

**Progress Report**  
**of**  
**Red Acid Soil Team**

**Basic Researches on Developing the Techniques for  
Sustainable Biological Production in  
the Regions of Red Acid Soils**

**THE DEVELOPMENT OF SUSTAINABLE  
BIOLOGICAL PRODUCTION TECHNOLOGIES  
HARMONIZED WITH REGIONAL ENVIRONMENTAL  
CONDITIONS IN EAST ASIA**

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**The organic matter composition of the red acid soils under different land uses in the deforested hilly area of West Lampung, South Sumatra, Indonesia**

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**Summary**

A series of soils under primary forest, secondary forest, coffee plantation, and crop lands developed on the same slope were collected at five locations in the hilly area of south Sumatra, where severe deforestation has taken place in the recent 30 years. Total C, N, pH, humus composition in free and combined forms, saccharide composition in non-cellulosic and cellulose fractions, and phenolic compounds derived by CuO-NaOH oxidation in these soils were determined to clarify the effect of land use change on the soil organic matter composition. Total amount of the extractable humus decreased almost in the order of primary forest > secondary forest > coffee plantation > crop land, in which the proportion of humic acid also decreased in this order while that of fulvic acid increased. The absorption due to Pg pigment in the uv-vis. absorption spectra of humic acid was intensified in the soils of coffee plantation and crop lands as well as in B layers. Soil saccharide explained 5 - 16 % of soil carbon. The proportion of non-cellulosic saccharide in the soils of coffee plantation and crop land was slightly larger than that in the soils of primary forest and secondary forest in almost all locations. The proportion of cellulosic saccharide did not show a consistent relationship with land use. Absolute amounts of phenolic compounds were always largest in the soils of primary forest soils. Phenolic acids predominated among phenolic compounds, indicating the highly oxidized state of lignin in the tropical soils. The yield of cinnamyl compounds were very low in the soils of coffee plantation, which is considered to be due to the removal of weed from the ground surface

*Key words:* humus composition, land use effects, phenolic compounds, saccharide composition, tropical soil

**INTRODUCTION**

Large area of forests in Southeast Asia develops on the "Red acid soils", and the soils lose rapidly the potentiality of sustaining 'fertile' vegetation, after they are opened to cultivated lands. As an typical area where such soil degradation is in progress, we have selected the hilly area and middle terrace area in the south Sumatra, Indonesia. Besides several co-operative studies accomplished in these areas from the aspects of land use change (Syam et al. 1997), soil survey, bio-chemistry (Salam et al. 1998), inorganic constituents, soil biology, agricultural engineering weed science, cropping systems, and plant pathology,

this study aimed to clarify the effects of land use changes on the composition of soil organic matter, which is the most vulnerable fraction. As soil organic components, we selected humic fractions in free and combined forms, saccharides in non-cellulosic and cellulosic fractions, and phenolic compounds derived by CuO-NaOH oxidation. Though land use effects on the humus composition have also been studied widely on various soils (Saviotti et al. 1994, Murata and Goh 1997), data on tropical soils are very few. In addition, very simple and important information on the quantitative distribution of humic fractions in various soils seems to be lacking behind the very sophisticated information on the composition and structure of humic substances. Carbohydrates and lignin-derived phenols have been used as good markers for clarifying the land use effects on the composition of soil organic matter (Guggenberger et al. 1994, 1995, Sanger et al. 1997). The components which constitutes the macro molecule of humic substances, polysaccharides, and lignin also differ in their origin and stability. We have investigated how the difference in land use affected their amounts and composition.

## MATERIALS AND METHODS

### Soil Samples

Soil samples were collected from five deforested locations (Bukit Ringgis, Sekincau, Tri Mulya, Tri Budi Syukur, and Pura Mekar) in July 1995 in the hilly area around Sumberjaya, West Lampung, South Sumatra, Indonesia. Locations are the same as those reported by Salam et al. (1998). Each location consisted of four different land use systems, i.e. primary forest, secondary forest, coffee plantation, and crop land. Another series of soil samples under different land use were collected from almost the same sites in Bukit Ringgis in the different year (early August in 1996 and 1997). The site name is designated as Bukit Ringgis II in Tables 1-4. Soil types (Soil Taxonomy, USDA) were Dystropepts under primary forest and secondary forest, and Kanhapludults under coffee plantation and crop land in all locations.

Several fundamental chemical properties and the compositions of major and minor inorganic elements have been also determined, which will be reported elsewhere. The carbon and nitrogen contents and pH are given in Table 1. Carbon and nitrogen were determined with Yanaco MT-500 CN analyzer using CuO as an oxidizing agent. The pH value of soils were determined in water and 0.1 M KCL at the soil to liquid ratio of 1:2.5.

### Analysis of humus composition

Humic composition in free and combined forms were analyzed successively according to the method of Kumada et al. (1967) and Kumada (1987). Finely ground air dry soil equivalent to 100 mg carbon or less was extracted first with 30 mL of 0.1 M NaOH in a steam bath and washed two times. Then, the residue was extracted with 30 mL of 0.1 M  $\text{Na}_4\text{P}_2\text{O}_7$  in a steam bath and washed two times. Each extract and washings were combined and separated to humic acid and fulvic acid fractions by acidifying with sulfuric acid. The ultraviolet and visible absorption spectra of humic acids were determined within 2 h after the solubilization into the alkaline solution. The yields of humic acid and fulvic acid on the basis of carbon were determined by colorimetric dichromate oxidation method by Tatsukawa (1966). Two parameters for the degree of humification were obtained as follows:  $\text{RF} = (\text{K}_{600} / \text{c}) \times 15$ , where  $\text{K}_{600}$  is the absorbance of humic acid at 600 nm, and c is carbon

mg per 1 mL humic acid solution used for determining the absorbance at 600 nm.

$\Delta \log K = \log K_{400} - \log K_{600}$  where K is the absorbance of humic acid at 400 nm or 600 nm.

Types of humic acids were determined on a diagram using these two parameters (Kumada et al. 1967).

#### Analysis of carbohydrate composition

Saccharides in non-cellulosic and cellulosic forms were extracted successively as recommended by Oades et al. (1970). Non-cellulosic saccharide was extracted by refluxing 2 g of finely ground air dry soil sample in 40 mL of 2.5 M H<sub>2</sub>SO<sub>4</sub> over boiling water bath for 2 h. Cellulosic saccharide was extracted by soaking the residue of non-cellulosic saccharide extraction in 13 M H<sub>2</sub>SO<sub>4</sub> for 16 h, then diluting it to 0.5 M H<sub>2</sub>SO<sub>4</sub> and refluxing over boiling water bath for 5 h. The extracted saccharides were alditol-acetylated according to the method of Spiteller (1980). The alditol-acetate derivatives of saccharides were analyzed by capillary gas chromatography. The used column was Chrompack CP-Sil 43CB 0.25mm x 25 m. The column temperature was increased from 195 to 225°C at the rate of 6°C min<sup>-1</sup> then held at 225°C for 11 min. The temperature at the injector port and at the detector port were 270 and 300°C, respectively.

#### Analysis of phenolic compounds by CuO-NaOH oxidation

Phenolic compounds released by CuO-NaOH oxidation were analyzed according to the method described in Tsutsuki et al. (1994), while the used capillary gas chromatography column was changed to Neutra Bond 1 (0.25 mm x 60 m) for improving the separation of compounds by using the longer column.

