial 2 or 3 years of fallow. The amount of tree species was not conspicuous. In the DP village, herbaceous species predominated in the initial 2 y of fallow and tree species gradually succeeded herbaceous species. Unlike in the RP village, bamboo species did not appear. The difference in the succession of vegetation during the fallow period was ascribed to the persistence of stumps or seeds of tree species at the end of the cropping period (Smitinand et al. 1978), because Hmong and Thai peoples in the RP village usually cultivated their fields for more than 2 y with repeated burning while Karen people only for 1 y. In addition, fire from the surrounding fields affected the fallow forest every year and may have killed the stumps of tree species in the RP village, while fire was well controlled in the DP village.

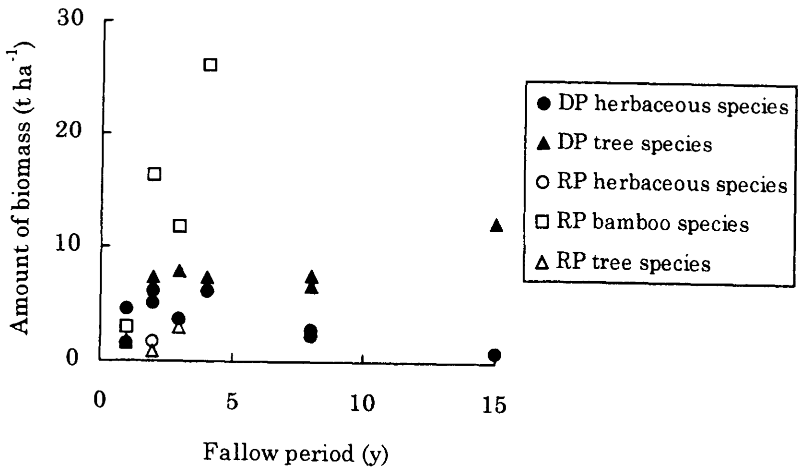


Fig. 4.5. The amount of aboveground biomass in the fallow forest in relation to the duration of the fallow period.

Table 4.2 shows the amount of aboveground biomass and the amounts of inorganic bases and titratable alkalinity in the ash from the biomass. In the early phase of fallow, herbaceous species accumulated a large amount of inorganic bases, especially of K. In the RP village, bamboo species rapidly accumulated K in preference over Mg or Ca, which consisted with the report from India by Ramakrishnan (1992). Tree species accumulated large amounts of the inorganic bases, especially Ca, into their bodies along with their growth. Andriesse and Schelhaas (1987) reported that a 10 y fallow forest in Chiang Mai Province in northern Thailand contained 52 t ha^{-1} of aboveground biomass and 27 kmol(+) ha^{-1} of inorganic bases (sum). Zinke et al. (1978) reported that in a 7 y forest in Mae Hong Son Province the corresponding values were 28 t ha^{-1} and 15 kmol(+) ha^{-1}, respectively. The 8 y fallow forest in this study may be comparable to the cases cited above since the results did not include the biomass of large stems.

Table 4.2. Amount of aboveground biomass and amounts of inorganic bases and titratable alkalinity in the ash from aboveground biomass.

Site (fallow years)	Vegetation species	Weight ($\mathrm{t\ ha^{-1}}$)	Na	K	Mg	Ca	Total	Alkalinity ($\mathrm{kmol(-)\ ha^{-1}}$)
			-------------	($\mathrm{kmol(+)\ ha^{-1}}$)	-------------			
DP-C196 (1 y)	herbaceous	1.6	0.09	0.81	0.26	0.23	1.39	1.17
	bamboo	trace						
	tree	1.6	0.05	0.13	0.29	0.14	0.61	0.61
	total	3.2	0.14	0.94	0.55	0.37	2.00	1.78
DP-C296 (1 y)	herbaceous	4.5	0.20	1.20	0.60	0.90	2.90	2.42
	bamboo	trace						
	tree	1.7	0.04	0.14	0.34	0.20	0.72	0.87
	total	6.2	0.24	1.34	0.94	1.10	3.62	3.29
DP-F496 (2 y)	herbaceous	5.2	0.27	1.20	0.28	0.58	2.33	1.90
	bamboo	trace						
	tree	trace						
	total	5.2	0.27	1.20	0.28	0.58	2.33	1.90
DP-F196 (2 y)	herbaceous	6.1	0.17	1.70	0.50	1.86	4.23	3.42
	bamboo	trace						
	tree	7.4	0.12	0.46	0.34	0.58	1.50	2.00
	total	13.5	0.29	2.16	0.84	2.44	5.73	5.42
DP-F1496 (3 y)	herbaceous	3.6	0.14	0.55	0.35	0.33	1.37	1.29
	bamboo	trace						
	tree	7.9	0.10	0.77	0.41	0.94	2.22	2.20
	total	11.5	0.24	1.32	0.76	1.27	3.59	3.49
DP-496 (4 y)	herbaceous	6.2	0.18	0.40	0.61	0.77	1.96	1.86
	bamboo	trace						
	tree	7.4	0.21	0.39	0.87	1.49	2.96	3.04
	total	13.6	0.39	0.79	1.48	2.26	4.92	4.90
DP-896 (8 y)	herbaceous	2.3	0.12	0.45	0.16	0.25	0.98	0.77
	bamboo	trace						
	tree	6.7	0.16	0.78	0.42	1.72	3.08	3.13
	total	9.0	0.28	1.23	0.58	1.97	4.06	3.90
DP-8S (8 y)	herbaceous	2.7	0.05	0.17	0.39	0.27	0.88	0.82
	bamboo	trace						
	tree	7.5	0.09	0.67	0.43	0.88	2.07	2.08
	total	10.2	0.14	0.84	0.82	1.15	2.95	2.90
DP-1596 (15 y)	herbaceous	0.8	0.02	0.07	0.12	0.07	0.28	0.26
	bamboo	trace						
	tree	12.3	0.38	1.08	1.21	3.13	5.80	5.85
	total	13.1	0.40	1.15	1.33	3.20	6.08	6.11
RP-C596 (1 y)	herbaceous	1.6	0.08	0.36	0.30	0.30	1.04	0.90
	bamboo	3.0	0.10	0.58	0.15	0.10	0.93	0.75
	tree	trace						
	total	4.6	0.18	0.94	0.45	0.40	1.97	1.65
RP-C196 (2 y)	herbaceous	1.7	0.06	0.45	0.06	0.06	0.63	0.56
	bamboo	16.2	0.90	3.34	0.60	0.27	5.11	3.95
	tree	0.8	0.02	0.15	0.11	0.19	0.47	0.42
	total	18.7	0.98	3.94	0.77	0.52	6.21	4.93
RP-F596 (3 y)	herbaceous	trace						
	bamboo	11.7	0.36	1.80	0.42	0.19	2.77	2.44
	tree	3.0	0.06	0.38	0.50	1.35	2.30	2.39
	total	14.7	0.42	2.19	0.92	1.54	5.07	4.83
RP-96 (4 y)	herbaceous	trace						
	bamboo	26.1	0.66	4.84	0.86	0.75	7.11	5.51
	tree	trace						
	total	26.1	0.66	4.84	0.86	0.75	7.11	5.51

All the data are expressed on a 70℃ oven-dried basis.

4.3.4 Composition of soil solution from the fallow/cropping fields

Figure 4.6 shows the concentrations of nutritional elements in the soil solution from the fields in the RP village during the cropping season. There was no significant difference in the concentrations in the soil solutions between the 10 y fallow forest (RP-F1) and cultivated fields (RP-C1, C3, and C5). This was firstly ascribed to the fact that the undergrowth in RP-F1 was also burnt by fire from surrounding areas at the time of burning or to the release of inorganic bases and N associated with the rapid decomposition of litterfall during the rainy season.

In the early period of sampling, the concentration of inorganic bases and N were highest both in the surface soils and subsoils. The concentrations in the subsoils were almost equivalent to those in the surface soils. It was considered that the inorganic bases added to the soil surface rapidly migrated downward in the soils by early rainfall. After several weeks, the concentrations of these elements decreased and became nearly constant both in the surface soils and subsoils. It was suggested that most of the inorganic bases that reached the subsoils might have been lost from the soil profile or adsorbed onto cation exchange sites of the soils.

Based on the incubation experiment on N mineralization pattern in Chapter 5, most of the N mineralized occurred in the NO_3^- form and a large amount of NH_4^+ was detected only at RP-C5, where a fairly large amount of aboveground biomass had been subjected to slash and burn. Therefore, most of the N detected in the soil solution from RP-F1, C1, and C3 mainly corresponded to NO_3^--N, though in the case of RP-C5 no definite conclusions were drawn. The average concentration of NO_3^- was estimated to be equivalent to 40 % of the sum of the measured inorganic bases, indicating that the NO_3^- ion derived from the soil burning effect or decomposition of organic matter played an important role as one of the counter anions for the movement or leaching of inorganic bases.

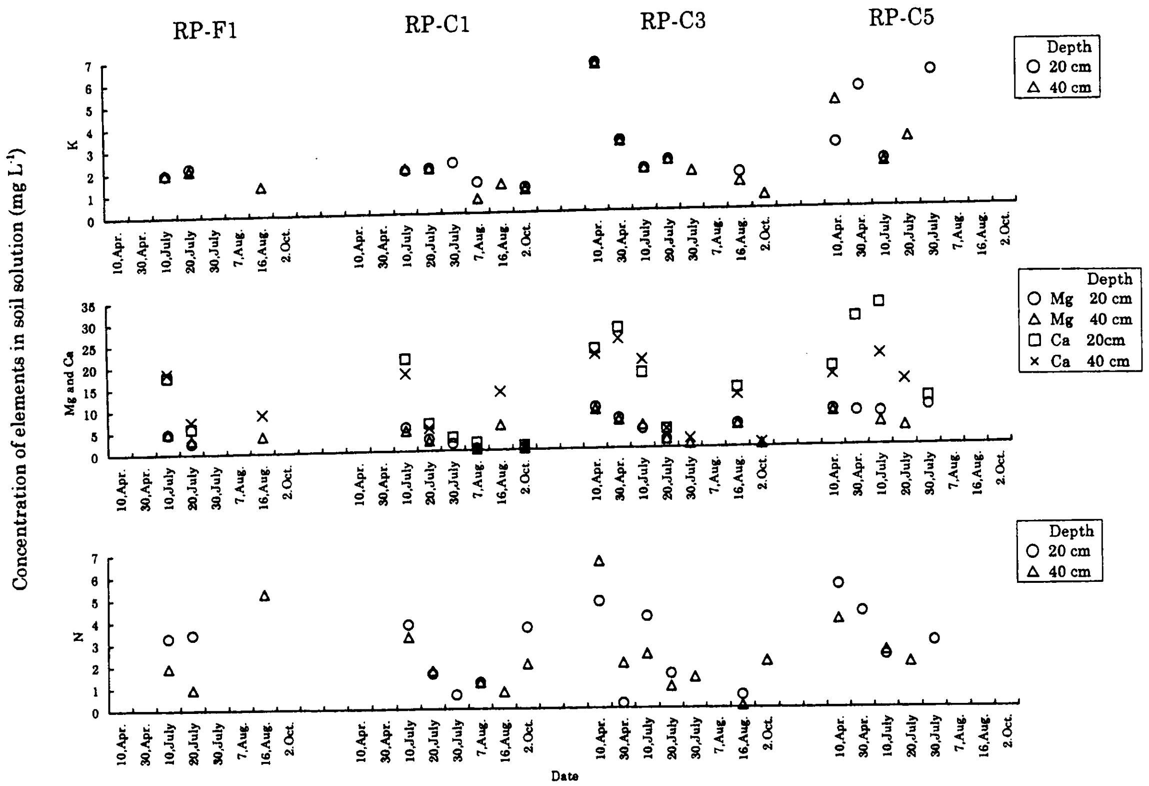


Fig. 4.6. Concentration of nutrients in the soil solution during the cropping season in the RP village

4.3.4 Dynamics of K, Mg, and Ca , and soil acidity in shifting cultivation

Significance of ash input in the decrease of soil acidity. The decrease in Al saturation observed in the subsoils after the slash and burn practice (Fig. 4.2) seems to be caused by the ash input, as pointed out by many researchers (Kyuma et al. 1985; Tulaphitak et al. 1985a; Ramakrishnan 1992). Since no pH change was clearly observed in the 0-10 cm soil layers after burning (Fig. 4.1), the subsoils with higher acidity were considered to consume the alkalinity supplied through ash input. As mentioned before, the soil solution composition suggested the occurrence of a rapid migration of the elements added as ash into the subsoil. Since the increase in pH in the subsoils was accompanied by a decrease in the content of exchangeable Al and concomitant increase in the contents of exchangeable bases, this process was assumed to involve the following sequence; hydrolysis of exchangeable Al to $Al(OH)_3$ by high alkalinity derived from ash, liberation of cation exchange sites of the soils, and adsorption of the inorganic bases added, especially divalent ones onto the sites (Mc Lean 1982).

Table 4.3 shows a comparison of the amounts of exchangeable bases and Al in the soils and the amounts of inorganic bases and titratable alkalinity in the ash from the aboveground biomass. The amounts of inorganic bases in the biomass were also small, compared with those of exchangeable bases in the soils. The discrepancy between the apparent decrease in Al saturation in the soils observed after the slash and burn practice and the amounts of inorganic bases and alkalinity supplied by ash input may be partly explained by the presence of other sources of ash: According to field observation, the larger stems excluded from the estimation of biomass were sometimes burnt by strong fire. Litter layer or organic matter in the surface soils might also be one of the possible sources of ash.

Soil acidification during the fallow period. Since the large amounts of inorganic bases stored in the aboveground biomass during the fallow period (Table 4.2), the exchangeable bases in the soil were considered to be rapidly absorbed by herbaceous species at the initial stage of the succession and then by tree or bamboo species. This phenomenon may account for the depletion in exchangeable bases and the more acidic nature of the soils under fallow forest than in the soils immediately after burning (Figs. 4.1 and 4.2). The bases accumulated in the vegetation may partly return to the surface soils through litterfall during the succession of vegetation, resulting in the development of secondary nutrient cycling between the soils and the fallow vegetation.

Table 4.3. Amounts of inorganic bases and titratable alkalinity in the ash from aboveground biomass and amounts of exchangeable bases and Al in the soils.

Site (fallow years, Dominant vegetation)	Na*	K*	Mg*	Ca*	Sum of bases*	Exch.Al	Alkalinity in ash
	----------	----------	----------	(kmol(+) ha^{-1})	----------	----------	(kmol(-) ha^{-1})
RP-C596 (1 y, herbaceous species)							
Biomass	0.2	0.9	0.5	0.4	2.0		1.7
Soil 0-10 cm	0.2	8.5	27.6	49.1	85.4	0.0	
10-50 cm	0.9	18.3	43.4	21.8	84.4	79.2	
RP-C196 (2 y, bamboo species)							
Biomass	1.0	3.9	0.8	0.5	6.2		4.9
Soil 0-10 cm	0.2	7.6	20.7	29.4	57.9	7.0	
10-50 cm	0.9	8.3	11.9	19.2	40.3	148.9	
RP-96 (4 y, bamboo species)							
Biomass	0.7	4.8	0.9	0.8	7.1		5.5
Soil 0-10 cm	0.1	2.4	8.4	13.9	24.8	25.7	
10-50 cm	0.6	5.5	4.7	6.7	17.4	148.6	
DP-496 (4 y, tree species)							
Biomass	0.4	0.8	1.5	2.3	4.9		4.9
Soil 0-10 cm	0.2	5.0	23.4	41.0	69.7	8.8	
10-50 cm	0.9	9.8	42.1	68.6	121.4	117.5	
DP-8S (8 y, tree species)							
Biomass	0.1	0.8	0.8	1.2	3.0		2.9
Soil 0-10 cm	0.2	7.5	25.3	79.4	112.5	0.0	
10-50 cm	1.0	23.1	42.8	37.6	104.5	107.3	
DP-1596 (15 y, tree species)							
Biomass	0.4	1.2	1.3	3.2	6.1		6.1
Soil 0-10 cm	0.2	20.5	37.5	56.1	114.3	0.0	
10-50 cm	1.0	42.7	28.8	23.7	96.1	106.0	

All the data are expressed on a 70℃ and 110℃ oven-dried basis for the aboveground biomass and soil samples, respectively. *For the soils, the data show the amounts of exchangeable bases.

Soil acidification in the field under continuous cultivation. Based on the high concentration in soil solution from the subsoils (Fig. 4.6), it was considered that under the continuous cultivation system adopted by Hmong and Thai peoples in the RP village, the decrease in the amount of exchangeable bases and resulting soil acidification proceeded through leaching loss of inorganic bases. In the continuously cultivated fields which lacked forest vegetation, the soil acidification process may be irreversible.

The leaching loss of inorganic bases could be accelerated by the supply of NO$_3^-$ through the rapid decomposition of soil organic matter in the cropping fields (Conyers et al. 1995; Chapter 5). Among the inorganic bases, Ca may be more readily depleted under continuous cropping because it occurred only in an exchangeable form in the soils and could not be compensated from soil minerals (Fig. 4.3). In contrast, K and sometimes Mg, could be supplied along with mineral weathering over a long period of time.

Thus, the shifting cultivation system adopted by the Karen people with 1 y cropping is considered to be effective to prevent leaching loss of nutrients through rapid recovery of the vegetation during the fallow period. On the other hand, the continuous cropping system for several years by the Hmong and Thai peoples may promote soil acidification and, hence, is thought to be less sustainable from a long term perspective. Alternative cropping systems in the area should able to alleviate the leaching loss of nutrients and soil acidification.

Chapter 5. Dynamics of soil organic matter along with land use in shifting cultivation

5.1 Introduction

In Chapter 3, it was clarified that the content of organic matter determined the CEC of the surface 10 cm soils. According to the ion adsorption curve experiment, soil organic matter seemed to contribute to increase in variable negative charges. In addition, the content of organic matter showed significant correlation with that of available N in the surface soils. Although it has been often reported that the slash and burning practice causes a drastic decrease in total organic matter of the soils (Andriesse and Schelhaas 1987b; Ramakrishnan 1992), recovery process of soil organic matter in course of the fallow period or decay process under cultivation is not still clear. On the other hand, some researchers reported that activity of N mineralization in the field was stimulated by the slash and burning practice (soil burning effect) (Tulaphitak et al. (1985a); Ramakrishnan 1992). In order to analyze the effect of fallow and cultivation on soil organic matter, in this chapter, the author investigates the dynamics of organic matter in the soils, including the decomposition rate of soil organic matter under the shifting cultivation and the pattern of N mineralization process in aerobic incubation with special reference to the soil burning effect.

5.2 Materials and methods

5.2.1 Total C and N and available N in the surface 10 cm depth soils

Soil samples were collected from the 0-10 cm layers at 40 sites including 17 sites in the DP village, 10 sites in the HM village, and 13 sites in the RP village (the

same sites to those in Chapter 3). The soil samples were air-dried and passed through a 2 mm mesh sieve. The contents of total C and N were measured with NC analyzer (Sumika Chem. Anal. Service, Sumigraph NC-800). The content of available N was evaluated by a biological method in duplicate (Inoko 1986): The amount of N (NH_4^+-N+NO_3^--N) mineralized during 4 weeks of aerobic incubation at 30 ℃ was determined by steam distillation using successive addition of MgO and Devarda's alloy after extraction with 2 M KCl solution from soils (Keeney and Nelson 1982). At the same time, the pH of the soil suspension in water (1:2) was also measured both before and after the incubation to estimate the pH change associated with N mineralization and subsequent nitrification.

5.2.2 CO_2 evolution from the soils

In order to evaluate the decomposition rate of soil organic matter caused by the biological activity in the field, carbon dioxide evolution from the soil (soil respiration) was measured in the RP-C1, C3, C4, C5, C9, F1, and F2 fields from March, 1993 to June, 1994, using the alkali-adsorption method (Anderson 1982), which is briefly described as follows: A PVC pipe (height 25 cm and diameter 21 cm) was inserted into the soil to a 5 cm depth in each field with five replications. After a dish filled with 10 mL of 1 M NaOH solution was placed in the pipe, the top of the pipe was wrapped and sealed with scotch tape. After 24 h, the alkali solution was collected and then titrated with a standard 0.2 M HCl solution, using first phenolphthalein and then methyl orange as indicators. The amount of CO_2 absorbed in the NaOH solution was determined in the 2nd titer, being equivalent to that evolved from the soil surface during the 24 h period. For comparison of the amount of organic carbon stored in the upper 50 cm layers of the soil profiles and that decomposed through soil respiration, the soils were collected from every 10 cm depth up to 50 cm in the same fields at the initial time of measuring soil respiration and the content of total C was determined by the NC analyzer introduced above.