## RESULTS AND DISCUSSION

### 1) Carbon, nitrogen and pH

Fundamental properties of the soil samples are listed in Table 1. All the sampling sites in Bukit Ringgis and Sekincau were located at the altitude higher than 1100 m. On the other hand, the sites in Tri Mulya, Pura Mekar, and Tri Budi Syukur were located below 1000 m. The soils of primary forest in Bukit Ringgis and Sekincau were strongly acidic as shown by pH(H<sub>2</sub>O) of 4.0 and 3.8. The pH(H<sub>2</sub>O) and pH(KCl) at coffee plantation and crop lands were both higher than those at primary forest in Bukit Ringgis and Sekincau. To the contrary, the soil pH at primary forest was moderate in Tri Mulya, Pura Mekar, and Tri Budi Syukur, as shown by pH(H<sub>2</sub>O) between 6.2 and 6.4 and pH(KCl) between 5.4 and 5.9. In these locations soil pH values at coffee plantation and crop land were lower than those at the primary forest.

The carbon content of soil decreased almost in the order of primary forest > secondary forest > coffee plantation > crop land in all locations. The exception was that the carbon content at coffee plantation was slightly larger than that at secondary forest in Sekincau and that the carbon contents at crop lands were slightly larger than those at coffee plantation in Tri Mulya and Tri Budi Syukur. In Bukit Ringgis and Sekincau, total carbon content was extremely larger than those under the other land uses. The difference in total carbon contents between different land use was smaller in Tri Mulya, Pura Mekar, and Tri Budi Syukur.

Total nitrogen showed almost the similar tendency with total carbon. The C/N ratios of primary forest soils were remarkably larger than those at the other land uses in Bukit Ringgis, Sekincau, and Pura Mekar. The C/N ratio decreased in the order of primary forest >

Table 1. Fundamental properties of the soils used.

	soil depth (cm)	altitude (m)	T-C (g kg <sup>-1</sup> )	T-N (g kg <sup>-1</sup> )	C/N	pH(H <sub>2</sub> O)	pH(KCl)
<b>Bukit Ringgis</b>							
PF	0-20	1550	179.2	8.3	21.6	4.02	3.38
SF	0-20	1400	49.5	2.6	19.0	5.34	4.60
CP	0-20	1120	35.6	2.4	14.8	4.30	3.98
CL	0-15	1100	30.1	2.3	13.1	4.32	3.86
<b>Sekincau</b>							
PF	0-23	1620	188.5	9.8	19.2	3.78	3.46
SF	0-21	1440	81.5	4.9	16.6	4.21	3.19
CP	0-16	1240	84.2	6.3	13.4	4.45	4.18
CL	0-29	1170	37.7	3.4	11.1	4.72	4.40
<b>Tri Mulya</b>							
PF	0-14	890	78.5	7.4	10.6	6.37	5.94
SF	0-19	740	43.1	4.4	9.8	6.46	5.97
CP	0-14	490	29.1	2.9	10.0	5.78	5.07
CL	0-13	465	29.3	2.8	10.5	5.54	4.90
<b>Pura Mekar</b>							
PF	0-20	940	37.7	2.2	17.1	6.15	5.37
SF	0-20	790	37.0	3.0	12.3	5.80	5.11
CP	0-20	540	33.7	2.8	12.0	5.21	4.65
CL	0-20	522	30.5	2.0	15.3	5.34	4.41
<b>Tri Budi Syukur</b>							
SF	0-11	985	51.7	4.4	11.8	6.42	5.61
CP	0-14	735	35.2	3.2	10.9	5.10	4.38
CL	0-12	710	22.8	2.0	11.5	4.49	3.98
<b>Bukit Ringgis II - PF</b>							
A	0-10	1550	109.0	6.1	17.9	4.35	3.69
B	10-30		32.8	2.1	15.6	4.71	3.96
<b>Bukit Ringgis II - SF</b>							
A/B	0-10	1400	37.5	2.5	15.0	4.82	4.00
B	10-30		19.4	1.4	13.9	4.87	3.91
<b>Bukit Ringgis II - CP</b>							
A1	0-4	1120	24.7	1.8	13.7	4.99	3.89
A2	4-20		28.5	2.1	13.6	4.73	3.86
B	20-30		10.5	0.8	13.1	4.78	3.89
<b>Bukit Ringgis II - CL</b>							
Ap	0-20	1100	23.4	1.9	12.3	4.41	3.87
B	20-30		9.6	0.8	12.0	4.42	3.80

**Abbreviations:**

PF: primary forest, SF: secondary forest, CP: coffee plantation, CL: cultivated land

secondary forest > coffee plantation > crop land in Bukit Ringgis and Sekincau. This suggested that the soil organic matter with wide C/N ratio originating from forest litter is decomposed and the proportion of soil organic matter with low C/N, such as microbial products increased. In Tri Mulya and Tri Budi Syukur, the C/N ratio were low and relatively constant among different land uses, suggesting that organic matter was already well decomposed in the primary forest soil.

## 2) Humus composition:

In the preceding paper, Watanabe et al. (1999) analyzed the humus composition of three series of soils in south Sumatra, which are used also in this study. They extracted humic fractions with 0.1 M NaOH at room temperature. Fulvic acid fraction were fractionated on PVP into adsorbed and non-adsorbed fractions and their pH difference spectra were investigated. In this paper, we carried out the analysis of humus composition according to the method of Kumada et al. (1967), in which free form and combined form humic fractions were extracted successively. Extraction was also carried out at heated condition on a steam bath. This method is very simple and reproducible, and the recovery ratio of humic fraction is very high. Though extraction with alkali at elevated temperature is often criticized, under very carefully controlled procedure of this method, the effect on the spectroscopic characteristic of humic acid is negligible. By successive extraction, furthermore, we can determine the humus in different forms. Humus extractable with 0.1 M NaOH is considered to be free form humus which is very weakly combined with mineral constituents in soils, while that extractable with 0.1 M  $\text{Na}_4\text{P}_2\text{O}_7$  is the humus combined with polyvalent cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{Fe}^{3+}$ ) in soil.

Table 2 shows the result of successive extraction of humic components from the soils of hilly area under different land uses.

Total amount of the extractable humus decreased almost in the order of primary forest > secondary forest > coffee plantation > crop land, though a few exceptions were observed in the order between secondary forest, coffee plantation and crop lands. The trend of decrease was more remarkable in the amount of humic acid fraction than in the fulvic acid fraction. Among the primary forest sites, the sites at higher altitude (Bukit Ringgis and Sekincau) were characterized by extremely larger amounts of extractable humus than the sites with lower altitude (Tri Mulya, Pura Mekar, and Tri Budi Syukur). In these primary forest sites with higher altitude, the amount of free form humic acid exceeded that of free form fulvic acid. In other sites or under different land uses, the amount of free form humic acid was almost equal to or less than the amount of fulvic acids. The percentage of humic acid in the free form humus, which is designated by  $\text{PQ}_1$ , as well as the ratio of humic acid carbon over fulvic acid carbon ( $\text{Ch/Cf}_1$ ), decreased in the order of primary forest > secondary forest > coffee plantation > crop land. Large amount of humus in primary forests especially at higher altitude may be formed under very restricted conditions, which are dense vegetation and large supply of forest litter, sufficient soil moisture, and shaded sun light. By the disturbance of such conditions by cutting off trees, burning and cultivation, the decomposition of soil humus was accelerated and the proportion of fulvic acid increased in the extractable humus.

The relative color intensity of free form humic acids ( $\text{RF}_1$ ) was also slightly higher in the soils of primary and secondary forest soils especially at high altitude (Bukit Ringgis and

Table 2. Humus composition of the red acid soils under different land use in the hilly area of South Sumatra region.

	Ch <sub>1</sub>	Cf <sub>1</sub>	PQ <sub>1</sub>	RF <sub>1</sub>	ΔlogK <sub>1</sub>	Type <sub>1</sub>	Ch <sub>2</sub>	Cf <sub>2</sub>	PQ <sub>2</sub>	RF <sub>2</sub>	ΔlogK <sub>2</sub>	Type <sub>2</sub>	(Ch/Cf) <sub>1</sub>	(Ch/Cf) <sub>2</sub>	fHumus	H <sub>ε</sub>	H <sub>T</sub>	
	gC kg <sup>-1</sup>		(%)				gC kg <sup>-1</sup>		(%)						(%)	gC kg <sup>-1</sup>		
<b>Bukit Ringgis</b>																		
PF	52.6	39.5	57	42	0.825	B±	2.6	3.0	46	49	0.687	B	1.33	0.87	94	98	179	
SF	9.2	9.0	51	53	0.701	B±	1.3	1.2	52	79	0.585	B+	1.02	1.08	88	21	50	
CP	4.3	10.1	30	50	0.683	B+	0.6	1.3	32	88	0.555	A+	0.43	0.46	88	16	36	
CL	3.9	8.4	32	35	0.772	Rp+	0.5	1.1	31	68	0.610	B++	0.46	0.45	88	14	30	
<b>Sekinceau</b>																		
PF	62.8	45.0	58	52	0.721	B+	2.0	2.8	42	56	0.559	P+	1.40	0.71	96	113	188	
SF	12.6	26.2	32	48	0.690	B++	1.5	2.7	36	57	0.610	P+	0.48	0.56	90	43	86	
CP	17.1	26.7	39	38	0.733	Rp++	2.0	3.2	38	44	0.577	P±	0.64	0.63	89	49	84	
CL	4.4	11.8	27	34	0.755	Rp+	0.9	2.1	30	54	0.602	P±	0.37	0.43	84	19	38	
<b>Tri Mulya</b>																		
PF	18.3	18.2	50	29	0.883	Rp	4.1	4.0	51	45	0.741	B	1.01	1.03	82	45	79	
SF	7.4	9.9	43	28	0.843	RP±	1.6	1.9	46	52	0.647	B++	0.75	0.84	83	21	43	
CP	4.1	9.0	31	37	0.748	Rp+	0.8	1.4	36	58	0.620	B++	0.46	0.57	86	15	29	
CL	3.7	8.8	30	36	0.795	Rp+	0.9	1.4	39	63	0.619	B++	0.42	0.64	84	15	29	
<b>Pura Mekar</b>																		
PF	7.9	7.9	50	35	0.744	Rp+	1.0	0.9	53	56	0.633	B++	1.00	1.11	89	18	38	
SF	6.5	9.5	41	33	0.719	Rp+	0.8	0.8	50	53	0.641	B++	0.68	1.00	91	18	37	
CP	3.8	9.5	29	43	0.772	B+	0.8	1.4	36	64	0.687	B++	0.40	0.57	86	16	34	
CL	5.9	7.8	43	52	0.682	B+	0.6	0.6	50	79	0.571	B++	0.76	1.00	92	15	31	
<b>Tri Budi Syukur</b>																		
SF	9.3	11.6	44	30	0.859	Rp±	2.4	2.1	53	49	0.760	B+	0.80	1.14	82	25	52	
CP	4.6	10.5	30	32	0.807	Rp±	0.9	2.5	26	60	0.617	B++	0.44	0.36	82	19	35	
CL	2.9	7.1	29	30	0.846	Rp±	0.3	0.5	38	56	0.681	B++	0.41	0.60	93	11	23	
<b>Bukit Ringgis II - PF</b>																		
A	27.9	27.6	50	34	0.708	Rp+	0.8	0.3	73	46	0.589	P	1.01	2.67	98	57	109	
B	3.7	9.8	27	28	0.614	P+	0.2	0.7	22	68	0.520	P+	0.38	0.29	94	14	33	
<b>Bukit Ringgis II - SF</b>																		
A/B	6.0	11.1	35	34	0.704	Rp+	0.4	0.5	44	58	0.599	P+	0.54	0.80	95	18	38	
B	1.4	6.3	18	33	0.724	Rp+	0.4	0.6	40	52	0.521	P+	0.22	0.67	89	9	19	
<b>Bukit Ringgis II - CP</b>																		
A1	3.3	7.3	31	40	0.739	B++	0.5	0.8	38	60	0.617	B++	0.45	0.63	89	12	25	
A2	3.5	9.0	28	46	0.728	B++	0.4	0.8	33	73	0.605	B++	0.39	0.50	91	14	29	
B	0.2	4.2	5	38	0.840	Rp++	0.1	0.8	11	51	0.596	P±	0.05	0.13	83	5	11	
<b>Bukit Ringgis II - CL</b>																		
Ap	3.1	7.4	30	31	0.779	Rp++	0.4	0.7	36	69	0.588	B++	0.42	0.57	91	12	23	
B	0.3	4.1	7	44	0.710	B++	0.1	0.5	17	69	0.556	B++	0.07	0.20	88	5	10	

Abbreviations:

PF: primary forest, SF: secondary forest, CP: coffee plantation, CL: cultivated land

Subscript 1 denotes the fraction extracted by 0.1 M NaOH, while subscript 2 denotes the fraction extracted by 0.1 M Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub>.

Ch: humic acid C / kg dry soil, Cf: fulvic acid C / kg dry soil

PQ: precipitation quotient,  $[\text{Ch}/(\text{Ch}+\text{Cf}) \times 100]$  (%)

RF:  $(\text{K}_{600}/\text{C}) \times 15$ , where K<sub>600</sub> is the absorbance at 600nm and C is the humic acid C (mg) in 1 ml humic acid solution.

ΔlogK:  $\log K_{400} - \log K_{600}$ , where K is the absorbance at 400 or 600 nm.

Ch/Cf: the ratio of humic acid C to fulvic acid C

fHumus: proportion of free form humus,  $[(\text{Ch}_1 + \text{Cf}_1) / \text{H}_\epsilon] \times 100\%$

H<sub>ε</sub>: total extractable humic carbon,  $\text{Ch}_1 + \text{Cf}_1 + \text{Ch}_2 + \text{Cf}_2$

H<sub>T</sub>: total humus carbon determined by CN analyzer.

Sekincau).

The inclination of the absorption curve in the visible range ( $\Delta\log K_1$ ) was almost same and did not show a consistent relationship to different land uses among different soils.

The types of free form humic acid were B type in these forest soils as well as in the soils of coffee plantation in Bukit Ringgis. In other villages, the types of free form humic acid were mostly Rp type, except in the coffee plantation and crop land of Pra Mekar. A slight ( $\pm$ ) to considerable ( $++$ ) contribution of Pg absorption was recognized in almost all of free form humic acids.

The percentage of free form humus as shown by 'fHumus' was remarkably high (82 - 96%) in all soils in the hilly area. This percentage was also higher in primary and secondary forest soils and slightly lower in the soils of coffee plantation and crop land. The tendency in the combined form humus was reverse to this. The amount of combined form humus was also largest in the primary forest, and decreased almost in the order of secondary forest > coffee plantation > crop land, with a few exceptions. However, the trend of decrease was not so remarkable as in the amount of free form humus.