5.2.3 N mineralization characteristics of the surface soils in relation to soil burning effect

Soil samples were collected from the surface 5 cm layers in the RP-C1 field (1st year of cultivation after 7 y of fallow), RP-C3 field (3rd year of cultivation), RP-C5 field (1st year of cultivation after nearly 20 y of fallow), and RP-F1 field (10 y of fallow forest) before cropping in March, 1993. In the RP-C1 and C5 fields, soil samples were collected both before and after burning. The samples collected were sent to Japan without air-drying and used for analysis as soon as possible. After moisture adjustment to 60 % of the water holding capacity of the soils, determined based on the three phase distribution of undisturbed soil sample, the soils were incubated at 30 ℃ in the dark for 1, 3, 5, 7 14, 21, 28, 35, 44, 59, 80, 104, and 134 d. The amount of N mineralized was determined by the steam distillation method after extraction with 2 M KCl solution.

5.3 Results and discussion

5.3.1 Dynamics of the contents of organic matter and available N in the shifting cultivation systems in northern Thailand

It must be emphasized that the difference in the climatic conditions in the study areas, especially in the annual precipitation or air temperature, may affect the organic matter-related properties described below. Annual precipitation in Mae Hong Son City is 1,200 mm, whereas that in Chiang Rai City is 1,600 mm (see Chapter 2). The altitude of the cropping fields in the DP, HM, and RP villages ranges from 1,100 to 1,300, from 700 to 850 m, and from 500 to 550 m, respectively.

Table 5.1. Organic matter-related properties of the surface 10 cm depth soils.

Village Site	Land use*	Total C	Total N	Avail. N (mg kg^{-1})	C/N ratio
		------- (g kg^{-1}) ------			
Ban Du La Poe village					
DP-C2	C (0/7)	35.3	2.4	96	14.7
DP-C3	C (0/7)	49.4	3.2	167	15.4
DP-F1	F (1/7)	31.7	2.5	110	12.7
DP-F4	F (1/7)	32.2	2.6	89	12.4
DP-F10	F (5/7)	63.3	4.8	136	13.2
DP-F11	F (5/7)	42.7	3.2	85	13.3
DP-F6	F (8/7)	32.5	2.0	84	16.3
DP-F7	F (8/7)	34.4	2.2	156	15.6
DP-F8	F (17/7)	33.7	2.3	97	14.7
DP-F5	NF	48.7	3.7	189	13.2
DP-F12	NF	43.0	2.7	152	15.9
DP-F13	NF	55.6	3.6	243	15.4
DP-C1	C (0/7)	24.5	2.1	89	11.7
DP-F14	F (2/7)	50.2	3.4	95	14.8
DP-F2	F (6/7)	43.8	3.3	105	13.3
DP-F3	F (25/7)	58.0	4.3	228	13.5
DP-F9	NF	42.3	3.3	176	12.8
Ban Huai Mak Nun village					
HM-C1	C (0/0)	29.4	2.3	52	12.8
HM-C2	C (0/0)	33.1	2.6	106	12.7
HM-F1	F (1/0)	15.4	1.1	13	14.0
HM-F2	F (1/0)	11.4	0.7	24	16.3
HM-F7	F (4/0)	35.8	3.0	140	11.9
HM-F8	F (4/0)	33.3	2.1	90	15.9
HM-F3	F (7/0)	19.3	1.2	60	16.1
HM-F4	F (7/0)	21.4	1.1	52	19.5
HM-F5	NF	38.3	3.3	167	11.6
HM-F6	NF	29.0	2.8	153	10.4
Ban Rakpaendin village					
RP-C8	C (6/5)	24.6	1.9	85	12.9
RP-C6	C (4/0)	18.5	1.7	97	10.9
RP-C9	C (5/5)	17.2	1.6	90	10.8
RP-C10	C (3/5)	20.7	1.8	71	11.5
RP-C3	C (2/0)	30.0	1.7	90	17.6
RP-C4	C (2/0)	21.8	1.5	44	14.5
RP-C2	F (2/0)	20.3	1.7	59	11.9
RP-C7	F (6/0)	38.2	2.8	92	13.6
RP-C1	F (7/0)	38.9	2.3	93	16.9
RP-F1	F (9/0)	32.4	2.0	130	16.2
RP-C5	F (>25/0)	37.2	1.8	70	20.7
RP-F2	NF	41.9	3.3	187	12.7
RP-F3	NF	31.0	3.0	146	10.3

* Parenthesis s the period of fallow or cropping in years/mont w, C: cropping, NF: natural forest.

The contents of total C and N, and available N in the soils from the surface 10 cm layers are given in Table 4.1. Because of the acidic nature of the soils studied, the content of C determined with a NC analyzer corresponds mostly to the organic form.

The contents of organic C and N, and available N in the surface soils are plotted against the land use stages in Figs. 5.1, 5.2, and 5.3. They fluctuated considerably presumably due to the variation in the slope direction and gradient, etc., except for the soils from the RP village, which is located on relatively gentle slopes (See Fig 3.1 in Chapter 3). Organic C and N contents in the surface 10 cm layers under continuous cropping was mostly less than 30 g C kg^{-1} and 2.0 g N kg^{-1}, respectively, whereas that in soils under prolonged fallow (more than 10 y) or natural forest exceeded 30 g C kg^{-1} and 2.0 g N kg^{-1}, respectively. In the Karen fields with 1 y cultivation and several years of fallow, the content of total C or N was intermediate between those in the natural forest and the field continuously cropped. A similar tendency was also observed for the content of available N, which exceeded 130 mg kg^{-1} under natural forest while it was lower than 100 mg kg^{-1} in the fields continuously cropped (Fig. 5.3). These results showed that the organic matter-related resources tended to decrease under continuous cropping.

Figure 5.4 depicts the amount of soil respiration measured in the RP village from March, 1993 to June, 1994, which showed almost the same level as that reported in northeastern Thailand by Tulaphitak et al. (1985b). The CO_2 evolution gave lower values in the dry season on around the 200th to 250th day in Fig 5.4, which was also consistent with the seasonal variation in the soil respiration reported by Tulaphitak et al. (1985b).

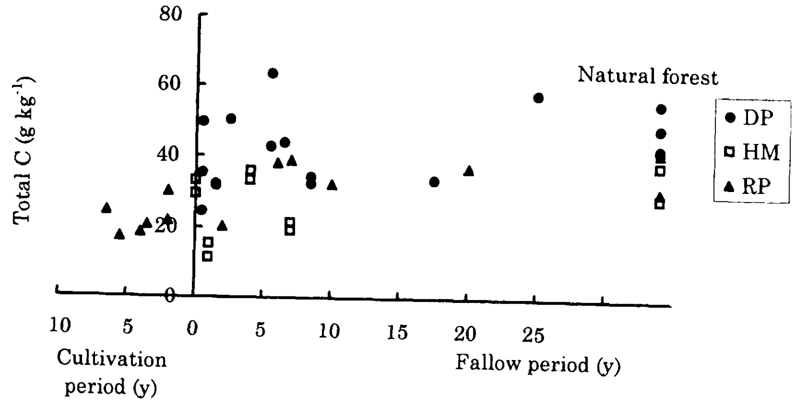


Fig. 5.1. Relationship between the land use and the content of total C in the 0-10 cm soil layers.

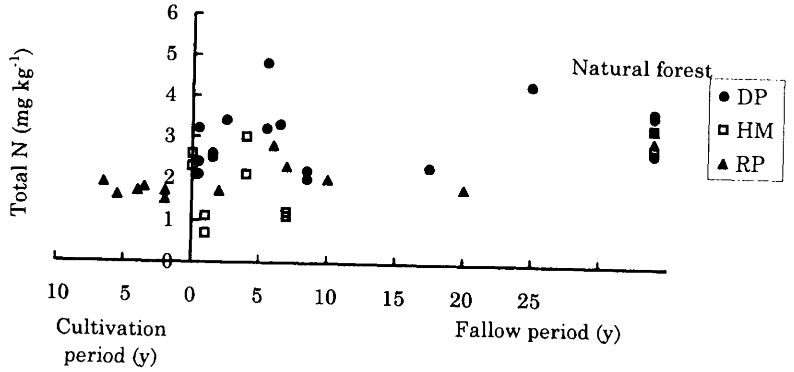


Fig. 5.2. Relationship between the land use and the content of total N in the 0-10 cm soil layers.

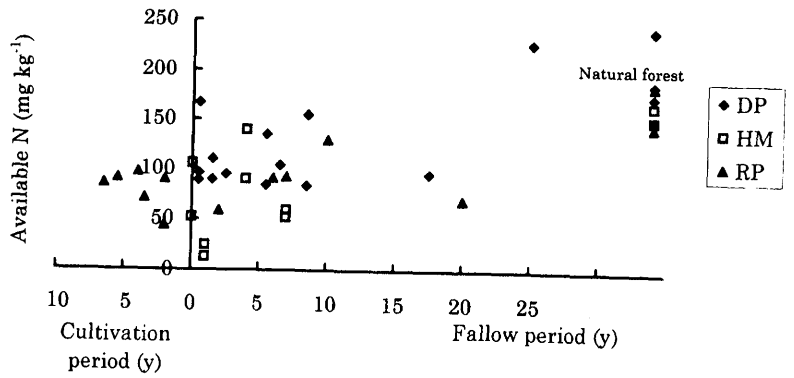


Fig. 5.3. Relationship between the land use and the content of available N in the 0-10 cm soil layers.

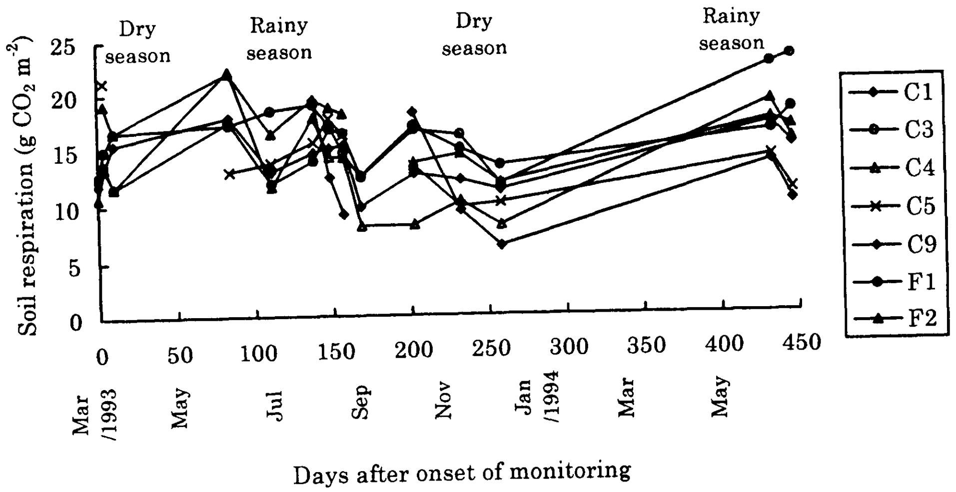


Fig. 5.4. Soil respiration measured in the selected fields in the RP village.

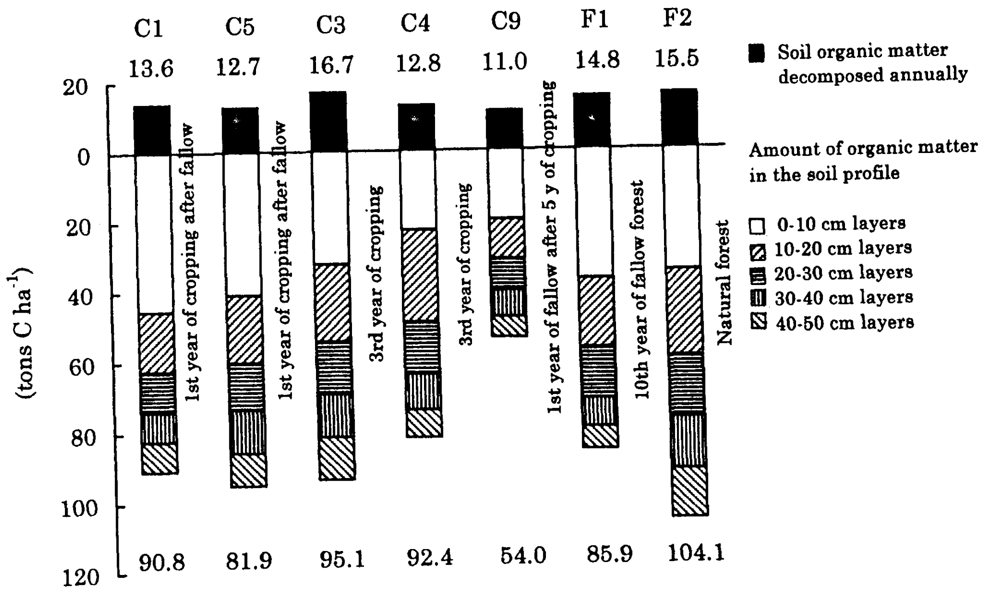


Fig. 5.5. Comparison of the amount of organic carbon stored in the upper 50 cm layers of the soil profiles and that estimated to be decomposed within one year.

Assuming that the CO$_2$ evolution measured in this experiment mostly originated from the decomposition of soil organic matter with minimal contribution of respiration by plant roots, the amount of organic matter decomposed during June, 1993 to June, 1994 was calculated based on the measurement of the soil respiration, and directly compared with that stored in the upper 50 cm layers of the soil profiles (Fig. 5.5). Although some overestimation may be involved due to respiration by plant roots, nearly 10 % of organic matter stored in the upper 50 cm layers of the soil profiles was decomposed within one year in the upland crop fields, where the return of organic matter by litterfall was hardly expected. Thus, soil organic matter and its related resources were considered to be rapidly depleted in the upland crop fields.

5.3.2 N mineralization characteristics with special reference to the soil burning effect and subsequent soil acidification

The patterns of N mineralization in the incubation experiment are presented in Fig. 5.6. The factors contributing to the N mineralization process will be discussed in more detail in Chapters 6 and 7.

In the soils from RP-C1 and C5 fields after burning, NO$_3^-$ was not detected at the initial period of the incubation experiment in spite of the active process of ammonification, suggesting that the activity of nitrifying bacteria did not recover rapidly after burning. This result was consistent with the field study reported Tulaphitak et al. (1985a), in which the increase in the content of NO$_3^-$ in the soils was observed after the increase in the NH$_4^+$ content with a certain lag time after burning.

There was no appreciable difference between the patterns of N mineralization in the soils collected before and after burning from RP-C1, in which a 7 y fallow forest with a small amount of vegetation biomass (38.7 t ha^{-1} in dry weight) was slashed and burnt. On the contrary, a distinct increase in the amount of N mineralized during the incubation experiment, that is, soil burning effect, was observed in the RP-C5 field, which had been covered by fallow vegetation more than 20 y old. The slashed materials in the RP-C5 field amounted to 58.4 t ha^{-1} (dry weight basis), excluding larger tree stems that were partly burnt out at the time of burning. Thus, the soil burning effect, which directly increased the amount of readily mineralizable N, may be manifested only after a relatively long period of fallow.

In the course of N mineralization and nitrification, since organic N (R-NH$_2$) in the soil consumes one proton in the process of ammonification and subsequently produces two protons at the time of nitrification, the net proton production is equal to the amount of (NO$_3^-$-N minus NH$_4^+$-N) (mol) released. Figure 5.7 shows the relationship between the amount of (NO$_3^-$-N minus NH$_4^+$-N) released and pH change in the 4-week incubation experiment to determine the content of available N. It was observed that nitrification following N mineralization could potentially lead to soil acidification and may promote a loss of basic cations from the soil profile if they are not fully taken up by plant roots. In the fields, not only crops but also herbaceous weed species or fallow vegetation, which grew rapidly after the slash and burning practice, may have prevented the rapid leaching loss of bases and NO$_3^-$ and soil acidification (Chapter 4).

Thus it is important to appropriately control the rate of N mineralization as well as to keep a vegetation cover in order to avoid excessive loss of basic cations. From this viewpoint, the traditional shifting cultivation system adopted by the Karen people, in which they planted crops for only 1 y with fallow period for about 10 y, seemed to be rather sound, because such a loss of basic cations along with the

process of nitrification may be more substantial in the long fallow systems due to a more pronounced soil burning effect or under the continuous cropping systems with poor vegetation cover.

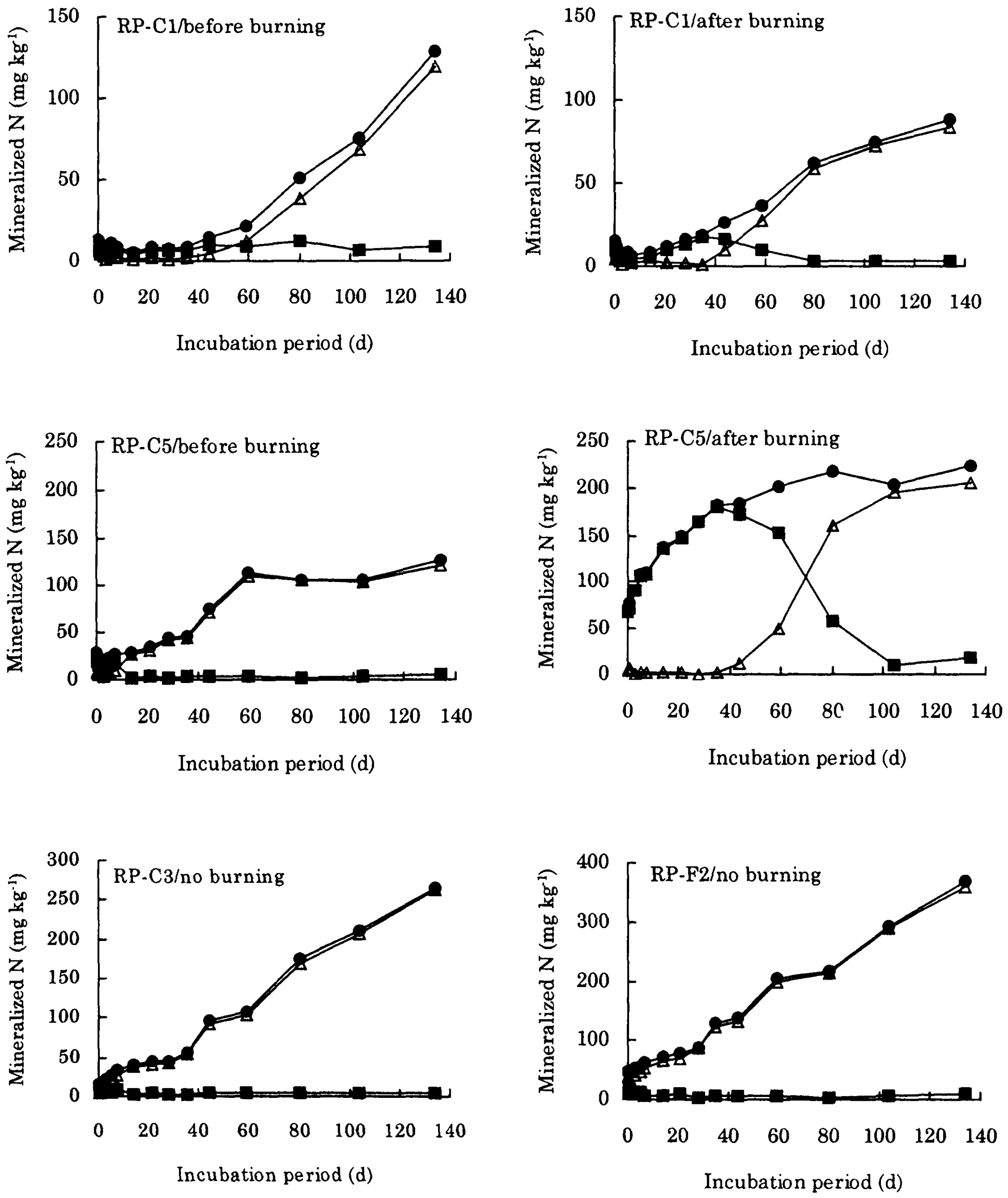


Fig. 5.6. Amounts of NH$_4^+$-N(■), NO$_3^-$-N (△), and total N(●) released in the incubation experiment using the fresh soils collected from selected fields in the RP village.

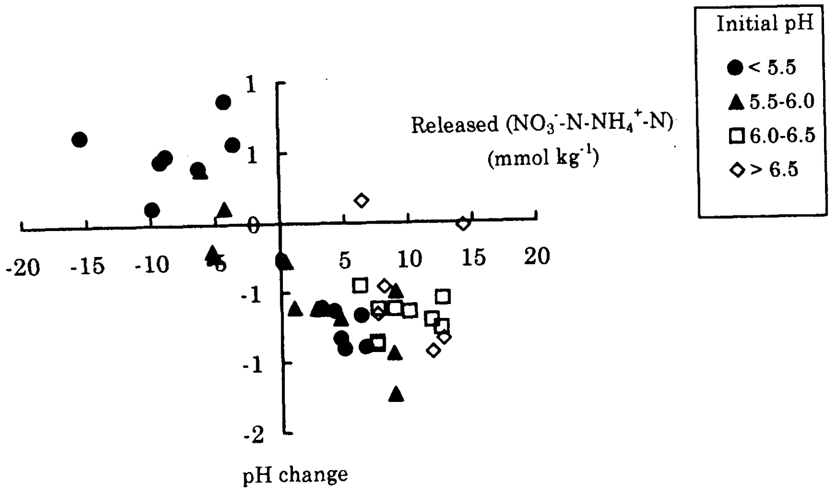


Fig. 5.7. Relationship between the amount of (NO_3^--N minus NH_4^+-N) released and the change in soil pH in the 4 week incubation experiment.

5.3.2 General considerations about the dynamics of organic matter-related properties in the shifting cultivation in northern Thailand

The soil properties related to the soil organic matter seem to deteriorate rapidly after the slash and burn practice in the fallow / cultivation systems. Such a rapid deterioration of the soil organic matter-related properties in the cropping fields may be one of the ecological reasons why upland fields must be returned to fallow within a few years after the slash and burn practice in the traditional shifting cultivation systems. Therefore, in alternative farming systems with more intensive and continuous land use, it is indispensable to apply organic materials into soils to reduce the rate of soil degradation, or to improve the soil fertility. This practice may, however, enhance soil acidification through the rapid decomposition of organic matter and subsequent nitrification, if the dynamics of N in the soil ecosystems is not carefully considered.

Chapter 6. Labile pools of organic matter and microbial biomass in the surface soils under shifting cultivation

6.1 Introduction

In Chapters 4 and 5, it was revealed that soil organic matter related properties under cropping seemed to decrease rapidly after the slash and burn practice (Chapter 5) and suggested that nitrification might potentially lead to soil acidification and might promote an excess loss of basic cations from the soil profile (Chapters 4 and 5).

Nitrogen mineralization process of the soils in the tropics or subtropics has been studied by several researchers (Singh et al. 1991; Haggar et al. 1993; Piccolo et al. 1994). However, many of these studies depend on periodical sampling of soils and measurement of the contents of mineral N. Although such studies are important to evaluate the nitrogen dynamics in the field, the results are often affected by climatic conditions at the sampling date. On the other hand, in order to estimate the N mineralization process in soils, a biological method has been applied, in which the parameters of the N mineralization pattern are determined through laboratory incubation experiments (Sugihara et al. 1986). Yonebayashi and Hattori (1986) analyzed the N mineralization process of paddy soils in tropical and temperate regions and reported that the process was regulated by the contents of α-amino-N in total N or polysaccharide-C in total C.

In order to analyze the N mineralization process in the traditional shifting cultivation system and relatively intensive cultivation system in study region, in this chapter, the author investigates the labile pools of organic matter accumulated in the surface 0-5 cm soil layers at the end of the dry season and their origins. The organic matter extracted with a 0.5 M K_2SO_4 solution in an autoclave is designated as the labile pool (Saito 1990) (fraction A), and the organic matter extracted with a 0.5 M K_2SO_4 solution at room temperature was as another pool (fraction B). Nitrogen mineralization process and significance of the pools in fractions A and B for the process will be discussed in the next chapter.

6.2 Materials and methods

6.2.1. Soil samples

Soil samples were collected in the DP and RP villages in March, 1997, at the end of the dry season. For this study, 22 fields were newly selected in the middle part of a slope under different land use stages (Table 6.1). In order to analyze the difference in the amounts of organic pools among the different land use stages by omitting the effects of topography, vegetation, or other factors, in this study, the author classified the fields under the different land use stages into some groups and designated them as follows: the fields cultivated for 1 y after slash and burn as 0F, the fields laid fallow for 1 y, 3 to 5 y, and 8-15 y as 1F, 3-5F, and 8-15F, respectively, the fields cultivated continuously for 3 to 5 y after the slash and burn practice as 3-5C, and natural forest as NF. The 8 to15 y of fallow period in the DP village and the 3 to 5 y in the RP village corresponded to the maximum length of fallow period, respectively. In this study, the field just after the slash and burn practice was not examined because it was difficult to conduct appropriate samplings due to the remarkable differences in the fire intensity even within one field. All the fields studied were cultivated or laid fallow without chemical fertilization, application of organic matter, or tractor tillage. Ten soil samples were collected from the surface 0-5 cm layers in a 10×10 m^2 quadrat in each field. The samples collected were

stored in a refrigerator before leaving Thailand and brought to Japan by airplane. They were passed through a 2 mm sieve quickly to avoid drying and mixed into one composite sample per one field. They were preserved at 4 ℃ until analysis and used as soon as possible. A portion of the samples was air-dried and used for the determination of the general physicochemical properties, which are summarized in Table 6.1. The pH(H_2O) of the soils ranged from 5.0 to 6.5, pH (KCl) of the soils ranged from 4 to 5.5, and clay content from 35 to 60 %. Since the soil samples were collected at the end of the dry season, the moisture content of fresh samples was considered to be minimum in a year.

6.2.2. Analytical methods

Determination of the contents of organic C, (organic+NH_4^+)-N, and hexose-C extracted with a 0.5 M K_2SO_4 solution. Organic matter was extracted from the fresh soils with a 0.5 M K_2SO_4 solution in a soil to solution ratio of 1:10 by heating at 110 ℃ for 6 h in an autoclave (fraction A) or by shaking at room temperature for 1 h with a reciprocal shaker (fraction B). The content of organic C was determined by titration with a 0.2 M $FeSO_4(NH_4)_2SO_4$ solution after digestion with $K_2Cr_2O_7$ under acid conditions by the Tinsley method (Bremner and Jenkinson 1960). The content of (organic+NH_4^+)-N was determined by steam distillation after Kjeldahl digestion (Bremner and Mulvaney 1982). The content of hexose-C was determined colorimetrically by the anthrone method (Tatsukawa 1966).

Determination of contents of C and N in microbial biomass. The contents of microbial biomass C and N were determined by the chloroform fumigation-extraction method in triplicate (Vance et al. 1987; Brookes et al. 1985), as follows: Fresh soil samples were kept for 10 d at room temperature without moisture

Table 6.1. Some physicochemical properties of the surface 0-5 cm soils.

Sample No.	Land* use	pH		T-C***	T-N***	C/N	Particle size distribution			Moisture content	
		(H_2O)	(KCl)	---- ($g\ kg^{-1}$) ---			Sand	Silt	Clay	Fresh	Air-dried
							----------	----------	(%)	----------	----------
Ban Du La Poe (DP)											
1	0F	6.1	5.0	43.3	3.1	13.9	32.7	14.1	53.2	4.5	3.2
2	0F	5.9	4.9	50.5	4.0	12.8	21.5	20.2	58.3	4.7	3.5
3	0F	6.0	5.0	46.6	3.5	13.4	18.3	22.6	59.1	5.2	3.5
4	1F	6.4	5.3	40.5	2.7	14.9	33.3	22.9	43.8	4.6	2.9
5	1F	6.5	5.6	37.9	2.6	14.6	29.6	24.1	46.3	4.5	3.1
6**	3F	6.3	5.1	46.2	2.7	17.1	43.5	18.7	37.8	5.2	3.5
7**	3F	6.0	4.9	35.9	2.7	13.4	52.0	12.0	36.1	3.3	3.3
8	4F	6.0	4.9	44.4	3.3	13.4	21.5	19.7	58.8	5.7	4.5
9**	5F	6.3	5.0	34.6	2.5	13.8	51.4	12.9	35.7	4.1	2.7
10**	8F	6.0	4.8	54.6	3.4	16.2	45.5	13.3	41.3	6.2	4.2
11	10F	5.9	4.5	64.0	3.4	18.7	24.9	20.9	54.2	12.9	6.6
12**	15F	5.5	4.2	58.3	3.4	17.0	34.8	19.5	45.7	9.6	3.9
13	NF	5.1	4.0	86.9	5.5	15.8	29.0	11.6	59.4	13.3	7.4
Ban Rakpaendin (RP)											
14	5C	5.8	4.1	23.0	1.9	12.3	27.9	16.4	55.7	8.2	3.2
15	3C	6.3	4.8	25.0	1.9	12.9	18.9	20.7	60.4	7.2	3.2
16	3C	5.7	4.7	29.1	2.5	11.5	20.3	22.9	56.9	5.2	3.1
17	0F	6.1	5.1	27.2	2.4	11.4	27.0	19.6	53.3	3.6	2.1
18	0F	5.9	4.5	39.9	2.6	15.4	15.0	22.2	62.8	4.7	3.4
19	3F	5.5	4.1	49.7	2.9	16.9	25.4	12.9	61.7	14.6	4.5
20	3F	5.9	4.6	29.3	2.1	14.1	27.3	21.9	50.8	6.4	2.6
21	5F	6.1	4.9	35.2	2.6	13.8	20.6	20.2	59.2	12.6	3.6
22	5F	5.5	4.0	31.0	2.3	13.5	25.5	16.6	58.0	12.6	3.4

Analytical methods were described in Chapter 3. *Number denotes the duration of fallow forest or cultivation. F, C, and NF denote fallow field, cultivated field and natural forest, respectively. **Soils derived from granite. ***Oven-dried basis.

adjustment under a constant humidity for conditioning incubation. Each 10 g of soil was fumigated with chloroform for 24 h, the fumigant was removed, and then C and N were extracted with a 0.5 M K_2SO_4 solution in a soil to solution ratio of 1 : 5. At the same time, C and N were also extracted from the soils without fumigation as control in the same way. The contents of C and N in the solution were determined by the methods mentioned above. The contents of biomass C and N were calculated from the following equations, respectively:

$$\text{Biomass C} = 2.64 \times [(\text{C from fumigated soil}) - (\text{C from non-fumigated soil})]$$

$$\text{Biomass N} = 2.22 \times [(\text{N from fumigated soil}) - (\text{N from non-fumigated soil})]$$

Statistical analysis. Significant difference of the data among the different land use stages was estimated by ANOVA program in SYSTAT 5.0 (Wilkinson 1992). The data from NF were excluded from this analysis because there was only one sample from NF.

6.3 Results

6.3.1. Contents of total soil C and N

Figure 6.1 shows the relationship between the contents of total soil C and N and the land use stages. According to this figure and Table 6.2, in the DP village, total soil C content showed the lowest value of 39.2 g kg^{-1} for the soil from 1F or 40.3 g kg^{-1} from 3-5F, and tended to increase along with the duration of the fallow period. The lower content of total N was 2.66 g kg^{-1} in the soil from 1F although there was no significant difference in the N content among the land use stages. The soil from NF was rich in total C and N. On the other hand, in the RP village, the difference in the content of total C or N among the land use stages were not significant statistically.

In the DP village, the C/N ratio of the soils from 0F was significantly lower than that from 8-15F (Table 6.2), suggesting that fresh organic matter with a high C/N ratio was supplied from forest vegetation under fallow and/or that the reduction rate of the C pool was higher than that of the N pool under cultivation. C/N ratio of the soil from NF was lower than that from 8-15F, suggesting that the activity of the soil microbes in the natural forest was higher than in fallow forest even in the dry season or that fresh organic matter was abundantly supplied from the vegetation to the soil surface in the fallow forest through the transition of vegetation.

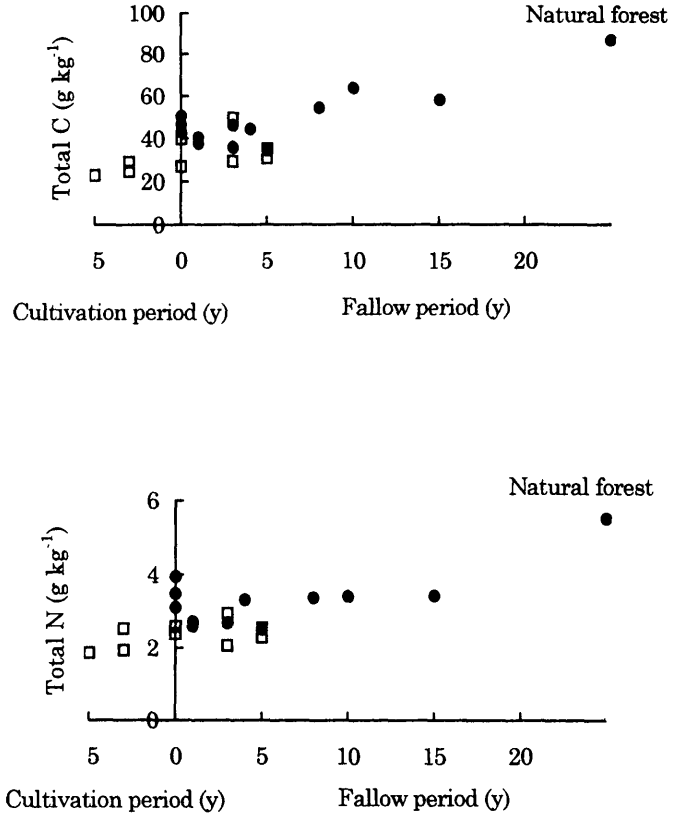


Fig. 6.1. Relationship between the land use stages in shifting cultivation and the contents of total C and N in the surface 5 cm layers of the soils. ●: Soils from the DP village. □: Soils from the RP village.

6.3.2. Contents of organic matter extracted with a 0.5 M K_2SO_4 solution and microbial biomass

Table 6.2 shows the mean values of organic C, (organic+NH_4^+)-N, and hexose-C in fractions A and B, and microbial biomass in relation to the land use groups. Figure 6.2 shows the relationship between the contents of the organic pools in fractions A and B and the land use stages in shifting cultivation.

Table 6.2. Mean values of the pools of soil organic matter and microbial biomass of the surface 0-5 cm soils in relation to the land use stages under shifting cultivation.

Land use	Sample N	Soil T-C	Soil T-N	Soil C/N	fraction A Organic-C	fraction A (Organic+NH_4^+)-N	fraction A Hexose-C	fraction B Organic-C	fraction B (Organic+NH_4^+)-N	fraction B Hexose-C	Microbial biomass C	Microbial biomass N
		----- (g kg^{-1}) ----						(mg kg^{-1})				
Ban Du La Poe												
0F	3	46.8 b	3.52 a	13.4 a	3210 b	432 b	946 a	548 c	84 b	167 c	335 a	<15 a
1F	2	39.2 ab	2.66 a	14.7 ab	2640 ab	310 a	647 a	375 a	41 a	100 b	292 a	< 15 a
3-5F	4	40.3 ab	2.80 a	14.4 ab	2600 ab	310 a	581 a	324 a	32 a	84 b	504 ab	25 b
8-15F	3	58.9 bc	3.41 a	17.3 b	3710 bc	401 ab	921 a	235 b	43 a	36 b	751 b	44 c
NF*	1	86.9	5.51	15. 8	6880	756	1917	401	92	54	1352	74
Ban Rakpaendin												
3-5C	3	25.7 A	2.10 A	12.2 A	1790 A	277 A	405 A	203 A	43 A	43 AB	419 A	<15 A
0F	2	33.5 A	2.49 A	13.4 A	2160 A	308 A	554 A	282 A	54 A	84 B	355 A	< 15 A
3-5F	4	36.3 A	2.47 A	14.6 A	2300 A	313 A	593 A	196 A	45 A	30 A	671 A	50 A

For each variable in DP village and in RP village, different letter indicates significant difference ($p<0.05$). *The soil from NF in the DP village is not included in the statistical analysis. All the data are expressed on an oven-dried basis.

Organic matter extracted by the autoclave method. In the DP village, the contents of organic C in fraction A of the soils from 1F and 3-5F were 2640 and 2600mg kg^{-1}, respectively and lower than that from 8-15F, whereas the contents of hexose-C were not significantly different among the land use stages. The content of (organic+NH_4^+)-N from 0F was 432 mg kg^{-1} and higher than that from 1F or 3-5F. These contents from NF were the highest among the soils. In the RP village, the difference in the content of organic C, (organic+NH_4^+)-N, or hexose-C among the 3 stages was not significant.

Organic matter extracted at room temperature. In the DP village, the contents of organic C, (organic+NH_4^+)-N, and hexose-C in fraction B of the soils from 0 F were 548, 84, and 167 mg kg^{-1}, respectively, and significantly the highest among the soils. These contents were decreased along with the number of years of the fallow period. The contents of organic C and hexose-C were minimum, 235 and 43 mg kg^{-1}, in 8-15F, respectively. The content of (organic+NH_4^+)-N from NF was almost as high as that from 0F while the content of hexose-C was as low as that from 8-15F.

On the other hand, in the RP village, the content of hexose-C from 0F was significantly higher than that from 3-5F. However the contents of organic C or (organic+NH_4^+)-N were not significantly different among the land use stages.

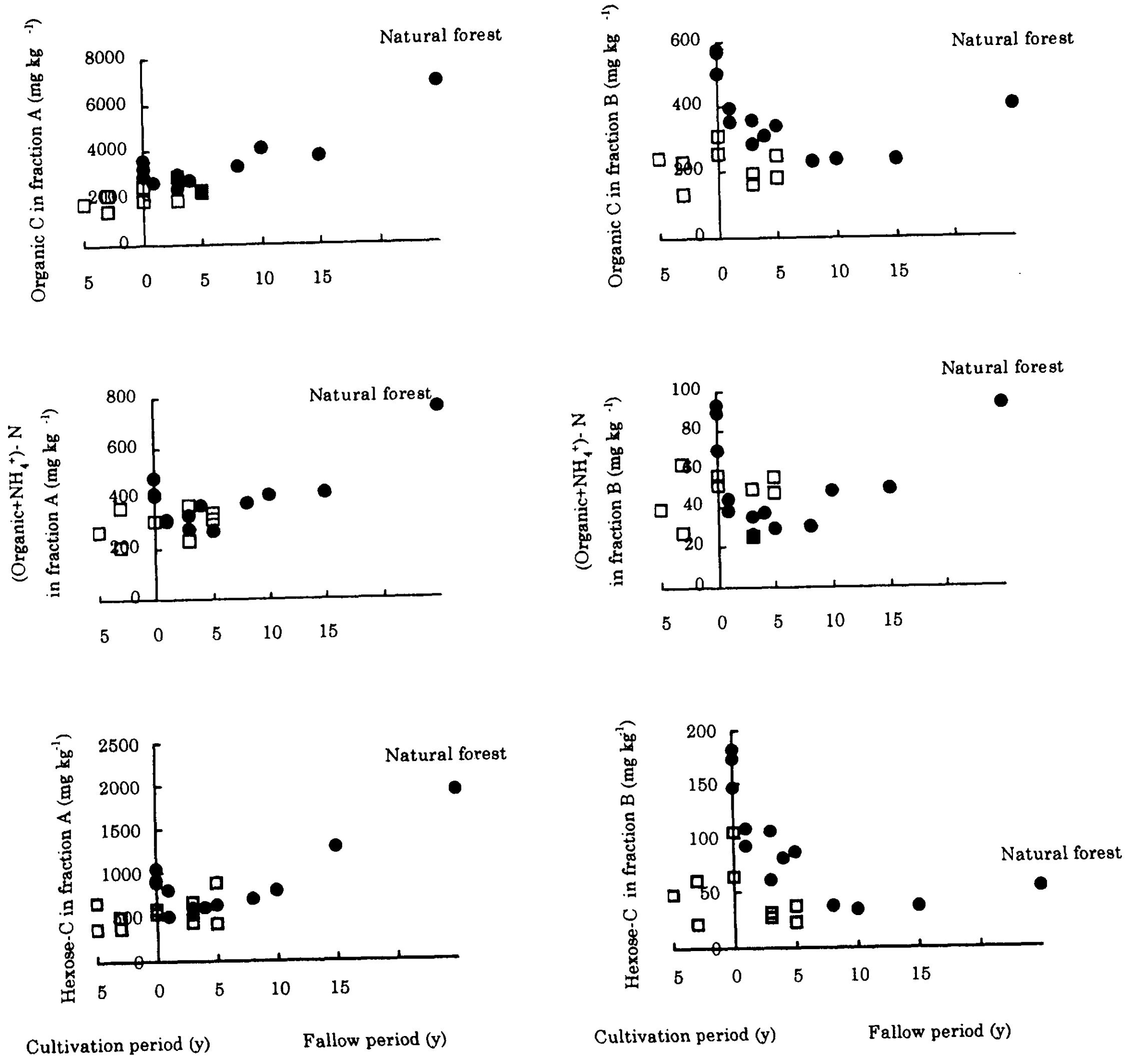


Fig. 6.2. Relationship between the land use stages in shifting cultivation and the contents of organic C, (organic+NH4+)-N, and hexose-C in fractions A and B extracted from the fresh soils in the surface 5 cm layers. ●:Soils from the DP village. □:Soils from the RP village.