As shown by  $PQ_2$  and  $(Ch/Cf)_2$ , fulvic acid predominated also in the combined form humus, though percentage of humic acid was slightly higher in the primary and secondary forest soils.

The color intensity of the combined form humic acid ( $RF_2$ ) was slightly higher than  $RF_1$ . The inclination of the absorption curve ( $\Delta\log K_2$ ) was also slightly lower than  $\Delta\log K_1$  in almost all soils, which indicated that combined form humic acids were characterized by higher degree of humification than the free form humic acids. The types of combined form humic acids were almost B type except in Sekincau village, in which combined form humic acid all belonged to P type under all land uses. The combined form humic acid in the soil of coffee plantation at Bukit Ringgis which belonged to A type was another exception. The contribution of Pg absorption was more prominent in the combined form humic acids.

For the formation of highly integrated structure of humic acids with high degree of humification, appropriate conditions, such as sufficient supply of organic debris, not so oxidative soil condition, and sufficient amount of basic minerals, may be necessary. Therefore, humic acid in combined forms with high degree of humification are considered to be formed under the past soil environment when forest vegetation still remained and basic minerals were more abundant in soil. Because the combined form humic acids are more stable component than the free form humic acids, they still remained under the more disturbed land uses such as coffee plantation and crop lands.

Table 3 shows the humus composition of a series of soils under different land uses at Bukit Ringgis village. Soil samples were collected at almost the same sites as those shown in Table 2 but on the different dates. Soil samples were collected also layer-wise. Tendency in the amounts of humic and fulvic acids were almost the same as those shown in Table 2. However, the types of free form humic acids in primary and secondary forest soils (A and A/B layers) were Rp type in Table 3 due to the lower  $RF_1$  values, but they were B type in Table 2. The types of combined form humic acids in the primary forest, secondary forest and coffee plantation were P, P+, and B++ in Table 3, while they were B, B+, A in Table 2, respectively. These differences may reflect the heterogeneity of the humus in the A layer of forest soils. The amount of humus in the B layer was very low, in which the percentage of



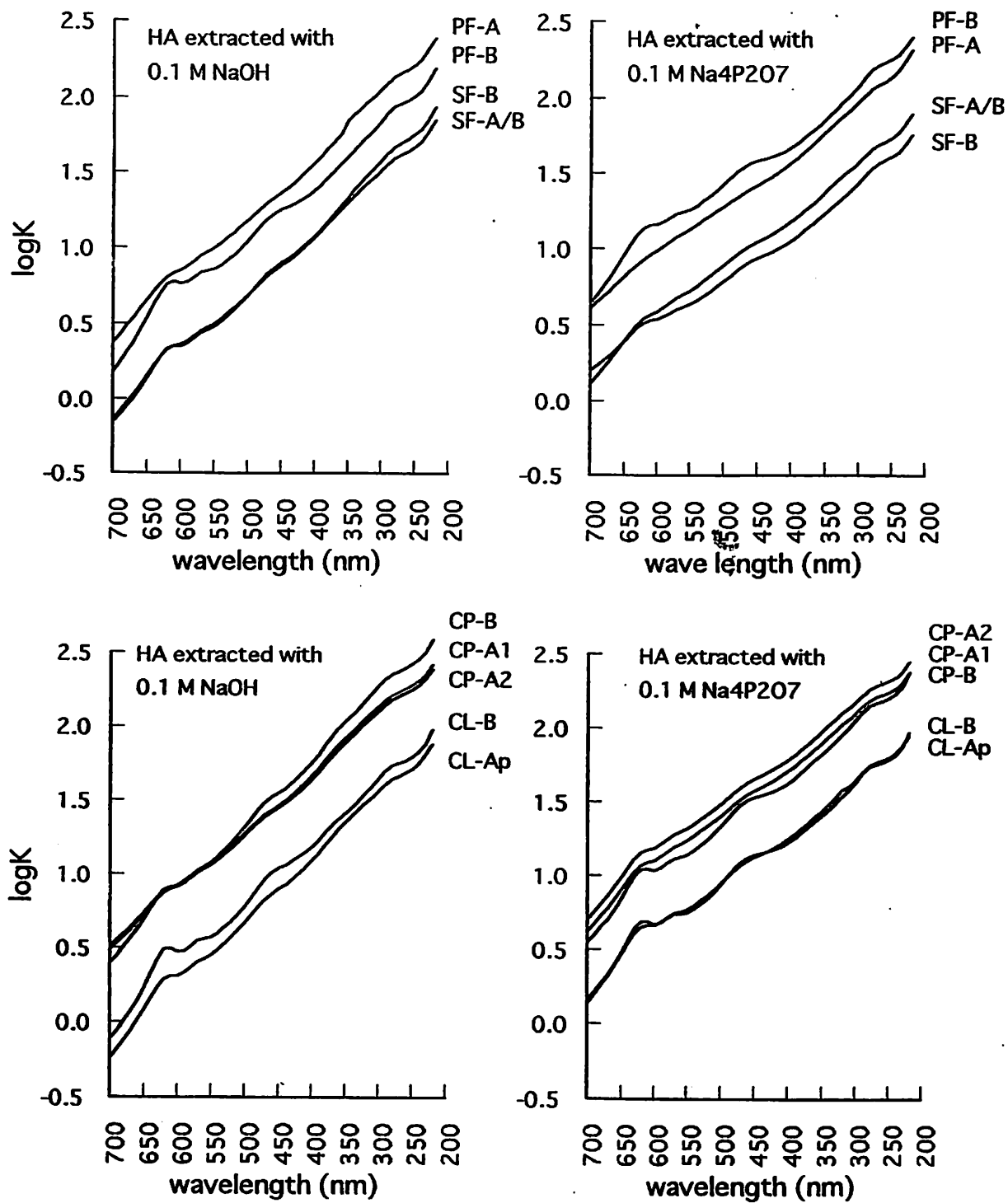


Fig. 1. Absorption spectra of free and combined form humic acids extracted from different layers of soils under primary forest (PF), secondary forest (SF), coffee plantation (CP), and crop land (CL) in Bukit Ringgis II.

fulvic acid predominated as shown by  $PQ_1$  and  $PQ_2$ .

Fig 1 shows the absorption spectra of humic acids extracted from the soils under different land use at Bukit Ringgis village. The contribution of Pg in the absorption spectra of humic acids tended to be intensified in the soils of coffee plantations and crop lands compared with those in the primary forests. It was also intensified in the humic acids of B layer soils than that of A layer soils. Combined form humic acid also showed a more intensified Pg absorption than the free form humic acids. Pg pigment, whose core is 4,9-dihydroxy-perylene-3,10-quinone, is a constituent of the sclerotia produced by a fungi, *Cenococcum ganiforme*, which forms ectotrophic and ectendotrophic association with unusually large number of tree, shrub, and herbaceous genera (Kumada 1987). Though it may be produced most abundantly under the vegetation of primary forest, its specific absorbance is masked by that of other humic substances in the soil of primary forest. However, because it is hardly decomposed compared with other constituents in humic acids, this pigment is concentrated in the humic acid fraction, as the decomposition of soil organic matter proceeds under the disturbed soil conditions.

### 3) Saccharide composition

Saccharides in the soil may be explained as the constituents of plant residues (cellulose and hemi-cellulose) which undergo degradation, the microbial cell constituents which are formed in soils, as well as those combined with humic constituents. Although it is considered to belong to non-humic substances in soil, some fraction of saccharides is very stable (Cheshire 1979, Murayama 1981). Therefore, saccharides are indispensable part of soil organic matter.