Microbial biomass C and N. In Fig. 6.3, the contents of microbial biomass C and N were plotted against the land use. In the DP village, the contents of biomass C in the soils from 0F, 1F, and 3-5F were 335, 292, and 504 mg kg^{-1}, respectively, and lower than that from 8-15F. The content from NF was 2 to 5 times as high as that from the other fields. In the RP village, the contents of biomass C were not significantly different among the land use stages. The microbial biomass N in each village showed a tendency similar to that of the microbial biomass C along with the land use stages (Fig. 6.3). However, the content of biomass N in the case of 3-5C, 0F, or 1F was less than 15, a value lower than the lower limit of determination of the biomass N assay. The C/N ratio of the microbial biomass of the soils from 3-5 F in the RP village was higher than that in the DP village, suggesting that the microbial community of the soils in the traditional shifting cultivation system may differ from that relatively intensive cultivation.

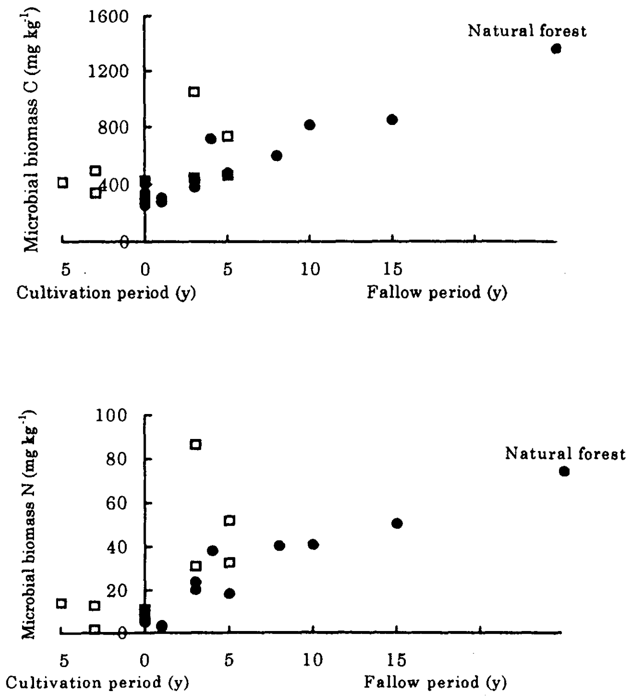


Fig. 6.3. Relationship between the land use stages in shifting cultivation and the contents of microbial biomass C and N in the surface 5 cm layers of the soils. ●: Soils from the DP village. □: Soils from the RP village.

6.4 Discussion

6.4.1. Factors contributing to the amounts of organic matter extracted with a K_2SO_4

solution by the autoclave method

As shown in Figs. 6.1 and 6.2, the difference in the content of organic C, (organic+NH_4^+)-N, or hexose-C in fraction A among the land use stages was similar to that of total soil C or N. In fact, a high correlation was observed between the content of total soil C and the content of organic C (Fig. 6.4) or hexose-C in fraction A, or between the content of total soil N and the content of (organic+NH_4^+)-N in this fraction in each village. In the DP village, organic C, hexose-C, and (organic+NH_4^+)-N in fraction A accounted for 8 % of total soil C, 2 % of total soil C, and 15 % of total soil N, respectively. In the RP village, they accounted for 5, 1, and 14 %, respectively. In both the villages, the ratio of the labile pool in fraction A to total soil organic matter was remained constant due to the input-output balance in the labile organic pool. The balance may include the input from organic matter of the forest vegetation, the input from humic substances (Yonebayashi 1997) which were not hydrolyzed by the autoclave treatment but were decomposed by microbes, and the output through the decomposition of the organic pool by microorganisms under natural conditions. Since there was a difference in the ratio of organic C or hexose-C to total soil C between the villages, the input-output balance may be affected by the land use systems.

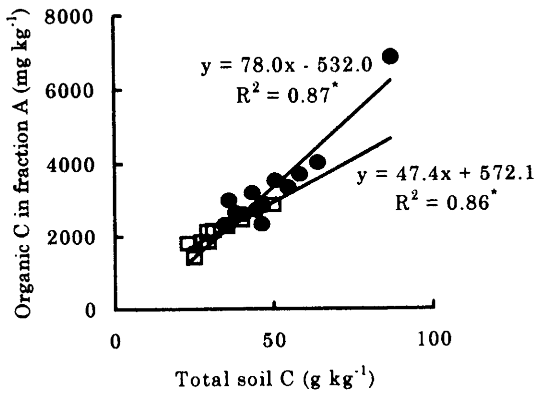


Fig. 6.4. Relationship between the contents of total soil C and the organic C in fraction A. ●: Soils from the DP village. □:Soils from the RP village.

6.4.2. Factors contributing to the amounts of organic matter extracted with a K_2SO_4 solution at room temperature

According to Table 6.2, the soils from 0F contained a larger amount of the labile pool in fraction B than expected from their contents of total soil C and N, in contrast to the case of fraction A. The size of the labile pool in fraction B was considered to be independent of total soil organic matter or the pool in fraction A.

In the soils from the DP village, there was a relationship between the content of microbial biomass C and the content of organic C or hexose-C in fraction B depending on the land use stages, except for the soil from NF (Fig. 6.5), as follows: The content of microbial biomass C was high but that of organic C or hexose-C was low in the soils from 8-15 F, whereas the content of biomass C was low but that of total C or hexose-C was high in the soils from 0F or 1F. In the soils from 3-5 F the content of organic C or hexose-C in fraction B or microbial biomass C was intermediate between that from 0F or 1F and that from 8-15F. The relationship in N was not clear because of the low content of microbial biomass N in the soils from 0F and 1F. There was a correlation between the content of microbial biomass C and the moisture content of the fresh soils from each village (Fig. 6.6). The difference in the slope of the regression curve between the DP and RP villages could be ascribed to the difference in the microbial community between the soils under the different land use systems in the villages, as discussed above.

Marumoto et al. (1997) suggested that the biomass of the bacteria in the paddy soils, which were killed by the air-drying treatment, was transferred into the pools of the organic matter extractable with 0.5 M K_2SO_4. Toriyama et al. (1988) reported that when paddy soil was air-dried below the water potential of pF 4 before submergence, the "air-drying effect" was observed and the amount of mineralized nitrogen increased linearly with the decrease in the soil water content. They assumed that nitrogen originated mainly from the microbial debris due to the decrease in the soil moisture content. Therefore, the labile pool of organic matter in fraction B was considered to be mainly derived from microbial debris associated with the drastic decrease in the soil moisture during the dry season. The difference in the content of the pool in fraction B among the land use groups could be attributed to the difference in the degree of drying of the soils at the end of the dry season. The soils from 0F contained a larger pool than that from 1F or 3-5F, especially in the DP village, although these two soil groups showed the same moisture contents. Therefore, in addition to the decrease in the soil moisture content, "field opening impact", for example, effect of burning (Chapter 5; Tulaphitak et al. 1985; Diaz-Ravina et al. 1992) or increase in the amount of direct sunshine over the soil surface may have also contributed to the increase in the microbial debris.

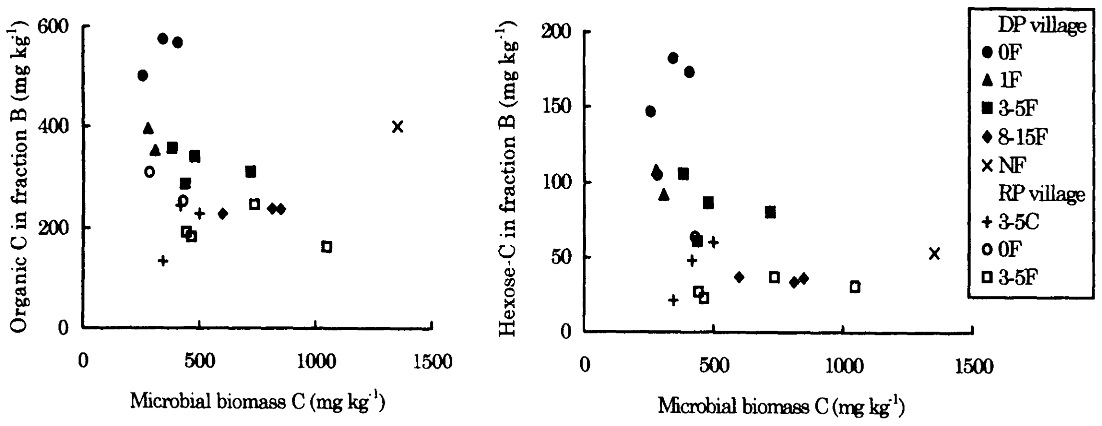


Fig. 6.5. Relationship between the content of microbial biomass C and the content of organic C or hexose-C in fraction B

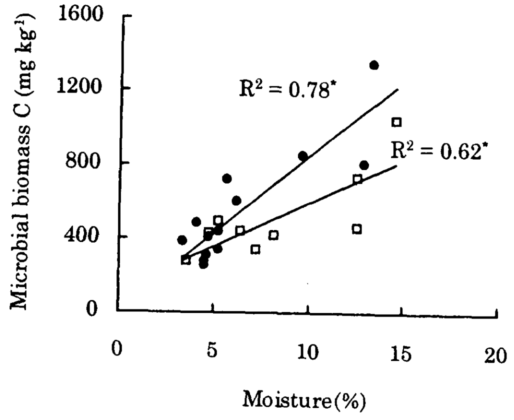


Fig. 6.6. Relationship between the moisture content and content of microbial biomass C of the fresh soil. ●: Soils from the DP village. □: Soils from the RP village

6.4.3. General considerations on organic matter and microbial biomass under shifting cultivation

In the traditional shifting cultivation system in the DP village, the pools of total soil organic matter and labile pool in fraction A changed along with the transition of the land use stages as follows: The soils under the fallow forests for 10 to 15 y had the large pools of total soil organic matter and labile organic matter in fraction A. After the slash and burn practice, the pools started to decrease through decomposition mainly during the rainy season (Chapter 5). This reduction proceeded throughout the 3 to 5 y of fallow period, suggesting that at the initial stage of the fallow period, the input of fresh organic matter from young forest vegetation could not compensate the output from the pools due to the high rate of decomposition of organic matter. After a fallow period of 10 y or more, an adequate input of organic matter from the forest vegetation enabled the organic pools to be compensated.

The labile pool in fraction B at the end of the dry season was most abundant in the soils from the field cultivated for 1 y after the slash and burn practice and decreased in the soils during a longer fallow period. The pool was considered to originate mainly from the microbial debris, due to the decrease in the soil moisture during the dry season and the amount was consiedered to depend on the degree of drying. In the field cultivated for 1 y after the slash and burn practice, the pool was very large because the microorganisms were killed by direct sunshine over the soil surface in addition to the decrease in moisture. Under prolonged fallow forest or natural forest, the source of organic matter in fraction B were preserved as microbial biomass even in the dry season because the forest vegetation enabled the preservation of moisture in soils. The pool in fraction B was considered to be rapidly consumed by the mineralization process in the rainy season, as discussed in the next chapter.

On the other hand, in the relatively intensive land use system in the RP village, the compensating mechanism for the pool in fractions A and B observed in the traditional shifting cultivation system could not operate well due to the lack of a sufficient input of organic matter from the fallow vegetation and the ability of soils to preserve moisture during the dry season, which was improved by the vegetation. Therefore, such a cultivation system results in the rapid decrease of organic matter sources and subsequent deterioration of soil fertility (Chapters 4 and 5).

Chapter 7. N mineralization process in the surface soils under shifting cultivation

7.1 Introduction

The labile pools of organic matter in the surface 0-5 cm soil layers at the end of the dry season and their origin were examined in Chapter 6. In this chapter, the author constructs statistical models for the determination of the N mineralization patterns of the soils by the incubation method and analyzes the relationship between the labile pools of organic matter and N mineralization process depending on the land use stages under shifting cultivation.

7.2 Materials and methods

7.2.1. Soil samples

Details of the sampling design presented in Chapter 6 are summarized as follows. Soil samples were collected from 22 fields in the DP and RP villages at the end of the dry season in March, 1997. In each field, 10 soil samples were collected from the surface 0-5 cm layers in a 10×10 cm^2 quadrat. The 10 subsamples were passed through a 2 mm mesh sieve and mixed into one composite sample per one field. Some of the physicochemical properties of the soils were presented in Chapter 6. In this Chapter, the field cultivated for 1 y after the slash and burn practice was designated as 0F, the field laid fallow for 3 y as 3F, and the field cultivated continuously for 3 y as 3C.

7.2.2. Analytical methods

Determination of the amount of N mineralized in aerobic incubation. A 10 g aliquot of fresh soils was weighed in a glass bottle. The bottle was sealed with a laboratory film (American National Can. TM) after moisture adjustment to 60 % of the water holding capacity. The samples were incubated at 30 ℃ in the dark for 0, 4, 7, 14, 21, 35, 42, 63, 91, and 139 d. Nitrogen mineralized was extracted with 50 mL of a 2 M KCl solution by shaking for 1 h with a reciprocal shaker. The amounts of NH_4^+-N and $(NO_2^-+NO_3^-)$-N were determined by the steam-distillation method with successive addition of MgO and Devardas' alloy (Keeney and Nelson 1982). In this Chapter, $(NH_4^++(NO_2^-+NO_3^-))$-N and $(NO_2^-+NO_{3-})$-N were abbreviated as total mineralized N and NO_3^--N, respectively.

Determination of labile pools of organic matter. Labile pools of organic matter were determined in Chapter 6. Organic matter was extracted with a 0.5 M K_2SO_4 solution in a soil to solution ratio of 1:10 by heating at 110 ℃ for 6 h in an autoclave (fraction A) or by shaking at room temperature for 1 h with a reciprocal shaker (fraction B), respectively. The contents of the organic C, (organic+NH_4^+)-N, and hexose-C were determined.

Determination of parameters for N mineralization curve. In order to evaluate the N mineralization process (ammonification plus nitrification) of the soils, the pattern of N mineralization in each sample was fitted to equations by the least squares method, using the SAS program (SAS Institute, Inc. 1982) registered at the Data Processing Center of Kyoto University as follows: As model function, first order kinetics model (Sugihara et al. 1986) and logistic model (Yonebayashi and Hattori 1986) were prepared:

First order kinetics model: $N = N_0 + N_{max}(1 - e^{-kt})$

and

Logistic model: $N = N_{max} / (1 + (N_{max} / N_0 - 1)\, e^{-kt})$

where N is the amount of total mineralized N measured and t is the incubation period, which are variables to be inputted, whereas k is the rate constant, N_0 is the amount of total inorganic N at 0 d, and N_{max} is the maximum amount of total mineralized N, which are parameters to be determined. Since it was difficult to directly compare k values between the two models, k value was used only to classify the soil samples into the groups based on the N mineralization pattern. If the N mineralization pattern showed an 'apparent' immobilization process in the initial period of the incubation experiment, Sugihara immobilization-mineralization model (Sugihara et al. 1986) was used with modification. This model consisted of two components of first order kinetics model or logistic model, that is, one for the immobilization process and the other for the mineralization process, respectively. For example, the equation was expressed as follows:

N = [first order kinetics model (immobilization)] + [first order kinetics model (mineralization)].

Gauss-Newton method was used to locate the least-squares estimate for the nonlinear model. Iteratively reweighted least squares could give an estimate for robust regression minimizing the residual values. In order to identify the model most suitable for the N mineralization pattern, the AIC (Akaike Information Criterion) values of the estimated model functions were compared (Akaike 1976). The AIC value could be calculated from the following equation:

$$AIC = u \log_e T + v$$

where u is the number of data, v is the number of parameters, and T is the sum of squares of the residual value estimated above. The model which showed the lowest AIC value was most fitted to the N mineralization pattern.

7.3 Results and Discussion

7.3.1. Curve fitting to the models and classification

Figure 7.1 shows the patterns of N mineralization and nitrification and Table 7.1 shows the parameters for N mineralization estimated from curve fitting. As shown in Fig. 7.1, the soils were classified into 8 groups according to the results of curve fitting. Types Ⅰ, Ⅱ, and Ⅳ soils were fitted to first order kinetics model (Fi) and their rate constants were $k > 0.01$, $0.01>k>0.002$, and $k<0.002$, respectively. Types Ⅲ and Ⅴ soils were fitted to logistic model (Lo) and their rate constants were $k>0.04$ and $k<0.04$, respectively. The mineralization pattern of Nos. 7 and 20 soils was not fitted to the models prepared, so that no curve was drawn in Fig. 7.1. Based on the their patterns of N mineralization, these two soils were classified into type Ⅲ. The patterns characterized by a shoulder peak at about 20 to 30 d were approximately fitted to logistic model and classified into type Ⅵ. Nos. 14 and 16 soils showed an 'apparent' immobilization process in the initial period of the incubation experiment. Sugihara immobilization-mineralization model was used with modification for these soils and classified them into type Ⅶ or Ⅷ, although the parameters of these models should be further studied. The plot pattern of nitrification was considered to correspond to the lag times in the initial period of incubation through comparison with the pattern of N mineralization.

7.3.2. Factors contributing to the initial rate of N mineralization

According to Chapter 6, the labile pool in fraction B was considered to be

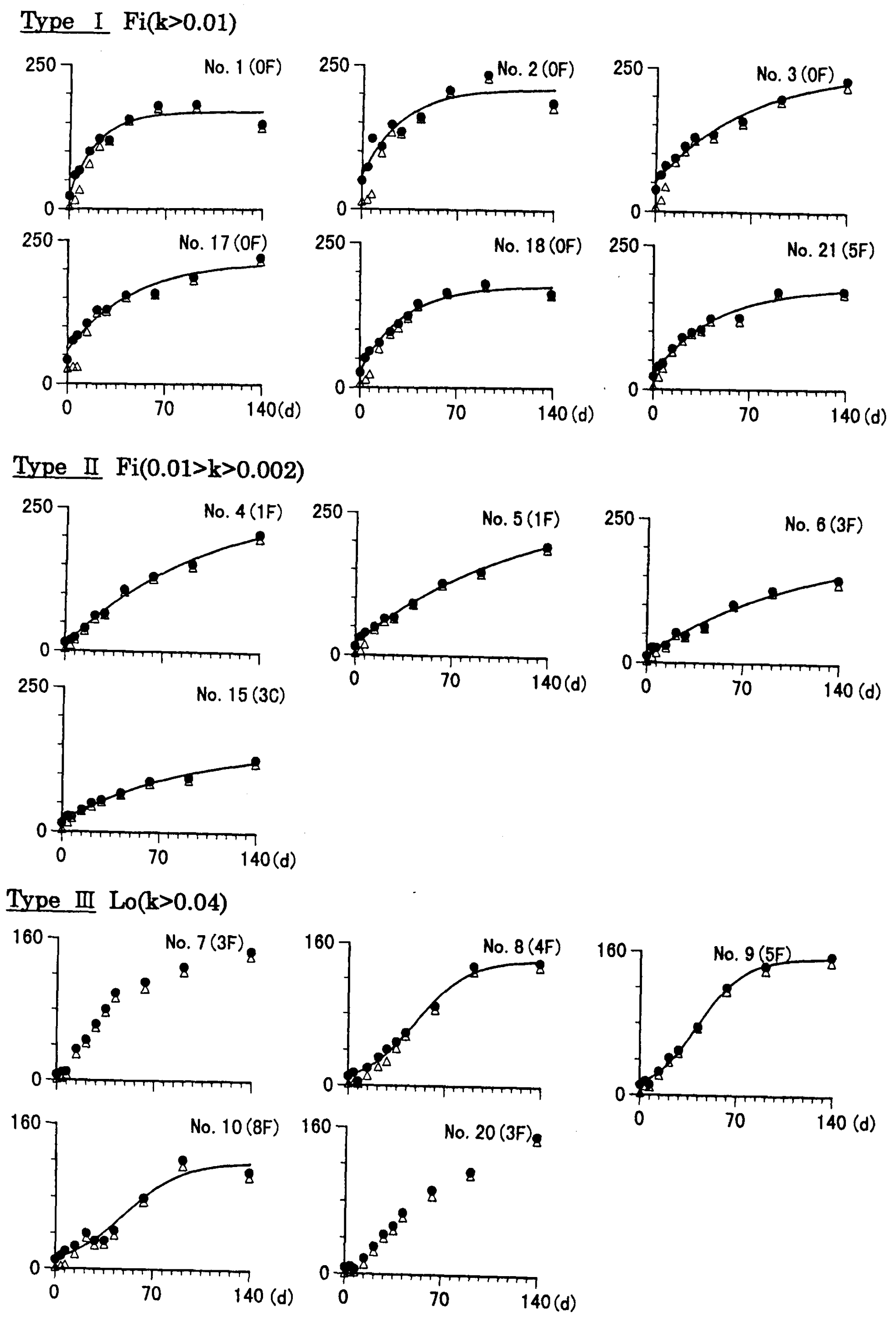


Fig. 7.1. Classification of the soils by curve fitting to N mineralization pattern. Fi and Lo denote first order kinetics model and logistic model, respectively. k is a rate constant (d^{-1}). The mineralization pattern of the Nos. 7 and 20 soils was not fitted to the models prepared, so that no curve was drawn in the figure. ●: Total N mineralized (mg kg^{-1}). △: NO_3^--N mineralized (mg kg^{-1}). □: NH_4^+-N for the No. 12 soil (mg kg^{-1})

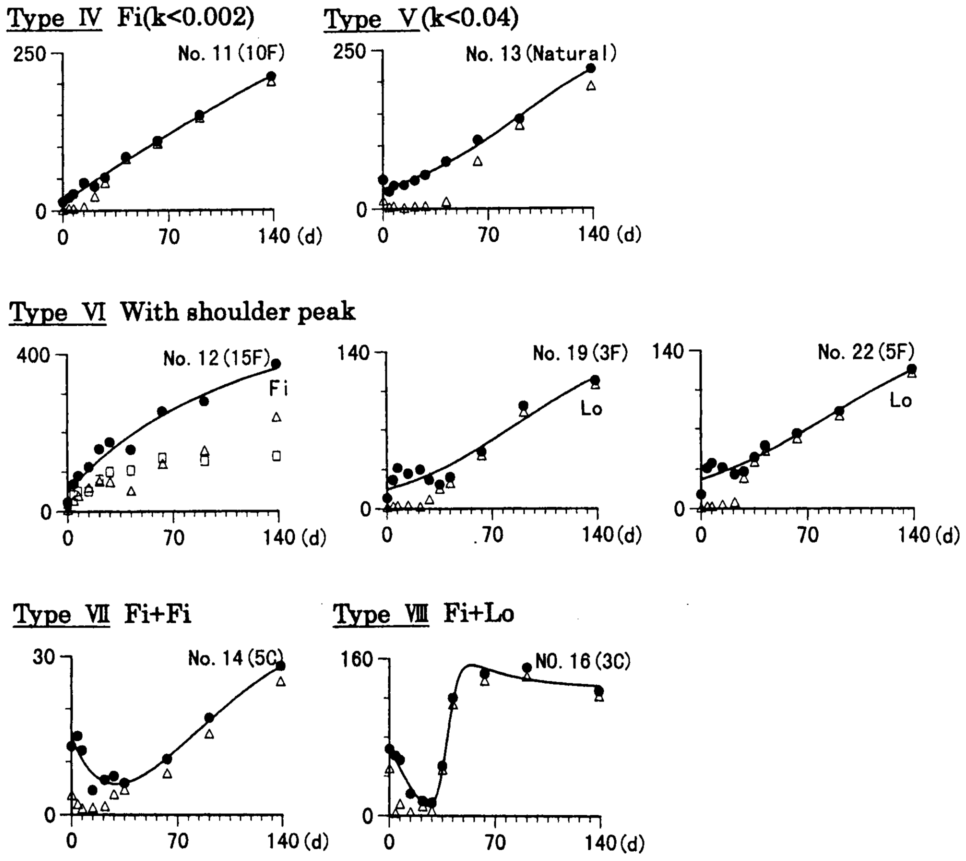


Fig. 7.1. Continued.

derived from microbial debris associated mainly with the decrease in the soil moisture during the dry season. Therefore, the pool in fraction B was considered to be more decomposable than that in fraction A. Marumoto et al. (1997) reported that organic N contained in microbial debris after the air-drying treatment was decomposed within 2 weeks in the anaerobic incubation experiment. The pool in fraction B was adopted as one of the factors to analyze the N mineralization pattern in the initial period of incubation (Table 7.2).

Table 7.1. Calculated parameters of N mineralization curve of the surface 0-5 cm soils with aerobic incubation experiment.

Curve type	Sample no. (Village)	Land* use	Model**	N_0*** --------	N_{MAX} (mg kg^{-1})****	N_0+N_{MAX} -------	k (d^{-1})
Ⅰ	1(DP)	0F	Fi	24.7	144.5	169.2	0.0504
Ⅰ	2(DP)	0F	Fi	57.7	153.3	211.0	0.0347
Ⅰ	3(DP)	0F	Fi	50.9	201.3	252.2	0.0144
Ⅰ	17(RP)	0F	Fi	56.0	159.6	215.6	0.0220
Ⅰ	18(RP)	0F	Fi	27.1	149.6	176.7	0.0317
Ⅰ	21(RP)	5F	Fi	24.7	153.4	178.1	0.0224
Ⅱ	4(DP)	1F	Fi	9.8	259.1	268.9	0.0097
Ⅱ	5(DP)	1F	Fi	20.4	258.0	278.4	0.0080
Ⅱ	6(DP)	3F	Fi	12.4	195.8	208.2	0.0087
Ⅱ	15(RP)	3C	Fi	17.6	134.1	151.7	0.0109
Ⅲ	7(DP)	3F	Not fitted				
Ⅲ	8(DP)	4F	Lo	10.3	142.0	152.3	0.0517
Ⅲ	9(DP)	5F	Lo	12.5	153.3	165.8	0.0584
Ⅲ	10(DP)	8F	Lo	11.0	119.0	130.0	0.0473
Ⅲ	20(RP)	3F	Not fitted				
Ⅳ	11(DP)	10F	Fi	13.4	988.7	1002.1	0.0016
Ⅴ	13(DP)	NF	Lo	31.8	289.0	320.8	0.0231
Ⅵ	12(DP)	15F	Fi	51.7	423.5	475.2	0.0095
Ⅵ	19(RP)	3F	Lo	17.5	153.7	171.2	0.0232
Ⅵ	22(RP)	5F	Lo	25.9	167.5	193.4	0.0195
Ⅶ	14(RP)	5C	Fi	14.6	-201.7	41.8	0.0225
			+Fi		228.9		0.0167
Ⅷ	16(RP)	3C	Fi	71.8	-128.7	131.2	0.0296
			+Lo	0.01	188.1		0.2571

*Number denotes the duration of fallow forest or cultivation. F, C, and NF denote fallow field, cultivated field, and natural forest, respectively. **Fi and Lo denote the first order kinetics model and the logistic model, respectively. ***In the Fi + Fi model, N_0 could not be calculated separately. ****Oven-dried basis.

Types Ⅰ, Ⅱ and Ⅲ soils. The soils belonging to types Ⅰ and Ⅱ did not show a lag time in the N mineralization process, while the soils belonging to type Ⅲ showed a short lag time within about 7 d. Comparison of the patterns between N mineralization and nitrification in these types (Fig. 7.1), it indicated that NH_4^+-N mineralized from organic N was immediately nitrified and that the occurrence in the lag time of type Ⅲ soils could be attributed to the delay in ammonification.

Table 7.2. Types of N mineralization curve and some properties of the surface 0-5 cm soils.

Curve type	Sample no. (village)	Land use*	pH(KCl)**	fraction B Organic C	Hexose-C	(Organic+ NH_4^+)-N	C/N****
				---------- (mg kg^{-1})***	----------		
I	1(DP)	0F	5.0	501	146	70	7.2
I	2(DP)	0F	4.9	568	173	93	6.1
I	3(DP)	0F	5.0	574	182	89	6.4
I	17(RP)	0F	5.1	310	105	57	5.5
I	18(RP)	0F	4.5	253	64	52	4.9
I	21(RP)	5F	4.9	183	23	48	3.8
II	4(DP)	1F	5.3	354	92	44	8.0
II	5(DP)	1F	5.6	396	108	38	10.4
II	6(DP)	3F	5.1	287	61	26	11.1
II	15(RP)	3C	4.8	134	21	27	4.9
III	7(DP)	3F	4.9	359	106	35	10.3
III	8(DP)	4F	4.9	311	81	37	8.3
III	9(DP)	5F	5.0	341	87	29	11.6
III	10(DP)	8F	4.8	228	37	30	7.6
III	20(RP)	3F	4.6	192	27	26	7.5
IV	12(DP)	15F	4.2	237	36	49	4.8
IV	19(RP)	3F	4.1	163	31	50	3.3
IV	22(RP)	5F	4.0	246	37	56	4.4
V	11(DP)	10F	4.5	239	34	49	4.9
VI	13(DP)	NF	4.0	401	54	92	4.3
VII	14(RP)	5C	4.1	245	48	39	6.2
VIII	16(RP)	3C	4.7	229	61	63	3.6

*Number denotes the duration of fallow forest or cultivation. F, C, and NF denote fallow field, cultivated field, and natural forest, respectively. **Glass electrode method with soil to solution ratio of 1:5. ***Oven-dried basis. ****Ratio of organic C to (organic+NH_4^+)-N.

Since the origin of the labile pool in fraction B was attributed to microbial debris, it was assumed that this pool was first utilized by microbes and contributed to the initial N mineralization process. In order to assess the relationship between the N mineralization rate in the initial period and the organic pool in fraction B, the rate at 7 d was used (Fig. 7.2.). This initial rate was calculated by differentiating the equation of the models by time. As shown in Fig. 2, the initial rate of N mineralization of types I and II soils depended on the amount of (organic+NH_4^+)-N in fraction B. However, the rate of type III was lower than that of types I and II in terms of the content of (organic+NH_4^+)-N in fraction B. Figure 7.3 shows relationship between the contents of (organic+NH_4^+)-N and organic C in fraction B in relation to the patterns of N mineralization. The ratio of organic C to (organic+NH_4^+)-N in this fraction in type III soils exceeded 7 and was higher than that in type I soils. Therefore, the lag time in type III soils was attributed mainly to the high C/N ratio in fraction B. However, the C/N ratio in fraction B of type II soils was as high as that in type III soils. It was suggested that, in addition to the amount of (organic+NH_4^+)-N in fraction B, the C/N ratio in this fraction may also contribute to the low mineralization rate in the initial period in types II and III soils although the ratio did not necessarily determine the type with or without lag time.

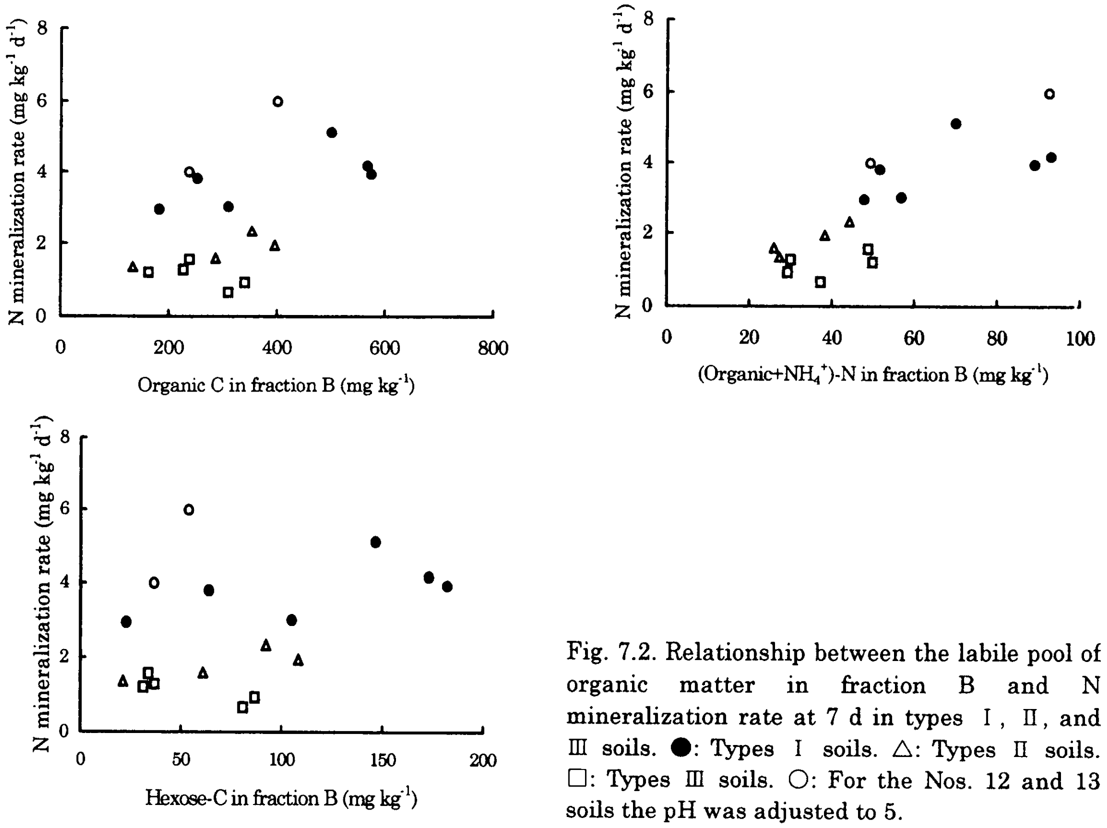


Fig. 7.2. Relationship between the labile pool of organic matter in fraction B and N mineralization rate at 7 d in types I, II, and III soils. ●: Types I soils. △: Types II soils. □: Types III soils. ○: For the Nos. 12 and 13 soils the pH was adjusted to 5.

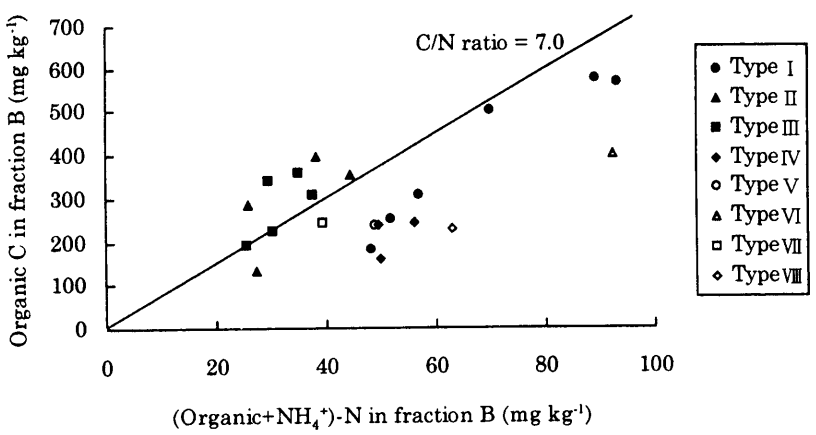


Fig. 7.3. Relationship between the contents of (organic + NH$_4^+$)-N and organic C in fraction B in relation to the curve types of N mineralization.

Types Ⅳ, Ⅴ, and Ⅵ soils. NO$_3^-$-N of in types Ⅳ, Ⅴ, and Ⅵ soils except for No.12 soil was not detected for more than 7 d after incubation (Fig. 7.1). In the case of No. 12 soil, the content of NH$_4^+$-N and NO$_3^-$-N increased simultaneously. Comparison of the pattern of nitrification with that of N mineralization in these soils, showed that ammonification proceeded normally. Since the pH(KCl) of these soils ranged from 4.0 to 4.2 (Table 7.2), the process of nitrification was inhibited by low pH in spite of the normal process of ammonification except for No. 11 soil which showed the shortest lag time for nitrification among the soils in these types. The above interpretation was supported by the following experiment. In the Nos. 12 and 13 soils, which showed a continuous increase in the content of NH$_4^+$-N and a long lag time of 40 d, respectively, the pH(KCl) increased to a value of about 5 by the addition of a CaCO$_3$ suspension and they were incubated in the same way (Table 7.3). The lag times both in the patterns of N mineralization and nitrification, which were observed in the untreated soils were no longer observed and the pattern of N mineralization was fitted to the first order kinetics model of type Ⅰ soils. The initial rates (7 d) in the treated soils were added in Fig. 7.2 as open circles for comparison with the labile pool in fraction B. The plots of these soils were distributed within the range expected from the contents of (organic+NH$_4^+$)-N in fraction B. Therefore, one of the possible reasons for the inhibition of the nitrification process at the initial stage was the low pH(KCl) with a value of less than about 4.2 (Table 2).

Table 7.3. Calculated parameters of N mineralization curve for Nos. 12 and 13 soils adjusted pH to 5.

Sample No.	Land use	Model*	N_0	N_{MAX}	N_0+N_{MAX}	k
			---------	(mg kg^{-1})**	---------	(d^{-1})
12	15F	Fi	24.5	293.8	318.3	0.0151
13	NF	Fi	69.6	351.1	420.7	0.0195

*Fi: first order kinetics model. **Oven dried basis.

Types Ⅶ and Ⅷ soils. Types Ⅶ and Ⅷ soils, which were samples from continuously cultivated fields, showed a decrease in the contents of total inorganic N and NO$_3^-$-N in the initial period of the incubation experiment (Fig. 7.1). Two of the three samples from the continuously cultivated fields showed such an 'apparent' immobilization process. According to Sugihara et al. (1986), the decrease in the content of inorganic N was due to immobilization process. They reported that the N mineralization of the sludge compost with a high C/N ratio sometimes showed an immobilization process and was fitted to the immobilization-mineralization model. However, types Ⅶ and Ⅷ soils had a low C/N ratio in fraction A and B (Fig. 7.3), and total organic matter. The reason for this immobilization could not be explained by any chemical variables used in this study. Activity of heterotrophic microbes incorporating NH$_4^+$-N may surpass that of nitrifiers using NH$_4^+$-N as substrate in the initial period of the incubation of the soils from the continuously cultivated fields. These findings require further studies for the development of the sustainable agriculture systems in future.

7.3. Factors contributing to N_0+N_{max} value

The content of organic N extracted by the autoclave treatment has sometimes been used as a chemical index for estimating the soil nitrogen availability (Saito 1990) and was compared with the amount of mineralizable N (N_{max} in this study). However, in this study, as shown in Fig. 7.1, NH_4^+-N accounted for most of the N_0 at 0 d in the incubation experiment, while NO_3^--N accounted for the most of total mineralized N and NH_4^+-N disappeared at the end of incubation experiment. These findings indicated that NH_4^+-N at 0 d was nitrified or immobilized by microbes. Therefore, the contents of organic C, (organic+NH_4^+)-N, and hexose-C in the fraction A were directly compared with the N_0+N_{max} value. The N_0+N_{max} value of No.11 soil was excluded from this assessment because the value was extremely high, which might have been overestimated due to the very low k value and the absence of inflection point during incubation. The N_0+N_{max} value of type Ⅰ soils including Nos. 12 and 13 after pH adjustment, and types Ⅱ, and Ⅲ soils was plotted against the contents of organic C, (organic+NH_4^+)-N and hexose-C in fraction A (Fig. 7.4). The N_0+N_{max} value of types Ⅳ to Ⅷ soils was excluded from this assessment because N mineralization of these types was considered to be inhibited by the low pH or showed an 'apparent' immobilization process. The N_0+N_{max} value was correlated with the contents of organic C, (organic+NH_4^+)-N and hexose-C, suggesting that the N_0+N_{max} value was regulated by the pool in fraction A. Most of types Ⅱ and Ⅲ soils showed a N_0+N_{max} value lower than that of the in type Ⅰ soils (Table 7.1, Fig. 7.4).