Fig 2 shows the total amount of soil saccharides in the soils of hilly area as a sum of non-cellulosic and cellulosic saccharides. The total amount of soil saccharides showed a similar tendency as total soil carbon. Non-cellulosic saccharide occupied 60 - 90 % of the total soil saccharide, and the rest was cellulosic saccharide. The percentage of cellulosic saccharide tended to be high in primary forest soils. This was considered to be due to the large supply of woody material into soil.

The composition of each saccharide in the non-cellulosic saccharide fraction was shown in Fig 3. Percentages of glucose and galactose were relatively unchanged among different land uses and among different villages. The percentage of mannose showed a larger fluctuation. It was larger in the secondary forest and coffee plantation soils than in primary forest soils. The origin of each saccharide in soil is very complicated. Though three hexoses (glucose, galactose, and mannose) are contained in both plants and microbes, the saccharides newly synthesized in the soil was composed mainly of glucose, mannose, and galactose according to Murayama (1988). Small proportion of rhamnose and fucose were also contained in the microbial saccharides. Arabinose and xylose were negligible or in trace amounts in the microbial saccharides. Therefore, the increase in the proportion of mannose suggests that organic matter in secondary forest and coffee plantation was more decomposed. On the other hand, the percentages of xylose and arabinose as well as the sum of them tended to be larger in the soils of primary forest soils, reflecting the large input of plant residue into the soil.

Saccharide composition of the soils of different layers under different land uses in the Bukit Ringgis village is also shown in Fig 3 (lower). The soils of primary forest collected on

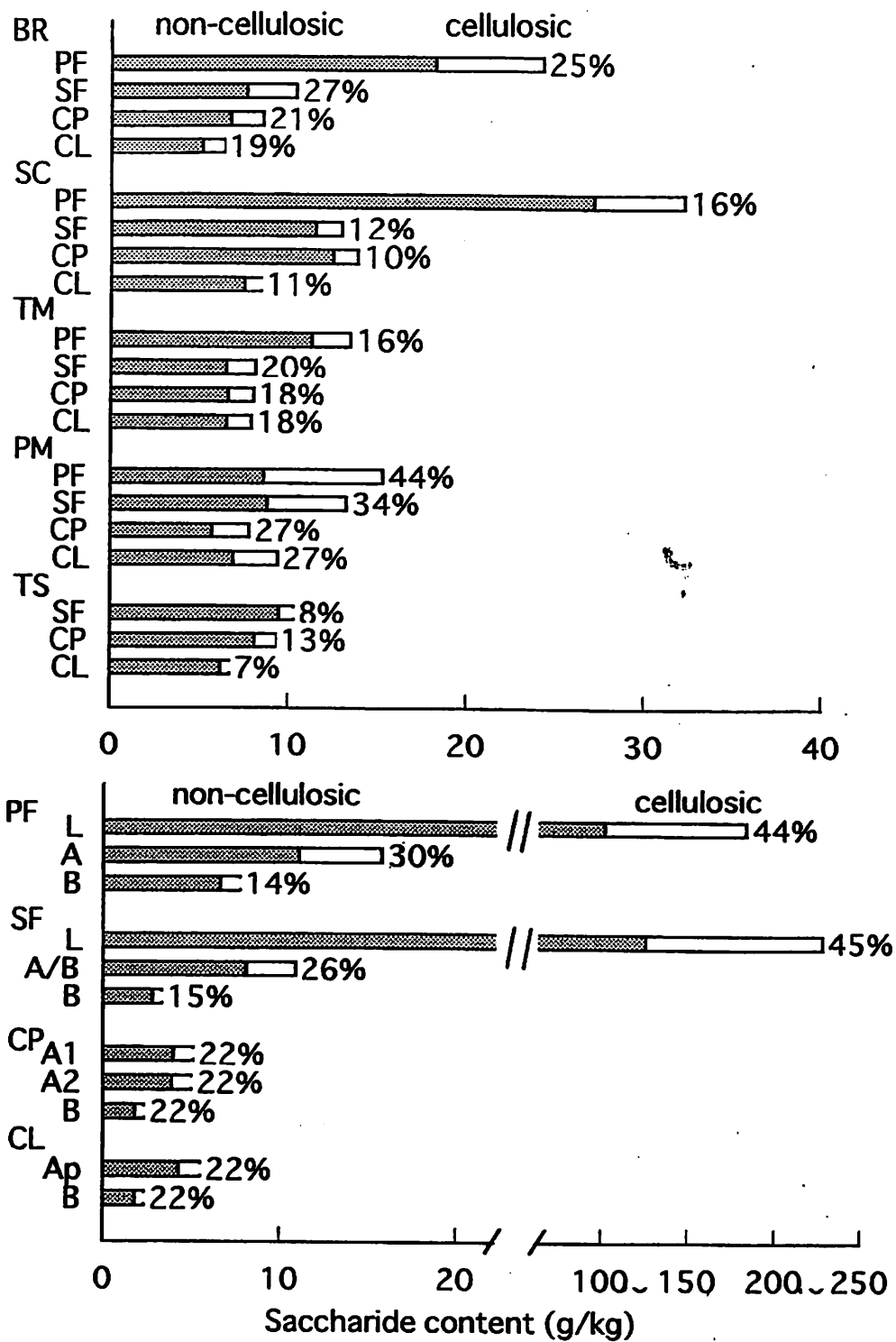
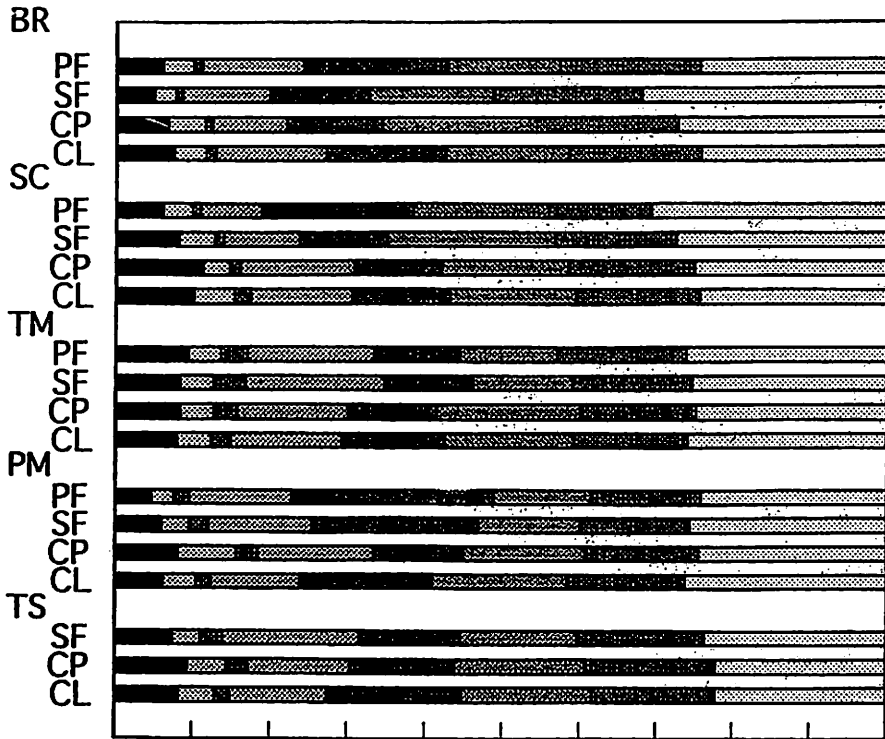


Fig. 2. Saccharide contents in the hilly area soils ( $\text{g kg}^{-1}$ ) and the percentage cellulose saccharide in total saccharide under different land use in five different locations (upper figure), and in different soil layers under different land uses at Bukit Ringgis (lower figure). PF: primary forest, SF: secondary forest, CP: coffee plantation, CL: crop land.