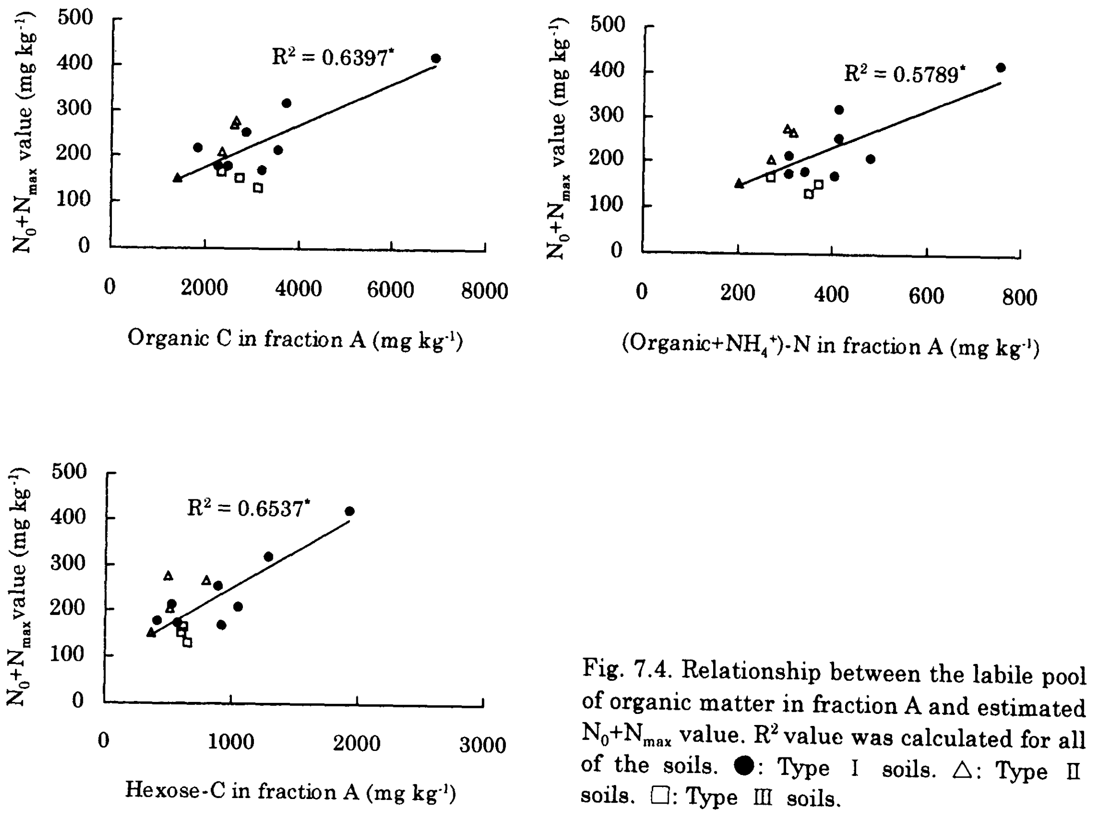


Fig. 7.4. Relationship between the labile pool of organic matter in fraction A and estimated N_0+N_{max} value. R² value was calculated for all of the soils. ●: Type Ⅰ soils. △: Type Ⅱ soils. □: Type Ⅲ soils.

7.4. General considerations on the N mineralization process in shifting cultivation systems

N mineralization process in the shifting cultivation systems is summarized as follows:

In the traditional cultivation system in the DP village, the soils from 0F had a large pool of labile organic matter in fraction B at the end of the dry season and showed a N mineralization pattern corresponding to type Ⅰ, which was characterized by a high rate of N mineralization without lag time. Therefore, in the soils in this land use stage, crops may grow well in the initial period of the rainy season just after germination through a sufficient supply of N. The soils from 1F to 8F had a smaller pool of labile organic matter in fraction B than those from 0F and were classified either into type Ⅱ fitted to the first order kinetics model with low rate of N mineralization or into type Ⅲ fitted to the logistic models with a short lag time of less than 7 d. It was suggested that these soil types had a low ability to supply mineralized N at the onset of the rainy season. Moreover, types Ⅱ and Ⅲ soils showed a N_0+N_{max} value of lower than the in type Ⅰ soils. It was considered that excess loss of inorganic N through leaching under poor fallow vegetation during the 1 to 8 y of fallow period (Chapter 4) was prevented by the low ability of N mineralization. In the soils from the areas with prolonged fallow or natural forests (Nos. 11, 12, and 13), nitrification was inhibited by low pH, but ammonification occurred normally. The soils in these land use stages could supply N to mature fallow vegetation.

On the other hand, in the relatively intensive cultivation system adopted in the RP village, N mineralization process depended on the properties of the soils rather than on the land use stages. No.21 soil from 5F was classified into type Ⅰ which was characterized by a high mineralization rate, whereas No. 19 soil from 3F and No. 22 soil from 5F were classified into type Ⅵ which was characterized by a nitrification process with a long lag time but normal ammonification process. These soils may show an excess loss of N because of the poor forest vegetation (Chapter 4). Two of the 3 soils from 3 to 5C showed an 'apparent' immobilization process in the initial period of incubation, which might have led to a competition for N between crops and microorganisms in the soils.

According to the results from Chapters 6 and 7, in alternating cultivation systems with more intensive and continuous land use in future, application of organic materials with low C/N ratio is required to produce microbial biomass as a source of labile organic matter and to supply enough mineralized N to crops, especially in the initial growth period.

Chapter 8. Summary and conclusions

8.1 General soil characteristics in the study area

In order to get basic information about the soil properties associated with shifting cultivation, physicochemical properties of the surface soils (0-10 cm) and subsoils (30-40 cm) were investigated in Chapter 3.

The physicochemical and mineralogical properties of the soils studied are summarized as follows:

(1) The soils were rich in organic matter, the content of which ranged from 11.4 to 63.3 g C kg^{-1} in the surface soil.

(2) The pH (H_2O) of the soils mostly ranged from 5 to 7 and soil acidity was more pronounced in the deeper horizons. In the surface soils, exchangeable Ca and Mg were generally dominant, whereas exchangeable Al was often predominant in the subsoils.

(3) Most of the soils showed a medium to fine texture with more than 30 % of clay. The clay mineral composition was characterized by various degrees of mixture of kaolin minerals and clay mica with, in some case, a certain amount of 2:1-2:1:1 intergrades.

Thus, the soils in the study area were considered to have the relatively high fertility, compared with the soils in the tropics or subtropics cited in chapter 1 or 3.

According to the ion adsorption curves, most of the B horizon soils were characterized by the predominance of permanent negative charges. On the other hand, organic matter contributed to the increase in variable negative charges in the surface soils. The content of organic matter and the percentage of clay fraction primarily determined the CEC of the surface 0-10 cm and 30-40 cm soils, respectively. Under field conditions, the composition of exchangeable cations largely reflected the soil acidity. In addition, the content of organic matter also showed a significant correlation with that available N in the surface soils, whereas the content of available P in the 0-10 cm soils increased in the high pH region. Thus, soil acidity both in the surface soils and subsoils, organic matter content in the surface soils, and clay content in the subsoils were considered to be the main factors that affected soil chemical fertility in the area.

8.2 Exchangeable bases and acidity in the soils

The soil acidity was considered to affect the contents of basic cations both in the surface and subsurface soils (Chapter 3). The dynamics of exchangeable bases and acidity in the soils were studied in relation to the land use stages in shifting cultivation in Chapter 4. The soils were more acidic and poorer in exchangeable bases in the fields under continuous cropping or relatively longer fallow than those in the fields within 3 y after the slash and burn practice. Uptake of inorganic bases by plant roots during the fallow duration may be one of main reasons for the depletion of exchangeable bases in the soils, whereas leaching loss of the bases was considered to cause soil acidification under continuous cropping. The strong soil acidity observed especially in the subsoils at the later stage of the fallow period seemed to be alleviated to some extent by ash input through the slash and burn practice. Because the amount of inorganic bases in the ash was small compared with that of the exchangeable bases stored in the soils, it was suggested that the shifting cultivation system in the study area was less dependent on the fertilization effect of ash input.

8.3 Soil organic matter in shifting cultivation systems.

Among the factors which affected soil chemical fertility, the dynamics of soil organic matter, which was thought to primarily determine the CEC values, was studied in Chapter 5. The contents of organic matter and available N in the surface 0-10 cm soils from the continuously cropped field were lower than those in the soils under prolonged fallow (more than 10 y) or natural forest. According to the soil respiration experiment, the amount of organic matter decomposed within 1 y was estimated to reach nearly 10 % of that stored in the upper 50 cm layers of the soil profile in the cropping fields, although there might be some overestimation due to respiration by plant roots. These results indicate that the resources of the soil organic matter markedly would be deteriorated by continuously cropping.

From the incubation experiment for N mineralization, the active process of nitrification after N mineralization was always associated with a sharp fall in soil pH. This result suggest that soil acidification was promoted and basic cations were lost from the soils by rapid decomposition of soil organic matter in the cropping field.

8.4 Soil burning effect

Soil burning effect on N supply was pronounced only when a fairly large amount of aboveground biomass was burnt (Chapter 5). For example, in this study, the soil burning effect was clearly observed in the RP-C5 field, of which aboveground biomass reached to 60 t ha^{-1}(dried weight). However, since the farmers, especially the Karen people, usually burned a relatively small amount of aboveground biomass, less than 20 t ha^{-1}, such a soil burning effect could be scarcely expected. In the continuously cropped field of Hmong and Thai farmers, little or no burning effect might be expected because the biomass amounted to several tons per hectare.

8.5 Labile pools of organic matter in the surface soils

The contents and origin of the labile organic pools extracted with K_2SO_4 solution by an autoclave at 110℃ (fraction A) and at room temperature (fraction B) was studied in Chapter 6. In the traditional cultivation system in the DP village, the ratio of the labile pool in fraction A to total soil organic matter was apparently held constant by an input-output balance in the pool and the content was high in the soils under long fallow forest for 10 to 15 y. On the other hand, labile organic pool in fraction B was considered to be derived mainly from microbial debris associated with the decrease in soil moisture content in the dry season. The content of the pool in fraction B was most abundant in the soils from the field cultivated for 1 y after the slash and burn practice and getting to be lower in the soils in longer fallow period.

In the relatively intensive cultivation system in the RP village, although the ratio of the pool in fraction A to total organic matter was also constant, there was no significant difference in the contents of the labile pools both in fraction A and B among the land use stages, suggesting the preserving mechanisms for these pools, which were observed under the traditional cultivation system, did not function well by the intensive system.

8.6 N mineralization process in the surface soils

In Chapter 7, N mineralization process and the effect of the labile organic pools in fractions A and B on the process was analyzed. The initial rate of N mineralization was determined by the contents of (organic+NH_4^+)-N and ratio of organic C to (organic+NH_4^+)-N of the labile pool in fraction B or soil pH, while the N_0+N_{max} value was affected by the contents of the labile pool in fraction A.

Under the traditional shifting cultivation in the DP village, ability to supply mineral N of the soils can be presumed as follows: The soils from 0F with the large pool of fraction B showed the N mineralization pattern which was characterized by high rate of the N mineralization. Therefore, in the soils under this land use stage, crops enabled to grow well in the initial stage of the rainy season through sufficient supply of N. The soils from 1F to 8F had the smaller pool in fraction B and lower rate of N mineralization than those from 0F. It was suggested that in these soils, an excess loss of inorganic N through leaching was prevented by low ability to supply mineralized N in spite of poor fallow vegetation. In the soils from the prolonged fallow or natural forests, nitrification was inhibited by low pH, but ammonification was normally occurred. The soils in this land use stage could supply N to mature fallow vegetation.

On the other hand, under the relatively intensive cultivation system in RP village, the initial rate and potential of the N mineralization depended on the properties of the soils rather than the land use systems.

8.6 Soil ecological interpretation of shifting cultivation in the area

The shifting cultivation systems by the Karen and Hmong / Thai peoples seemed to depend mainly on the relatively high fertility inherent in the soils, and less on a fertilization effect from ash input or N supply from the soil burning effect. Main objective of the slash and burn practice was to alleviate the subsoil acidity by the high alkalinity of ash and presumably supply of P (e.g. Tulaphitak et al. 1985) in

addition to weed control as often referred (e.g. Nye and Greenland 1960). The significance of fallow forest were to prevent excess loss of nutrients from soil profile and to regulate the dynamics of soil organic matter (total organic matter, labile organic pools, and microbial biomass) in addition to protect soils from severe erosion (Lal 1986). From these points, it is considered that the traditional shifting cultivation system adopted by the Karen people with 1 y cropping is effective on soil conservation. On the other hand, the continuous cropping system adopted by the Hmong and Thai peoples may promote the decomposition of organic matter and soil acidification as well as soil erosion and, hence, is considered to be less sustainable.

8.7 Problems to address for developing alternative agriculture in the area

Nowadays, the fallow period tends to become shorter in the Karen system or the cropping period longer in the Hmong and Thai system. In the former system, the minimum fallow period, which is required to prevent the soils from undergoing serious erosion or acidification, should be carefully determined. The minimum fallow period is probably around 5 y because the soils at this stage showed a more acidic nature and a larger part of exchangeable bases was assumed to be already taken up by the aboveground biomass. However, even if such an apparently balanced system would be established in a short time, gradual decomposition loss of soil organic matter and concomitant decrease in the amount of exchangeable bases may be unavoidable without the stage of mature fallow forest in the long run. The continuous cultivation system for several years adopted by the Hmong and Thai peoples may inevitably lead to a decrease of the soil fertility.

The author considers that another agriculture-forest system should be developed and introduced as possible as soon. Alternative cropping system in the area should be able to prevent the depletion of organic matter-related resources and soil acidification as well as soil erosion. One of the solutions is agroforestry. This agricultural measure is defined as the land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and/or livestock in a spatial arrangement and rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system (Young 1989). Many researchers recommended the agroforestry system for soil conservation and economical development of farmers (Shikoku National Agricultural Experiment Station 1994). However, the introduction of this system might require the initial investment of capital from government or another organization. Mulching associated with no tillage cultivation system might be a measure more easily utilized by farmers and expected to protect soils from erosion and to supply organic matter to soils (Lal 1986). From the results of this study, organic matter with a low C/N ratio such as manure or compost ripening well is recommended as mulching materials in terms of N mineralization process, although soil acidification through rapid decomposition of organic matter and the following nitrification should be take care.

References

Akaike, K. 1976: What is an information criterion of AIC. *Suurikagaku (Mathematical Science)*, **14**, 5-11 (in Japanese)

Anderson, J.P.E. 1982: Soil respiration. In Method of Soil Analysis, Part 2, Chemical and Mineralogical Properties, Ed. A.L Page, R.H.Miller, and D.R.Keeney, p. 831-871, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison

Andriesse, J.P. and Schelhaas, R.M. 1987a: A monitoring study of nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. Ⅱ. Nutrient stores in biomass and soil-results of baseline studies. *Agric Ecosyst. Environ.*, **19**, 285-310

Andriesse, J.P. and Schelhaas, R.M. 1987b: A monitoring study of nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. Ⅲ. The effects of land clearing through burning on fertility level. *Agric Ecosyst. Environ.*, **19**, 311-332

Black, C.A. 1968: Potassium. In Soil-Plant Relationships, 2nd ed., p. 654-773, John Wiley and Sons, Inc., New York

Bremner, J.M. and Jenkinson, D.S. 1960: determination of organic carbon in soil. Ⅰ. Oxidation by dichromate of organic matter in soil and plant materials. *J. Soil Sci.*, **11**, 394-402

Bremner, J.M. and Mulvaney, C.S. 1982: Nitrogen-Total. *In* Methods of Soil Analysis, Part 2, Chemical and Mineralogical Properties, Ed. A.L Page, R.H.Miller, and D.R.Keeney, p. 595-624, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison

Brookes, P.C. Landman, A., Pruden, G., and Jenkinson, D.S. 1985: Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil Biol. Biochem.*, **17**, 837-842

Conyers, M.K., Uren, N.C. and Helyer, K.R. 1995: Causes of changes in pH in acidic mineral soils. *Soil Biol. Biochem.*, **27**, 1383-1392

Diaz-Ravina, M., Prieto, A., Acea, M.J., and Carballas, T. 1992: Fumigation-extraction method to estimate microbial biomass in heated soils. *Soil Biol. Biochem.*, **24**, 259-264

Fox, J., Krummel, J., Yarnasarn, S., Ekasingh, M., and Podger, N. 1995: Land use and landscape dynamics in northern Thailand: Assessing change in three upland watersheds since 1954, *Ambio* **24**, 328-334

Geological Survey Division 1983: Geological map of Thailand, 1:500,000. Department of Mineral Resources, Bangkok

Gillman, G.P. 1984: Using variable charge characteristics to understand the exchange cation status of oxic soil. *Aust. J. Soil Res.,* **22**, 71-80

Gillman, G.P. and Sumpter, E.A. 1986: Surface charge characteristics and lime requirements of soils derived from basaltic, granitic, and metamorphic rocks in high-rainfall tropical Queensland. *Aust. J. Soil Res.,* **24**, 173-192

Haggar, J.P., Tanner, E.V.J., Beer, J. W., and Kass, D.C.L. 1993: Nitrogen dynamics of tropical agroforestry and annual cropping systems. *Soil Biol. Biochem.,* **25**, 1363-1378

Inoko, A. 1986: Available nitrogen. *In* Standard Method of Soil Analysis, Ed. Committee for Standard Method of Soil Analysis, p. 118-124, Hakuyusha, Tokyo (in Japanese)

Keeney, D.R. and Nelson, D.W. 1982: Nitrogen-Inorganic forms. *In* Methods of Soil Analysis, Part 2, Chemical and Mineralogical Properties, Ed. A.L Page, R.H.Miller, and D.R.Keeney, p. 643-698, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison

Kunstadter, P. and Chapman, E.C. 1978: Problem of shifting cultivation and economic development in northern Thailand. *In* Farmers in the Forest, Ed. P. Kunstadter, E.C. Chapman, and S. Sabhasri, p. 3-23, The University Press of Hawaii, Honolulu

Kyuma, K., Tulaphitak, T., and Pairintra, C. 1985: Changes in soil fertility and tilth under shifting cultivation. Ⅰ. General description of soil and effect of burning on the soil characteristics. *Soil Sci. Plat Nutr.,* **31**, 227-238

Kunstadter, P., Chapman, E.C., and Sabhasri, S. eds. 1978: Farmers in the Forest. The University Press of Hawaii, Honolulu

Kyuma, K. 1972: Numerical classification of the climate of South and Southeast Asia. *Southeast Asian Stud.,* **9**, 502-521

Kyuma, K. and Pairintra, C. eds. 1983: Shifting Cultivation, An Experiment at Nam Phrom, Northeast Thailand, and Its Implications for Upland Farming in the Monsoon Tropics. Faculty of Agriculture, Kyoto University, Kyoto

Lal, R. 1986: Soil surface management in the tropics for intensive land use and high and sustained production. *In* Advances in Soil Science, Vol. 5, Ed. B.A.Stewart, p.1-109, Springer-Verlag New York, Inc., New York

Lim, C.H. and Jackson, M.L. 1982: Dissolution for total elemental analysis. *In* Methods of Soil Analysis, Part 2. Chemical and Mineralogical Properties, Ed. A.L.Page, R.H. Millar, and D.R. Keeney, p. 1-12, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin

Marumoto, T., Andoh, H., and Wada, G. 1997: Air-drying treatment and mineralization of biomass nitrogen in paddy soils. *Jpn. J. Soil Sci. Plant Nutr.,* **68**, 376-380 (in Japanese with English summary)

Mc Lean, E.O. 1982: Soil pH and lime requirement. *In* Methods of Soil Analysis, Part 2. Chemical and Mineralogical Properties, Ed. A.L.Page, R.H. Millar, and D.R. Keeney, p. 199-224, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin

Meteorological Department 1987: Annual Climatological Data of Thailand. (in Thai)

Miura, K. 1991: Natural conditions and field crop cultivation in Northeast Thailand. *In* Expert Bulletin, **12** p.1-17, Association for International Cooperation of Agriculture and Forestry, Tokyo (in Japanese)

Muramoto, J., Goto, I., and Ninaki, M. 1992: Application of inductively plasma atomic emission spectrometry (ICP-AES) to soil analysis (Part 6). Rapid analysis of exchangeable cations and cation exchange capacity (CEC) of soils by a shaking extraction method. *Jpn. J. Soil Sci. Plant Nutr.,* **63**, 210-215 (in Japanese with English summary)

Nakano, K. 1978: An ecological study of swidden agriculture at a village of northern Thailand. *South East Asian Studies,* **16**, 411-446

Nye, P.H. and Greenland, D.J. 1960: The Soils under Shifting Cultivation. Technical Communication No. 51, Commonwealth Bureau of Soils, Harpenden, Commonwealth Agricultural Bureaux, Farnham Royal, Bucks

Office of Agricultural Economics 1989: Agricultural Statistics of Thailand Crop Year 1988/89. Center for Agricultural Statistics of Thailand, Office for Agricultural Economics, Ministry of Agricultural and Cooperatives, Bangkok

Office of Agricultural Economics 1993: Agricultural Statistics of Thailand Crop Year 1992/93. Center for Agricultural Statistics of Thailand, Office for Agricultural Economics, Ministry of Agricultural and Cooperatives, Bangkok

Office of Agricultural Economics 1995: Agricultural Statistics of Thailand Crop Year 1994/95. Center for Agricultural Statistics of Thailand, Office for Agricultural Economics, Ministry of Agricultural and Cooperatives, Bangkok

Ohta, S., Effendi, S., Tanaka, N., and Miura, S. 1993: Ultisols of lowland *Dipterocarp* forest in east Kalimantan, Indonesia. Ⅲ. Clay minerals, free oxides, and exchangeable cations. *Soil Sci.*

Plant Nutr., **39,** 1-12

Ota, T., Wichidit, P., Pramojanee, P., Sukchan, S., Kohyama, K., and Wada, H. 1997: Virgin soils and their degradation by agricultural practices in northeast Thailand. *Pedologist,* **41,** 41-52

Ogawa, K., Phetchawee, S., and Suriyapan., O. 1981: Clay minerals in some upland soils from Thailand. *Soil Sci. Plant Nutr.,* **27,** 73-81

Piccolo, M.C., Neill, C., and Cerri, C.C. 1994: Net nitrogen mineralization and net nitrification along a tropical forest-to-pasture chronosequence. *Plant and Soil,* **162,** 61-70

Ramakrishnan, P.S. 1992: Shifting Agriculture and Sustainable Development. Man and the Biosphere Series, Vol. 10, UNESCO, Paris, Parthenon Publishing Group Limited, Lancs, UK, and Parthenon Publishing Group Inc., Park Ridge, New Jersey

Royal Forest Department 1992: Forestry statistics of Thailand 1992, Bangkok

Saito, M. 1990: Nitrogen mineralization parameters and its availability indices of soils in Tohoku District, Japan: Their relationship. *Jpn. J. Soil Sci. Plant Nutr.,* **61,** 265-272 (in Japanese with English summary)

Sakurai, K., Kozasa, S., Yuasa, T., Puriyakorn, B., Preechapanya, P., Tanpibal, V., Muangnil., K., and Prachaiyo, B. 1996: Changes in soil properties after land degradation associated with various human activities in Thailand. *Soil Sci Plant Nutr.,* **42,** 81-92

Sanchez, P.A. 1973: Soil management under shifting cultivation. *In* A review of Soils Research in Tropical Latin America. p 46-67, North Carolina Agr. Exp. Sta. Tech. Bull., 219

Singh, R.S., Raghubanshi, A.S., and Singh, J. S. 1991: Nitrogen-mineralization in dry tropical savanna: effects of burning and grazing. *Soil Biol. Biochem.,* **23,** 269-273

SAS Institute, Inc. 1982: SAS user's guide: Statistics 1982 edition

Shikoku National Agricultural Experiment Station 1994: International Symposium on Development of Slopeland Agriculture

Soil Survey Staff 1992: Keys to Soil Taxonomy, 5th ed., SMSS Technical Monograph No. 19, 541 pp., Blacksberg, Verginia

Smitinand, T., Sabhasri., S and Kunstadter, P. 1978: The environment of northern Thailand. In farmers in the Forest, Ed. P. Kunstadter, E.C. Chapman, and S. Sabhasri, p. 24-40, The University Press of Hawaii, Honolulu

Sugihara, S., Konno, T., and Ishii, K. 1986: kinetics of mineralization of organic nitrogen in soil. *Bull. Natl. Inst. Agro-Eviron, Sci.,* **1,** 127-166 (in Japanese with English summary)

Tatsukawa, R. 1966: Rapid determination of organic matter with special reference to soil: determinations for sugars, uronic acids, and amino sugars. *Jpn. J. Soil Sci. Plant Nutr.,* **37,** 28-33 (in Japanese)

Thomas, G.W. 1982: Exchangeable cations. *In* Methods of Soil Analysis, Part 2, Chemical and Mineralogical Properties, Ed. A.L Page, R.H.Miller, and D.R.Keeney, p. 159-165, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison

Toriyama, K., Sekiya, S., and Miyamori, Y. 1988: Quantification of effect of air-drying of paddy soil before submergence on amount of nitrogen mineralization. *Jpn. J. Soil Sci. Plant Nutr.,* **59,** 531-537 (in Japanese with English summary)

Truog, E. 1930: The determination of the readily available phosphorus of the soils. *J. Am. Soc. Agron.,* **22** 874-882

Tulaphitak, T., Pairintra, C., and Kyuma, K. 1985a: Changes in soil fertility and tilth under shifting cultivation. Ⅱ. Changes in soil nutrient status. *Soil Sci. Plant Nutr.,* **31,** 239-249

Tulaphitak, T., Pairintra, C., and Kyuma, K. 1985b: Changes in soil fertility and tilth under shifting cultivation. Ⅲ. Soil respiration and soil tilth. *Soil Sci. Plant Nutr.,* **31,** 251-261

Vance, E.D., Brookes, P.C., and Jenkinson, D.S. 1987: An extraction method for measuring soil microbial biomass C. *Soil Biol. Biochem.,* **19,** 703-707

Van Raij, B. and Peech, M. 1972: Electrochemical properties of some Oxisols and Alfisols of the tropics. *Soil Sci. Soc Am. Proc.,* **36,** 587-593

Wada, S.-I 1986: Exchangeable ions, surface charge characteristics and iron oxides. *Pedol. Jpn.,* **30,** 35-41 (in Japanese)

Wada, S.-I. and Wada, K. 1985 Charge characteristics and exchangeable cation status of Korean Ultisols and Alfisols and Thai Ultisols and Oxisols. *J. Soil Sci.,* **36,** 21-29

Wilkinson, L. 1992: SYSTAT for Windows. SYSTAT, Inc., Evanston, Illinois

Yonebayashi, K. 1997: Soil organic matter. **In** Saishin-dojougaku, Ed. K.Kyuma, p.43-53, Asakura Shoten, Tokyo (in Japanese)

Yonebayashi, K. and Hattori, T. 1986: Patterns and factors controlling nitrogen mineralization in paddy soils in tropical and temperate regions. *Soil Sci. Plant Nutr.,* **32,** 407-420

Yoshinaga, N., Kato, Y., and Nakai, M. 1989 Mineralogy of red- and yellow-colored soils from Thailand. *Soil Sci. Plant Nutr.,* **35,** 181-205

Young, A. 1989: Agroforestry for soil conservation. P. 276 CAB International (cited from Kyuma, K.

1994: Problem in the development of slopeland agriculture in Asia. In International Symposium on Development of Slopeland Agriculture, Shikoku National Agricultural Experiment Station, Ⅰ-1)

Zinke, P.J., Sabhasri, S., and Kunstadter, P. 1978: Soil fertility aspects of the Lua' forest fallow system of shifting cultivation. In farmers in the forest, Ed. P. Kunstadter, E.C. Chapman, and S. Sabhasri, p. 24-40, The University Press of Hawaii, Honolulu

Appendix

DP series (derived from fine textured sedimentary rocks)

Location: Ban Du La Poe, Tambol Tha Pha Phum, Amphoe Mae La Noi, Changwat Mae Hong Son (N18° 24', E98° 05')

Site: DP-C2
Sampling date: 1994/11/4
Land use: upland rice cultivation after 8 year's fallow
Topography: gradient 25°, north 45° east

Hor.	Depth(cm)	Description
A	0-10	Brown (7.5YR4/4); moderately dry; light clay; moderate medium subangular blocky; slightly hard; slightly sticky, slightly plastic; many fine and common coarse roots; no gravel; clear smooth boundary to
BA	10-25	Brown (7.5YR4/6); moist; heavy clay; moderate medium subangular blocky; friable; sticky, plastic; many fine roots; no gravel; clear smooth boundary to
Bt	25-60+	Reddish brown (5YR4/8); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; friable; sticky, plastic; common fine roots; no gravel

Site: DP-C3
Sampling date: 1994/11/4
Land use: upland rice cultivation after 8 year's fallow
Topography: gradient 27°, north 10° east

Site: DP-F1
Sampling date: 1994/11/3
Land use: 1st year of fallow forest after 1 year's cultivation
Topography: gradient 22°, north 35° east

Hor.	Depth(cm)	Description
A	0-5	Dark reddish brown (5YR3/2); moist; heavy clay; moderate fine subangular blocky; slightly sticky, plastic; many fine roots; few moderately weathered gravels; clear smooth boundary to
B1	5-30	Dark reddish brown (5YR3/4); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; sticky, plastic; common fine roots; common moderately weathered gravels; gradual smooth boundary to
B2	30-50+	Dark reddish brown (5YR3/6); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; sticky, plastic; few fine roots; common moderately weathered gravels

Site: DP-F4
Sampling date: 1994/11/4
Land use: 1st year of fallow forest after 1 year's cultivation
Topography: 28°, south 10° west

Site: DP-F5
Sampling date: 1994/11/4
Land use: more than 40 year's fallow forest
Topography: gradient 15°, south 30° west

Hor.	Depth(cm)	Description
A	0-10	Very dark reddish brown (5YR2/3); moist; clay loam; moderate coarse crumb; very friable; slightly sticky, plastic; many fine roots; no gravel; clear smooth boundary to
AB	10-25	Dark reddish brown (5YR3/4); moist; light clay; moderate medium to fine subangular blocky; friable; sticky, plastic; many coarse roots; common strongly weathered pebbles; gradual smooth boundary to
B	25-50+	Dark reddish brown (5YR3/6); moist; light clay; moderate medium subangular blocky; friable; sticky, plastic; few fine roots; common strongly weathered pebbles

Site: DP-F6
Sampling date: 1994/11/5
Land use: 8th year of fallow forest
Topography: gradient 22°, south 20° west

Hor.	Depth(cm)	Description
A	0-10	Very dark reddish brown (5YR2/4); moist; light clay; moderate medium to fine subangular blocky; slightly firm; slightly sticky, plastic; common fine roots; no gravel; abrupt smooth boundary to
B1t	10-35	Reddish brown (5YR4/8); moist; heavy clay; moderate medium subangular blocky; friable; sticky, plastic; common medium roots; few strongly weathered pebbles; clear smooth boundary to
B2t	35-60+	Dark reddish brown (2.5YR3/6); moist; heavy clay; weak medium subangular blocky; friable; sticky, plastic; few coarse roots; few strongly weathered pebbles

Site: DP-F7
Sampling date: 1994/11/5
Land use: 8th year of fallow forest
Topography: gradient 28°, north 10° west

Site: DP-F8
Sampling date: 1994/11/5
Land use: 17th year of fallow forest
Topography: gradient 32°, south 55° west

Hor.	Depth(cm)	Description
A	0-5	Dark reddish brown (5YR3/3); moist; light clay; moderate medium subangular blocky; very friable; slightly sticky, plastic; many fine roots; common strongly weathered gravels; abrupt smooth boundary to
B1t	5-35	Reddish brown (5YR4/8); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; friable; sticky, plastic; many fine and common medium roots; common strongly weathered gravels and pebbles; clear smooth boundary to
B2t	35-60+	Reddish brown (2.5YR3/6); moist; heavy clay; thin clay cutan on the ped surface; weak fine subangular blocky; very friable; sticky, plastic; few coarse roots; common strongly weathered pebbles

Site: DP-F10
Sampling date: 1994/11/5
Land use: 5th year of fallow forest
Topography: gradient 15,° south 50° west

Site: DP-F11
Sampling date: 1994/11/5
Land use: 5th year of fallow forest
Topography: gradient 22°, south 30° east

Hor.	Depth(cm)	Description
A	0-10	Dull reddish brown (5YR4/3); moderately dry; clay loam; weak fine subangular blocky; slightly firm; slightly sticky, slightly plastic; many fine roots; common strongly weathered gravels; clear smooth boundary to
B1	10-25	Dark reddish brown (2.5YR3/3); moist; light clay; weak medium subangular blocky; friable; slightly sticky, plastic; common fine roots; common strongly weathered pebbles; gradual smooth boundary to
B2	25-60+	Dark reddish brown (5YR3/6); moist; light clay; moderate medium subangular blocky; friable; slightly sticky, plastic; few coarse roots; common strongly weathered pebbles

Site: DP-F12
Sampling date: 1994/11/6
Land use: natural forest
Topography: gradient 18°, south

Hor.	Depth(cm)	Description
A	0-5	Dark brown (7.5YR3/4); moist; light clay; weak fine subangular blocky; very friable; slightly sticky, slightly plastic; many fine roots; common strongly weathered gravels; clear smooth boundary to
BA	5-20	Reddish brown (7.5YR4/6); moist; light clay; moderate medium subangular blocky; friable; sticky, plastic; few fine roots; many strongly weathered pebbles; clear smooth boundary to
Bt	20-60+	Bright brown (5YR5/8); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; friable; sticky, very plastic; few fine roots; few strongly weathered pebbles

Site: DP-F13
Sampling date: 1994/11/6
Land use: natural forest
Topography: gradient 20°, north 10° west

DP series (derived from granite)

Location: Ban Du La Poe, Tambol Tha Pha Phum, Amphoe Mae La Noi, Changwat Mae Hong Son (N18° 24', E98° 05')

Site: DP-C1
Sampling date: 1994/11/3
Land use: upland rice cultivation after 9 year's fallow
Topography: gradient 32°, north 30° west

Hor.	Depth(cm)	Description
A	0-7	Grayish brown (7.5YR4/1); moderately dry; sandy clay loam; weak fine subangular blocky; friable; slightly sticky, slightly plastic; many fine roots; many strongly weathered gravels; clear smooth boundary to
AB	7-30	Brown (7.5YR4/3); moist; clay loam; weak medium subangular blocky; friable slightly sticky, slightly plastic; many fine roots; many strongly weathered gravels; clear wavy boundary to
Bw	30-60	Brown (7.5YR4/4); moist; clay loam; weak medium subangular blocky; friable; slightly sticky, slightly plastic; few fine roots; many strongly weathered gravels; clear wavy boundary to
C	60+	Composed of many strongly weathered pebbles

Site: DP-F2
Sampling date: 1994/11/3
Land use: 5th year of fallow forest
Topography: gradient 28°, south 80° east

Hor.	Depth(cm)	Description
A	0-5	Very dark reddish brown (5YR2/3); moist; moderate fine subangular blocky; friable; many fine roots; few slightly weathered gravels; clear smooth boundary to
B	5-30	Dark reddish brown (5YR3/3); moist; weak fine subangular blocky; very friable; common to many fine roots; common slightly weathered gravels; clear smooth boundary to
BC	30-60+	Dull reddish brown (5YR4/4); moist; weak fine subangular blocky; very friable; few fine roots; common slightly weathered gravels

Site: DP-F3
Sampling date: 1994/11/4
Land use: more than 25 year's fallow forest
Topography: gradient 27°, east

Hor.	Depth(cm)	Description
A	0-5	Brownish black (5YR2/2); moist; Clay loam; moderate medium crumb; very friable; slightly sticky, plastic; many fine roots; common slightly weathered gravels; clear smooth boundary to
AB	5-25	Very dark reddish brown (5YR2/4); moist; clay loam; moderate medium subangular blocky; friable; slightly sticky, plastic; common fine and medium roots; few strongly weathered gravels; clear smooth boundary to
B	25-50+	Dull reddish brown (5YR4/4); moist; light clay; moderate medium subangular blocky; slightly sticky, plastic; common medium and coarse roots; few slightly weathered gravels

Site: DP-F9
Sampling date: 1994/11/5
Land use: natural forest
Topography: gradient 31°, north 70° west

Hor.	Depth(cm)	Description
A	0-15	Dark brown (7.5YR3/4); moist; loam; weak medium subangular blocky; friable; slightly sticky, slightly plastic; few fine roots; many slightly weathered gravels; clear smooth boundary to
AB	15-40	Dark brown (7.5YR3/4); moist; clay loam; moderate fine subangular blocky; friable; slightly sticky, plastic; many fine and common medium roots; many slightly weathered gravels; clear smooth boundary to
Bw	40-60+	Brown (7.5YR4/6); moist clay loam; weak fine subangular blocky; very friable; slightly sticky, plastic; few coarse roots; many slightly weathered gravels

Site: DP-F14
Sampling date: 1994/11/6
Land use: 2nd year of fallow after cultivation
Topography: gradient 22°, north 20° west

Hor.	Depth(cm)	Description
A	0-10	Brownish black (7.5YR2/2); moist; clay loam; weak fine subangular blocky; very friable; slightly sticky, slightly plastic; many fine roots; few slightly weathered gravels; clear smooth boundary to
BA	10-25	Brown (7.5YR4/6), moist; clay loam; weak fine subangular blocky; friable; slightly sticky, slightly plastic; common fine roots; common slightly weathered gravels; clear smooth boundary to
B	25-45	Brown (7.5YR4/6); moist; clay loam; moderate medium subangular blocky; very friable; slightly sticky, slightly plastic; few fine roots; common slightly weathered gravels; clear wavy boundary to
BC	45-55+	moist

HM series (derived from granite)

Location: Ban Huai Mak Nun, Tambol Tha Pha Phum, Amphoe Mae La Noi, Changwat Mae Hong Son (N18° 20', E98° 00')

Site: HM-C1
Sampling date: 1994/4/28
Land use: 1st year of cultivation after 3 year's fallow
Topography: gradient 15°, north 40° west

Hor.	Depth(cm)	Description
A	0-13	Dull yellowish brown (10YR4/3); dry (upper part) and moist; (lower part); clay loam; weak fine subangular blocky; friable; slightly sticky, slightly plastic; many fine roots; few moderate weathered gravels; penetrometer 20 mm; clear smooth boundary to
BA	13-27	Dark brown (10YR3/4); moist; clay loam; moderate fine subangular blocky; friable; slightly sticky, slightly plastic; many fine roots; few slightly weathered gravels; penetrometer 22mm; clear smooth boundary to
Bw	27-65+	Brown(7.5YR4/4); moist; clay loam; moderate medium subangular blocky; friable; slightly sticky, plastic; common fine roots; many slightly weathered gravels (quarts); penetrometer 25 mm

Site: HM-C2
Sampling date: 1994/4/28
Land use: 1st year of cultivation after 3 year's fallow
Topography: gradient 25°, north 45° east

Site: HM-F1
Sampling date: 1994/4/28
Land use: 1st year of fallow forest after 1 year's cultivation
Topography: gradient 28°, north 40° east