**Bukit Ringgis II**

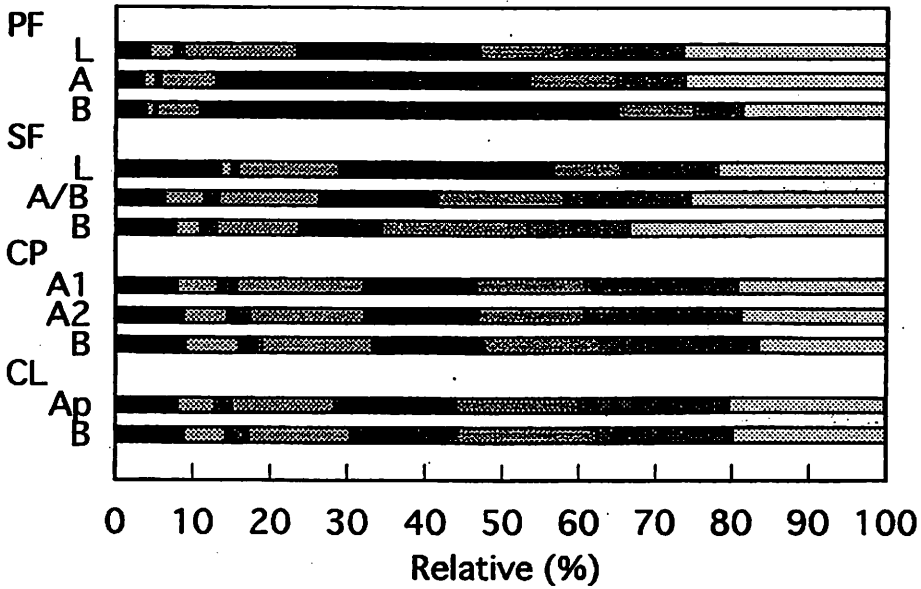


Fig 3. Composition of non-cellulosic saccharide in the hilly area soils under different land use in five different locations (upper figure), and in different soil layers under different land uses at Bukit Ringgis (lower figure). PF: primary forest, SF: secondary forest, CP: coffee plantation, CL: crop land.

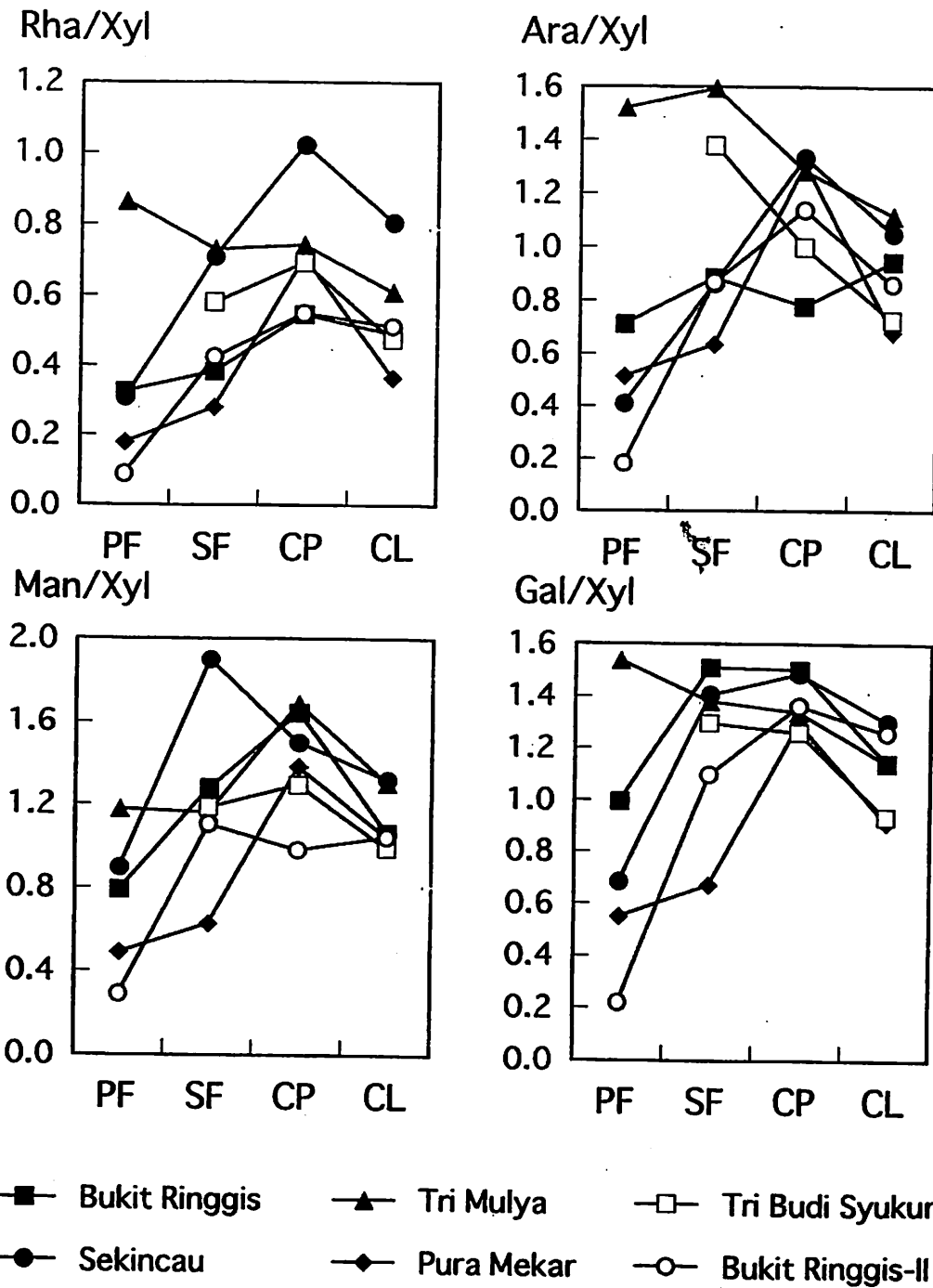


Fig. 4. Ratio of rhamnose, arabinose, mannose, and galactose over xylose in the non-cellulosic saccharide in the hilly area soils under different land use in five different locations. (Bukit Ringgis soils were collected twice in different years.)

this occasion contained a much larger proportion of xylose than the primary forest soil of Bukit Ringgis collected on another date (Fig 3, upper). This suggests the heterogeneity of the soils of primary forest, where supplied amount of organic residue may differ from site to site. Under other land uses in Fig 3 (lower), the percentages of xylose decreased and those of rhamnose, fucose, ribose, arabinose, mannose and galactose increased. The composition of saccharides were almost similar among secondary forest, coffee plantation, and crop land as far as mineral soil layers were concerned. This suggested that the most remarkable change in saccharide composition occurs after the clearance of the primary forest, and almost similar saccharide composition was established in the soils disturbed by human activity.

The change in saccharide composition in the non-cellulosic fraction was also shown by the ratio of monosaccharides in the hydrolysate (Fig 4). The ratios of four saccharides, rhamnose, arabinose, mannose and galactose to xylose were compared among the soils of primary forest, secondary forest, coffee plantation, and crop land. The tendency between the different land uses were similar among different villages. These ratios were all lowest in the primary forest, and increased in the order of secondary forest to coffee plantation, then decreased again in the crop land. The exception was the Tri Mulya village, in which the ratios were also high in the primary forest soil. Also in the amount of free form humus, very little difference was observed between primary forest and secondary forest in Tri Mulya. This may suggest that soil organic matter in the primary forest of Tri Mulya is more decomposed than the primary forest soils in the other villages. The lower altitude and the higher soil pH of this site compared with other primary forest site may have promoted the decomposition of soil organic matter.

The increase in the proportions of rhamnose, mannose and galactose over xylose suggests the increase in the contribution of microbial products in the soil organic matter. In this study, the arabinose / xylose ratio showed a similar tendency with other ratios, though the origin of arabinose is supposed to be mainly plant material. Therefore, the source of arabinose may be different from that of xylose in these soils. These ratios became maximum in coffee plantation or secondary forest and became lower again in the crop land. In the crop land, the amounts of saccharides were as low as those in the coffee plantation soils, suggesting that soil saccharides are decomposed remarkably under both in the coffee plantation and in the crop land. The reason for the difference in the sugar ratios may be related to the presence or absence of tree vegetation, but the mechanism is not clarified yet.

#### 4) Composition of phenolic compounds derived by CuO-NaOH oxidation

CuO-NaOH oxidation is a mild oxidative degradation method which can yield specific phenolic compounds from the surface of lignin molecule (Hedges and Ertel 1982). As the composition of phenolic compounds contained in a lignin molecule differs by plant species, it can serve as a tool to deduce the origin of the very altered organic matter in the environment which may have its origin in lignin structure.

Among the phenolic compounds, p-hydroxy phenyl compounds are not specific to lignin structure and have wider origin in the polyphenols produced by a wide range of plant kingdom including all kinds of trees and grasses, ferns, mosses and lichens. Vanillyl compounds are contained in all types of lignin produced by gymnosperm and angiosperm woods. Syringyl compounds are not found in gymnosperm lignin, and found only in

Table 3. Amount of phenolic compounds obtained by CuO-NaOH oxidation of soils (mg kg<sup>-1</sup>).

	pHBaC	pHBAI	pHAcP	VaAc	VnIn	AcVn	SyAc	SyAl	AcS	pCmAc	FerAc	SinAc	total	VSC
<b>Bukit Ringgis</b>														
PF	88	45	10	201	0	33	147	0	41	106	178	0	849	706
SF	37	11	5	53	7	10	41	0	16	43	75	0	298	245
CP	19	26	2	33	0	4	18	0	5	21	19	0	147	100
CL	19	22	2	29	0	4	17	0	5	18	16	0	132	89
<b>Sekincau</b>														
PF	837	93	0	491	0	53	273	0	64	104	220	0	2135	1205
SF	50	39	8	97	10	10	44	0	12	50	65	0	385	288
CP	36	31	0	169	0	28	75	0	20	44	62	0	465	398
CL	12	27	0	32	0	4	18	7	7	15	16	0	138	99
<b>Tri Mulya</b>														
PF	186	40	16	47	0	6	38	0	16	18	16	0	383	141
SF	35	29	0	43	0	8	24	0	8	17	10	0	174	110
CP	11	22	0	24	0	4	21	0	5	12	12	0	111	78
CL	14	18	1	25	0	5	19	0	10	15	14	0	121	88
<b>Pura Mekar</b>														
PF	51	20	4	66	8	13	54	4	21	118	72	0	431	356
SF	28	22	5	50	0	10	37	0	17	85	59	0	313	258
CP	14	23	0	21	0	3	18	0	6	7	9	0	101	64
CL	17	19	3	30	0	5	16	0	10	38	29	0	167	128
<b>Tri Budi Syukur</b>														
SF	38	29	7	47	0	9	40	0	14	43	35	0	262	188
CP	18	25	2	32	0	4	18	0	8	15	20	0	142	97
CL	13	11	0	24	0	0	24	0	11	28	22	0	133	109
<b>Bukit Ringgis II - PF</b>														
L	595	89	58	528	87	153	329	0	124	346	552	0	2861	2119
A	100	78	0	171	0	17	88	0	0	88	130	0	672	494
B	14	24	0	25	0	4	13	0	0	26	26	0	132	94
<b>Bukit Ringgis II - SF</b>														
L	1043	172	364	309	0	121	300	0	122	668	355	0	3454	1875
A/B	39	35	4	42	0	0	18	0	0	25	25	0	188	110
B	10	22	0	15	0	0	8	0	0	4	5	0	64	32
<b>Bukit Ringgis II - CP</b>														
A1	6	12	0	15	0	0	8	0	0	8	6	0	55	37
A2	9	23	0	21	0	0	9	0	40	14	10	0	126	94
<b>Bukit Ringgis II - CL</b>														
Ap	12	14	0	22	0	7	10	0	0	11	12	0	88	62

Abbreviations:

pHBaC: p-OH benzoic acid, pHBAI: p-OH benzaldehyde, pHAcP: p-OH acetophenone, VaAc: vanillic acid, VnIn: vanillin, AcVn: acetovanillone, SyAc: syringic acid, SyAl: syringaldehyde, AcS: acetosyringone, pCmAc: p-coumaric acid, FerAc: ferulic acid, SinAc: sinapic acid, total: total phenolic compounds, VSC: sum of vanillic, syringic, and cinnamyl compounds.

angiosperm woody and non-woody tissues. Cinnamyl compounds are found in non-woody tissue of angiosperm plants. Especially lignin of grasses contain a large amount of p-coumaric acid, the most abundant cinnamyl compound.

Table 3 shows the amounts of phenolic compounds obtained from each soils. Absolute amounts of phenolic compounds were always largest in the soils of primary forest soils. Phenolic acids predominated among phenolic compounds. Among phenolic aldehydes, only p-OH benzaldehyde was detected in considerable amounts, while the amounts of vanillin and syringaldehyde were very low. Phenolic ketons (p-OH acetophenone, acetovanillone, acetosyringone) were also minor constituents. This suggested that the lignin structure was in highly oxidized state in these soils. The most abundant phenolic compound was p-OH benzoic acid or vanillic acid. The amount of syringic acid was about two thirds of vanillic acid. Among cinnamyl compounds, either p-coumaric acid or ferulic acid was more abundant depending on soils. Ferulic acid was more abundant in the primary and secondary forest soils of Bukit Ringgis and Sekincau village. This may be the specific feature of forest litter. Sinapic acid was not detected in all soils.

#### 5) Distribution of carbon among soil organic constituents.

Table 4 shows the percentage of carbon explained by extractable humic fractions, saccharides, and phenolic compounds in the total carbon of soils.

Extractable humic fractions explained 32 - 60 % of total carbon. In the soils of primary forests, free form humic acids occupied the largest proportion of carbon (20 - 33 %). In the soils of coffee plantation and crop land, the proportion of free form humic acid decreased considerably, and that of free form fulvic acid increased. In the soils of B layers, the proportion of free form humic acid was much lower and the proportion of free form fulvic acid was much larger than those in the soils of A layers under different land use in Bukit Ringgis II soil.

Soil saccharide explained 5 - 16 % of soil carbon. The proportion of non-cellulosic saccharide in coffee plantation and crop land was slightly larger than that in primary forest and secondary forest in Bukit Ringgis, Sekincau, and Tri Mulya soils. This tendency conforms to the increase in free form fulvic acid fraction in these soils. The proportion of cellulosic saccharide did not show a consistent relationship with land use. The considerably little difference in the proportion of saccharide carbon may be because some saccharides are newly formed in soils in accordance with the decomposition of soil organic matter.