Hor.	Depth(cm)	Description
A	0-12	Dull yellowish brown (10YR5/3); dry; clay loam; no structure; firm; slightly sticky, slightly plastic; common fine roots; common strongly weathered gravels; penetrometer 24 mm; clear smooth boundary to
B1	12-30	Bright brown (7.5YR5/8); moderate dry; clay loam; moderate fine subangular blocky; slightly firm; slightly sticky, plastic; few fine roots; many slightly weathered gravels; penetrometer 27 mm; gradual smooth boundary to
B2	30-65+	Bright brown (5YR5/8); moist; light clay; weak moderate angular blocky; firm; sticky, plastic; few fine roots; many slightly weathered gravels (quarts); penetrometer 28 mm

Site: HM-F2
Sampling date: 1994/4/28
Land use: 1st year of fallow forest after 1 year's cultivation
Topography: gradient 27°, south 50° east

Site: HM-F3
Sampling date: 1994/4/28
Land use: 7th year of fallow forest
Topography: gradient 23°, north 5° east

Hor.	Depth(cm)	Description
A	0-15	Brown (10YR4/6); moderately dry; clay loam; moderate medium subangular blocky; slightly firm; slightly sticky, plastic; many fine and common coarse roots; common strongly weathered gravels; penetrometer 24 mm; clear smooth boundary to
BA	15-30	Brown (7.5YR4/6); moist; clay loam; moderate fine angular blocky; slightly sticky, plastic; common coarse roots; common slightly weathered gravels; penetrometer 28 mm; clear smooth boundary to
Bw	30-65+	Blight reddish brown (5YR5/8); moist; light clay; moderate medium subangular blocky; sticky, plastic; common to few coarse roots; common slightly weathered gravels (quarts); penetrometer 28 mm

Site: HM-F4
Sampling date: 1994/4/29
Land use: 7th year of fallow forest
Topography: gradient 29°, north 60° east

Site: HM-F5
Sampling date: 1994/4/29
Land use: natural forest
Topography: gradient 30°, north 30° west

Hor.	Depth(cm)	Description
A	0-10	Brownish black (10YR3/2); moderately dry; light clay; moderate medium subangular blocky; slightly sticky, slightly plastic; many fine and few coarse roots; no gravel; penetrometer 17 mm; clear smooth boundary to
BA	10-20	Brown (10YR4/4); moist; light clay; weak medium subangular blocky; slightly sticky, slightly plastic; few fine and coarse roots; few strongly weathered gravels; penetrometer 25 mm;
Bw	20-65+	Brown (10YR4/6); moist; light clay; weak fine subangular blocky; slightly sticky, slightly plastic; few coarse roots; many strongly weathered gravels; penetrometer 28 mm

Site: HM-F6
Date: 1994/4/29
Land use: natural forest
Topography: gradient 25°, south 45° west

Site: HM-F7
Sampling date: 1994/4/29
Land use: 4th year of fallow forest
Topography: gradient 20°, north 20° west

Hor.	Depth(cm)	Description
A	0-10	Dark brown (10YR3/4); clay loam; moderate fine subangular blocky; slightly sticky, plastic; many fine roots; no gravel; penetrometer 20 mm; clear smooth boundary to
BA	10-25	Brown (7.5YR4/4); clay loam; moderate medium subangular blocky; slightly sticky, plastic; common fine roots; no gravel; penetrometer 24 mm; clear smooth boundary to
Bw	25-70+	Reddish brown (5YR4/8); clay loam; moderate medium subangular blocky; sticky, plastic; few fine roots; common strongly weathered gravels; penetrometer 22 mm

Site: HM-F8
Sampling date: 1994/4/30
Land use: 4th year of fallow forest
Topography: gradient 33°, north 60° east

RP series (derived from Paleozoic shale)

Location: Ban Rakpaendin, Tambol Tab Tao, Amphoe Thoeng, Changwat Chiang Rai (N19° 49', E100° 22')

Site: RP-C1

Sampling date: 1993/3/7

Land use: just after clear-cutting for cultivation after 7 year's fallow

Topography: gradient 10° ,east

Hor.	Depth(cm)	Description
A1	0-1	Brownish black (10YR3/1); ash layer; abrupt smooth boundary to
A2	1-11	Dull yellowish brown (10YR4/3); dry; light clay; moderate fine subangular blocky; slightly firm, slightly plastic; many fine roots; no gravel; penetrometer 23mm; abrupt smooth boundary to
BA	11-18	Bright brown (7.5YR5/6); moderately dry; heavy clay; moderate medium angular blocky; firm; slightly sticky, very plastic; common to many fine roots; no gravel; penetrometer 25mm; clear smooth boundary to
Bt1	18-40	Bright brown (7.5YR5/8); moderately moist; heavy clay; thin clay cutan on the ped surface; moderate fine angular blocky; firm; sticky, very plastic; common fine roots; no gravel; penetrometer 29mm; gradual smooth boundary to
Bt2	40-80+	Bright brown (7.5YR5/8); moderately moist; heavy clay; thin clay cutan on the ped surface; weak fine angular blocky; sticky, very plastic; few fine roots; no gravel; penetrometer 30mm

Site: RP-C2

Sampling date: 1993/3/7

Land use: just after clear-cutting for cultivation after 2 year's fallow

Topography: gradient 10°, south 50° east

Hor.	Depth(cm)	Description
Ap	0-10/13	Dark brown (7.5YR3/4); moderately dry; heavy clay; weak fine subangular blocky; slightly firm; sticky, very plastic; abundant fine and few medium roots; few strongly weathered gravels; penetrometer 14mm; clear smooth boundary to
Bt	10/13-21/26	Reddish brown (5YR4/8); moderately moist; heavy clay; thin clay cutan on the ped surface; weak fine subangular blocky; slightly firm; sticky, very plastic; few medium roots; few strongly weathered pebbles; penetrometer 25mm; abrupt wavy boundary to
C	21/26-59+	Composed of abundant strongly weathered rocks; few fine roots

Site: RP-C3

Sampling date: 1993/3/8

Land use: 3rd year of cultivation after 5 year's fallow

Topography: gradient 22°,north 20° west

Hor.	Depth(cm)	Description
Ap	0-6	Grayish yellow brown (10YR5/2); dry; light clay; weak fine subangular blocky; slightly firm; slightly sticky, slightly plastic; many fine roots; common strongly weathered gravels and pebbles; penetrometer 19mm; clear smooth boundary to
AB	6-17/28	Brown (7.5YR4/4); moderately dry; light clay; medium fine subangular blocky; firm; slightly sticky, plastic; many fine roots; many strongly weathered gravels and pebbles; penetrometer 23mm; clear wavy boundary to
BA	17/28-25/30	Brown (7.5YR4/6); moderately moist; heavy clay; moderate medium to fine angular blocky; firm; sticky, very plastic; common fine roots; common strongly weathered gravels; penetrometer 28mm; clear wavy boundary to
Bt	25/30-68	Reddish brown (5YR4/6); moderately moist; heavy clay; thin clay cutan on the ped surface; moderate medium angular blocky; firm; sticky, very plastic; few fine roots; few strongly weathered gravels; penetrometer 27mm; abrupt smooth boundary to
BC	68-78+	Reddish brown (5YR4/8); moderately moist; heavy clay; weak fine subangular blocky; firm; sticky, very plastic; very few fine roots; abundant strongly weathered pebbles and gravels; penetrometer 28mm

Site: RP-C4

Sampling date: 1993/3/8

Land use: 3rd year of cultivation after 5 year's fallow with tractor tillage in 1991

Topography: gradient 8°,south 80° west

Hor.	Depth(cm)	Description
AP	0-20	Dull orange (7.5YR6/4); dry; clay loam; weak fine subangular blocky; slightly firm; slightly sticky, slightly plastic; many fine roots; few strongly weathered pebbles; penetrometer 13mm; abrupt smooth boundary to
Bt1	20-30	Reddish brown (5YR4/8); moderately moist; heavy clay; thin clay cutan on the ped surface; moderate fine angular blocky; firm; sticky, very plastic; few medium to fine roots; few strongly weathered gravels; penetrometer 26mm; clear smooth boundary to
Bt2	30-70+	Bright reddish brown (5YR5/8); moderately moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; firm; sticky, very plastic; few fine roots; few strongly weathered gravels; penetrometer 28mm

Site: RP-C5

Sampling date: 1993/3/12

Land use: just after clear-cutting for cultivation after very long year's fallow

Vegetation: bamboo and some woody species

Topography: gradient 20°, south 70° west

Hor.	Depth(cm)	Description
A	0-5	Very dark brown (7.5YR2/3); moist; light clay; weak fine subangular blocky; friable; slightly sticky, plastic; common fine roots; no gravel; penetrometer 15mm; clear smooth boundary to
AB	5-19	Dull reddish brown (5YR4/4); moderately dry; heavy clay; weak medium subangular blocky; slightly firm; sticky, very plastic; common fine roots with few coarse tree roots; no gravel; penetrometer 23mm; clear smooth boundary to
BA	19-27	Reddish brown (5YR4/6); moist; light clay; moderate medium subangular blocky; slightly firm; slightly sticky, plastic; common fine roots; common strongly weathered gravels and pebbles; penetrometer 25mm; clear smooth boundary to
Bt1	27-48	Dark reddish brown (5YR3/6); moist; heavy clay; moderate medium angular blocky; slightly firm; sticky, very plastic; common to few fine roots; common strongly weathered gravels; penetrometer 28mm; clear smooth boundary to
Bt2	48-70/75	Dark reddish brown (5YR3/6); moist; heavy clay; moderate medium angular blocky; firm; sticky, very plastic; few fine roots; common strongly weathered pebbles and cobbles; penetrometer 30mm; clear smooth boundary to
BCt	70/75-80+	Dull reddish brown (2.5YR4/4); moist; heavy clay; thin clay cutan on the ped surface; weak fine angular blocky; slightly firm; sticky, very plastic; very few fine roots; many strongly weathered pebbles and cobbles; penetrometer 30mm

Site: RP-C6

Sampling date: 1993/3/19

Land use: 5th year of cultivation after 2 year's fallow

Topography: gradient 18° , north 5° west

Hor.	Depth(cm)	Description
AP	0-5/7	Brown (7.5YR4/6); moderately dry; light clay; weak medium to fine subangular blocky; friable; sticky, plastic; many fine roots with few coarse roots; strongly weathered gravels; penetrometer 15mm; clear smooth boundary to
BA	5/7-18	Reddish brown (5YR4/6); weak medium to fine subangular blocky; moist; heavy clay; friable; sticky, very plastic; common fine roots; strongly weathered gravels; penetrometer 22mm; clear smooth boundary to
Bt	18-44	Reddish brown (5YR4/8); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; slightly firm; sticky, very plastic; few fine roots; moderately to strongly weathered pebbles; penetrometer 28mm; clear smooth boundary to
BC	44-64	Reddish brown (5YR4/8); moist; heavy clay; moderate medium subangular blocky; friable; sticky, very plastic; very few fine roots; moderately to strongly weathered pebbles; penetrometer 26mm; clear smooth boundary to
C	64-78+	Reddish brown (5YR4/8); light clay; no structure; sticky, very plastic; very few fine roots; moderately to strongly weathered pebbles; penetrometer 26mm

Site: RP-C7
Sampling date: 1993/3/19
Land use: just after clear-cutting for cultivation after 6 year's fallow
Topography: gradient 22°, south 10° east

Hor.	Depth(cm)	Description
AP	0-7/11	Brown (7.5YR4/4); moderately dry; weak medium subangular blocky; friable; slightly sticky, plastic; many fine roots; no gravel; penetrometer 15mm; clear smooth boundary to
BAt	7/11-27/30	Bright brown (7.5YR5/6); moderately moist; heavy clay; thin clay cutan on the ped surface; moderate medium to fine angular blocky; slightly firm; sticky, very plastic; common fine roots and few coarse bamboo roots; few strongly weathered gravels; penetrometer 22mm; clear smooth boundary to
Bt1	27/30-60	Reddish brown (5YR4/8); moist; heavy clay; thin clay cutan on the ped surface; moderate medium angular blocky; firm; sticky, very plastic; common to fine and few medium roots; few strongly weathered gravels; penetrometer 25mm; gradual smooth boundary to
Bt2	60-80	Reddish brown (5YR4/8); moist; heavy clay; thin clay cutan on the ped surface; weak medium angular blocky; slightly firm; sticky, very plastic; few fine and few coarse roots; few strongly weathered gravels; penetrometer 28mm

Site: RP-C8
Sampling date: 1993/7/25
Land use: 7th year of cultivation after 4 year's fallow with tractor tillage in 1989 and 1990 and with chemical fertilizer in 1991.
Topography: gradient 12°, north 65° east

Hor.	Depth(cm)	Description
Ap1	0-8	Brown (7.5YR4/4); moderately dry; heavy clay; weak medium subangular blocky; friable; sticky, very plastic; many fine roots; no gravel; penetrometer 14mm; clear wavy boundary to
AP2	8-25	Brown (7.5YR4/4) with brown (7.5YR4/3); moist; heavy clay; weak fine subangular blocky; friable sticky, very plastic; common fine roots; few strongly weathered gravels; penetrometer 18mm; clear wavy boundary to
Bt	28+	Bright brown (7.5YR5/6); moist; heavy clay; moderate medium subangular blocky; friable; sticky, very plastic; few fine roots; few strongly weathered pebbles; penetrometer 20mm

Site: RP-C9
Sampling date: 1993/7/26
Land use: 1st year of fallow forest after 5 year's cultivation
Topography: gradient 18°, north 20° west

Hor.	Depth(cm)	Description
Ap	0-12	Dark reddish brown (2.5YR3/3); moist; heavy clay; moderate medium to coarse subangular blocky; friable; sticky, very plastic; many fine roots; few strongly weathered gravels; penetrometer 10mm; clear wavy boundary to
Bt1	12-30	Dark reddish brown (2.5YR3/4); moist; heavy clay; thin clay cutan on the ped surface; weak medium subangular blocky; friable; sticky, plastic; few fine roots; none gravel; penetrometer 20mm; clear wavy boundary to
Bt2	30-65	Dark reddish brown (2.5YR3/6); moist; heavy clay; thin clay cutan on the ped surface; weak medium subangular blocky; friable; sticky, plastic; very few fine roots; common strongly weathered gravels; penetrometer 22mm; clear smooth boundary to
C	65+	Composed of abundant strongly weathered gravels

Site: RP-C10
Sampling date: 1993/7/27
Land use: 1st year of fallow forest after 3 year's cultivation with chemical fertilizer in 1992
Topography: gradient 25°, south 15° east

Hor.	Depth(cm)	Description
A	0-5	Dark brown (7.5YR3/3); moist; heavy clay; weak fine subangular blocky; friable; slightly sticky, slightly plastic; many fine roots; few strongly weathered gravels; penetrometer 7mm;clear wavy boundary to
Bt	5-30	Reddish brown (5YR4/6); moist; heavy clay; thin clay cutan on the ped surface; weak medium subangular blocky; friable; sticky, plastic; many fine roots; common strongly weathered gravels; penetrometer 16mm clear wavy boundary to
BC	30-55	Reddish brown (5YR4/8); moist; heavy clay; thin clay cutan on the ped surface; weak fine subangular blocky; friable; sticky, plastic; common fine roots; many strongly weathered pebbles and cobbles; penetrometer 19mm; clear wavy boundary to
C	55-70+	Abundant strongly weathered boulds

Site: RP-F1
Sampling date: 1993/3/7
Land use: 10th year of fallow forest
Topography: gradient 12°, east

Hor.	Depth(cm)	Description
L	4-0	Mainly composed of coarse litter of bamboo species
A	0-10/15	Dark brown (10YR3/4); moderately dry; light clay; moderate fine subangular blocky; slightly firm; sticky, plastic; abundant fine and few coarse roots; no gravel; penetrometer 26mm; clear smooth boundary to
BA	10/15-20/25	Brown (7.5YR4/4); moderately moist; heavy clay; moderate medium angular blocky; firm; very sticky, very plastic; common fine roots; few strongly weathered gravels; penetrometer 27mm; clear smooth boundary to
Bt1	20/25-40	Reddish brown (5YR4/6); moderately moist; thin clay cutan on the ped surface; moderate medium to coarse angular blocky; firm; very sticky, very plastic; common fine roots; no gravel; penetrometer 28mm; gradual smooth boundary to
Bt2	40-70/85+	Bright reddish brown (5YR5/6) with common dark reddish brown (5YR3/6) of mottle (contrast; faint); moderately moist; heavy clay; thin clay cutan on the ped surface; moderate fine angular blocky; slightly firm; very sticky, very plastic; few very fine roots; no gravel; penetrometer 29mm; clear wavy boundary to

Site: RP-F2
Sampling date: 1993/3/13
Land use: natural forest
Topography:

Hor.	Depth(cm)	Description
A	0-6	Dark brown (10YR3/3); moist; heavy clay; moderate fine subangular blocky; friable; sticky, very plastic; many fine and common coarse roots; no gravel; penetrometer 13mm; clear smooth boundary to
AB	6-12	Brown (7.5YR4/3); moist; heavy clay; moderate fine subangular blocky; slightly firm; sticky, very plastic; common fine roots; few strongly weathered gravels; penetrometer 23mm; clear smooth boundary to
Bat	12-18	Brown (7.5YR4/6); moist; heavy clay; thin clay cutan on the ped surface; moderate medium angular blocky; slightly firm; sticky, very plastic; few fine roots; common strongly weathered gravels; penetrometer 27mm; gradual smooth boundary to
Bt2	8-70/80	Bright reddish brown (5YR5/6); moist; heavy clay; thin clay cutan on the ped surface; moderate medium angular blocky; firm; sticky, very plastic; few fine and few coarse roots; common strongly weathered gravels; penetrometer 26mm; clear smooth boundary to
BCt	70/80-85+	Reddish brown (5YR4/6); moist; heavy clay; thin clay cutan on the ped surface; weak fine angular blocky; slightly firm; sticky, very plastic; no root; abundant strongly weathered pebbles and cobbles; penetrometer 26mm

Site: RP-F3
Sampling date: 1993/7/26
Land use: natural forest
Topography: gradient 30°,south 50° west

Hor.	Depth(cm)	Description
A	0-12	Dark reddish brown (5YR3/4); moist; heavy clay; weak medium subangular blocky; friable; sticky, plastic; many fine roots, few medium roots and coarse tree roots; few strongly weathered gravels; penetrometer12mm; clear smooth boundary to
BAt	12-23	Dark reddish brown (5YR3/6); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; friable; sticky, plastic; common fine roots and few medium roots; few strongly weathered gravels and cobbles; penetrometer 15mm; clear smooth boundary to
Bt	23-43	Dark reddish brown (2.5YR3/4); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; friable; sticky, plastic; few fine roots; common strongly weathered cobbles; penetrometer 14mm; clear smooth boundary to
BCt	43-70+	Dark reddish brown (2.5YR3/4); moist; heavy clay; thin clay cutan on the ped surface; moderate medium subangular blocky; friable; sticky, plastic; few fine roots; abundant strongly weathered cobbles; penetrometer 18mm

Publications

Chapter 3

Funakawa, S., Tanaka, S., Kaewkongka, T., Hattori, T., and Yonebayashi, K. 1997:
Physicochemical properties of the soils associated with shifting cultivation in northern Thailand with special reference to factors determining soil fertility. *Soil Sci. Plant Nutr.,* 43(3), 665-679

Chapter 4

Tanaka, S., Funakawa, S., Kaewkongka, T., Hattori, T., and Yonebayashi, K. 1997:
Soil ecological study on dynamics of K, Mg, and Ca, and soil acidity in shifting cultivation in northern Thailand. *Soil Sci. Plant Nutr.,* 43(3), 695-708

Chapter 5

Funakawa, S., Tanaka, S., Shinko, H., Kaewkongka, T., Hattori, T., and Yonebayashi, K. 1997:
Ecological study on the dynamics of soil organic matter and its related properties in shifting cultivation systems of northern Thailand. *Soil Sci. Plant Nutr.,* 43(3), 681-693

Chapter 6

Tanaka, S., Funakawa, S., Kaewkhongkha, T., and Yonebayashi, K. 1998:
Labile pools of organic matter and microbial biomass in the surface soils under shifting cultivation in northern Thailand. *Soil Sci. Plant Nutr.,* 44(4), 527-537

Chapter 7

Tanaka, S., Funakawa, S., Kaewkhongkha, T., and Yonebayashi, K. 1998:
N mineralization process of the surface soils under shifting cultivation in northern Thailand. *Soil Sci. Plant Nutr.,* 44(4), 539-549