These very low percentages (0.2 - 1.1 % of total carbon) do not necessarily mean that the total lignin content were low in the soils, because CuO-NaOH oxidation is a very mild procedure and degrades only the surface of lignin molecule. The proportion of phenolic compounds was highest in the primary forest soils with one exception in Bukit Ringgis soil. However, in Bukit Ringgis II soil it was largest in the primary forest soil.

In the soils of secondary forest, coffee plantation and crop lands, percentages of the carbon in phenolic compounds to the total carbon were lower than that in primary forest and did not fluctuate so much. These tendency suggested that lignin structure in tropical soils are readily decomposed, and that most significant change in the lignin constituents occurred just after the clearance of forest. Among the phenolic compounds, the fluctuation in the amounts of cinnamyl compounds and p-hydroxyphenyl compounds was larger than those of vanillyl and syringyl compounds. This may be because cinnamyl and p-



Table 4. Distribution of carbon in humic fractions, saccharides, and phenolic compounds in total soil carbon (mg g<sup>-1</sup>).

	Humus-C/total-C					Saccharide-C/total-C			phenolic/total-C				
	HA <sub>1</sub>	FA <sub>1</sub>	HA <sub>2</sub>	FA <sub>2</sub>	total	Non cel.	Cel.	total	V	S	C	H	total
<b>Bukit Ringgis</b>													
PF	294	221	15	17	546	41.0	13.4	54.4	1.31	1.05	1.58	0.80	4.74
SF	184	180	26	24	414	61.6	22.5	84.1	1.41	1.15	2.38	1.07	6.02
CP	119	281	17	36	453	76.1	19.8	95.9	1.04	0.65	1.12	1.32	4.13
CL	130	280	17	37	463	68.3	15.3	83.6	1.10	0.73	1.13	1.43	4.39
<b>Sekincau</b>													
PF	334	239	11	15	599	58.0	10.9	68.9	2.89	1.79	1.72	4.93	11.33
SF	147	305	17	31	500	57.3	7.3	64.6	1.44	0.69	1.41	1.19	4.72
CP	204	318	24	38	583	60.1	6.4	66.5	2.34	1.13	1.26	0.80	5.52
CL	116	311	24	55	505	80.3	9.5	89.8	0.95	0.85	0.82	1.03	3.66
<b>Tri Mulya</b>													
PF	232	230	52	51	565	58.4	11.2	69.7	0.68	0.69	0.43	3.08	4.88
SF	172	230	37	44	484	61.4	14.7	76.2	1.18	0.74	0.63	1.48	4.04
CP	141	310	28	48	528	92.1	19.4	111.5	0.96	0.89	0.82	1.13	3.81
CL	128	303	31	48	510	90.4	19.0	109.4	1.02	0.99	0.99	1.13	4.13
<b>Pura Mekar</b>													
PF	208	208	26	24	466	91.4	70.9	162.3	2.31	2.10	5.04	1.99	11.43
SF	176	257	22	22	476	96.5	48.5	145.0	1.62	1.46	3.89	1.49	8.46
CP	112	279	24	41	456	68.2	24.8	93.0	0.71	0.71	0.47	1.10	3.00
CL	190	252	19	19	481	92.0	32.3	124.3	1.15	0.85	2.20	1.28	5.48
<b>Tri Budi Syukur</b>													
SF	179	223	46	40	488	74.2	6.4	80.6	1.08	1.04	1.51	1.43	5.07
CP	131	298	26	71	526	93.3	14.0	107.4	1.02	0.74	0.99	1.28	4.03
CL	127	311	13	22	474	110.3	8.5	118.8	1.05	1.54	2.19	1.05	5.83
<b>Bukit Ringgis II - PF</b>													
A	256	253	7	3	519	40.9	17.9	58.8	1.72	0.81	2.00	1.63	6.17
B	112	297	6	21	436	81.0	14.4	95.4	0.88	0.40	1.59	1.16	4.02
<b>Bukit Ringgis II - SF</b>													
A/B	158	292	11	13	474	87.5	31.3	118.8	1.12	0.48	1.33	2.08	5.01
B	74	332	21	32	458	58.8	11.3	70.1	0.77	0.41	0.46	1.65	3.30
<b>Bukit Ringgis II - CP</b>													
A1	134	296	20	32	482	65.5	18.3	83.7	0.61	0.32	0.57	0.73	2.23
A2	123	316	14	28	481	55.1	16.2	71.3	0.74	1.72	0.84	1.12	4.42
B	19	400	10	76	505	67.7	20.7	88.4					
<b>Bukit Ringgis II - CL</b>													
Ap	132	316	17	30	496	73.6	20.8	94.3	1.24	0.43	0.98	1.11	3.76
B	31	427	10	52	521	76.5	23.7	100.2					

**Abbreviation:**HA<sub>1</sub>, FA<sub>1</sub>: humic acid and fulvic acid extracted with 0.1 M NaOH.HA<sub>2</sub>, FA<sub>2</sub>: humic acid and fulvic acid extracted with 0.1 M Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub>.

Non cel.: Non-cellulosic saccharides, Cel.: Cellulosic saccharides,

V: vanillyl phenolic compounds, S: syringyl phenolic compounds,

C: cinnamyl phenolic compounds, H: p-hydroxy phenolic compounds

hydroxyphenyl compounds are contained in more readily decomposable non-woody tissues as well as in polyphenols other than lignin. Both in Tables 3 and 4, it was found that amount of cinnamyl phenols were very low in the soils of coffee plantation at all locations. This may be because the input of non woody lignin is very little in the coffee plantations where weeds are very well controlled.

#### 6) Effect of land use on the soil organic matter composition

Considerable difference was observed in the organic matter composition of the soils under different land use as described above. The sites under different land use selected for this study were located at different altitudes. It was inevitable to select these sites, because representative land use for primary forests and secondary forests could be found only at very elevated altitudes. The altitude may also have effects on soil organic matter through the difference in soil temperature and moisture. The sites were located also considerably apart, though they were aligned on the same slope. Therefore, mineralogy of the soils may be different. The primary forest and secondary forest were all located on very steep slopes and coffee plantation and crop lands were on undulated landscape. The erosion of soil may be very severe under such circumstances. Therefore, not only the decomposition but also the loss by erosion of soil organic matter should be taken into account. Burning is also another cause of soil organic matter change because slash and burn is the usual procedure for turning forest to crop lands or plantations in this area. From these facts, it may be concluded that difference in soil organic matter composition was caused synthetically by various factors including the difference in land use.

However, it should be clarified how far the difference is explained by the factor of land use. Noordwijk et al. (1997) analyzed statistically the data for 2800 soil profiles in Sumatra, and established the relationship between soil organic carbon content and various other factors including pH, texture, altitude, slope, land use, and soil types. According to them, the increase in pH, altitude, and slope all causes the decrease in soil organic matter content. Therefore, difference in carbon content between primary forest and coffee plantation or crop land may be become narrower by these factors. Texture (very rich in clay) and mineral constituents were almost similar among different land uses along the same slope (unpublished data by authors). Difference in soil organic matter according to the difference in land use should be considered larger than the actual difference which we can see at present state. Contributions due to the acceleration of soil organic matter, loss by erosion, and combustion by burning can not be estimated separately at present. Such factors which constitute land use effects need to be studied further.

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