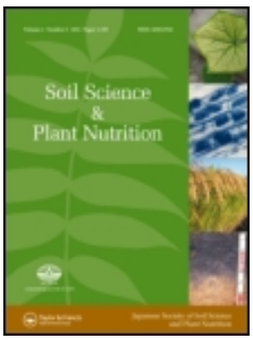

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Activities of Some Soil Enzymes in Different Land Use Systems after Deforestation in Hilly Areas of West Lampung, South Sumatra, Indonesia

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The activities of acid and alkaline phosphatases, β-glucosidase and urease were determined in soils under different land-use systems after deforestation in hilly areas of West Lampung, South Sumatra, Indonesia. Soil samples (topsoils, 0-20 cm and subsoils, 20-40 cm) were collected from 5 different locations, each consisting of 4 different land-use systems: i.e. primary forests, secondary forests, coffee plantations, and cultivated lands (upland fields and paddy fields). Enzyme analyses showed that the activities of phosphatases, β-glucosidase, and urease were significantly higher in most cases in the primary forests or in the secondary forests than in the other two land-use systems, indicating that clearing the forests and converting them to other land-use systems significantly disturbed the growth of enzyme-producing organisms. There was no significant difference in the enzymatic activities between cultivated upland fields and paddy fields. The activity of alkaline phosphatase showed the most drastic decrease after the conversion to the other land uses. Laboratory experiment showed that the optimum pH for phosphatases shifted to higher values due to the land-use conversion from the primary forests to the other land-use systems. Analysis of subsoils showed significantly lower enzymatic activities compared to those in the topsoils. The activities of all soil enzymes in the topsoil were closely related to the soil organic-C and total-N contents, indicating that these properties are important for maintaining the soil enzymatic activities. Based on the land use change from 1978 in the study area (27 km×27 km), the land conversion was estimated to have decreased the activities of the soil enzymes tested by 4-12% by 1984 and by 7-20% by 1990 in the uppermost 0-20 cm layers, and by 6-12% by 1984 and by 6-18% by 1990 in the next 20-40 cm layers from the levels in 1978, respectively.

Key Words: **deforestation, β-glucosidase, phosphatase, soil enzyme, urease.**

Deforestation in the tropical regions has long been considered to lead to the degradation of the soil properties related to soil fertility. Soil enzymatic activity is one of the important soil properties determining soil fertility that is considered to be greatly affected by forest clearing and its conversion to other land uses. However, data on the impact of deforestation on the soil enzymatic properties for tropical soils are not available.

Forest clearing and its conversion to other land uses change the soil microclimate, mainly the soil temperature and water regimes. This may result in a change of the activities of soil enzymes because the soil microclimate affects considerably the microbial communities and root development, the main enzyme producers in the soil system (Tate III 1987). In addition, because deforestation for opening arable lands may induce a reduction in soil fertility and populations of microbial flora and fauna of soils and may result in applications of N and P fertilizers, soil enzymes such as urease, phosphatases and β-glucosidase are expected to be seriously affected. Jha et al. (1992) reported that in north-eastern India the activities of some soil enzymes, including dehydrogenase, urease, and phosphatase, were higher in the less degraded than in the more degraded forest soils based on the differences in the fungal and bacterial population numbers between them.

Activities of soil enzymes have been reported to be well correlated with some soil properties including soil temperature, moisture contents, nutrient status, organic matter contents, and soil pH. Soil temperature may exert direct and/or an indirect effect on the soil enzymatic properties. Neal (1990) showed that the soil enzymatic activity decreased significantly in proportion to the decrease in the soil temperature. Dash et al. (1981) reported that the maximum urease activity occurred at 47°C among the soil temperatures ranging from 0 to 57°C. Moyo et al. (1989) also showed that the increase of the soil temperature from 5 to 45°C enhanced the urea hydrolysis rate in soils. It was also reported that the activity of acid phosphatase in soil samples stored under moist conditions was higher than that in soil samples stored under dry conditions (Baligar et al. 1988), suggesting the importance of water regimes for maintaining the soil enzymatic activities.

Application of P-fertilizers decreased the phosphatase activity in rhizosphere soils (Pang and Kolenko 1986; Fox and Comerford 1992). But, the total C, N, and P contents of soils showed significant and positive relationships with the activities of phosphatase, urease, and protease (Nannipieri et al. 1980; Frankenberger and Dick 1983; Baruah and Mishra 1984; Baligar et al. 1988).

Since organic matter is the source of substrates and energy for enzyme-producing microorganisms in soils, it is related to the soil enzymatic activities (Tate III 1984). The microbial and enzymatic activities in the O horizons (litter layers) were found to be 2 to 25 fold greater than those in the A horizons with a low content in organic matter (Tate III et al. 1991). Martens et al. (1992) showed that the enzymatic activities involved in the cycles of C, N, P, and S in soils amended with organic matter were significantly higher compared with those in the control soils. Klein and Koths (1980) also showed that the activities of soil enzymes, including urease and acid phosphatase, were higher in no-tillage soils than in tillage soils, all the enzymes being related to the higher organic matter and water contents in no-tillage soils.

Soil biochemists reported that soil enzymatic activities are considerably affected by the soil pH. Soil pH is particularly important for phosphatases, since it determines the magnitude of their activities and their types (Malcolm 1983; Rojo et al. 1990).

Forest clearing and its conversion to other land uses may change one or more of the above factors and, thereby, may affect the soil enzymatic properties. This report is intended to evaluate the changes in the activities of phosphatases (acid and alkaline phosphatases), β-glucosidase, and urease in some land use systems in deforested areas of West Lampung, South Sumatra, Indonesia.

MATERIALS AND METHODS

Soil samples. Soil samples were collected from 5 deforested locations (Bukit Ringgis, Sekincau, Tri Mulya, Tri Budi Syukur, and Pura Mekar) in West Lampung, South Sumatra, Indonesia (Fig. 1); each consisted of 4 different land-use systems, i.e. primary forests, secondary forests, coffee plantations, and cultivated lands. Soil types of primary forests and secondary forests of these locations were Dystropepts. Soil types of coffee plantations and cultivated lands were only identified at Bukit Ringgis as Kanhapludults. Primary forest of Tri Budi Syukur was dominated by family Ficus such as *Ficus septica, F. ampelas,* and *F. variegata,* and family Mevaceae (*Hibiscus* spp.). *Shorea* spp., *Hopea* spp., *Dipterocarpus* sp., and *Dryobalanops* spp. were also found at lower frequencies and densities. In the other locations, *Shorea* spp., *Hopea* spp., *Dipterocarpus* sp., and *Dryobalanops* spp. were the dominant vegetation in the primary forests. Secondary forests at all locations were dominated by *Ficus septica*, *F. ampelas*, and *F. variegata*, and family Mevaceae (*Hibiscus* spp.). In the cultivated lands tomato, beans, etc. had been grown at Bukit Ringgis, Sekincau, and Tri Mulya, and paddy rice at Tri Budi Syukur and Pura Mekar, respectively.

The changes in the land use pattern in this area from 1970 to 1990 were reported by Syam et al. (1997). For every land-use system at every location, the soil was sampled at two different depths, 0–20 cm (topsoil) and 20–40 cm (subsoil), after taking off the litter layer.

Analyses of soil enzymatic activities in soil and other soil properties. Enzymatic activities in the soil samples were determined for phosphatases (acid and alkaline

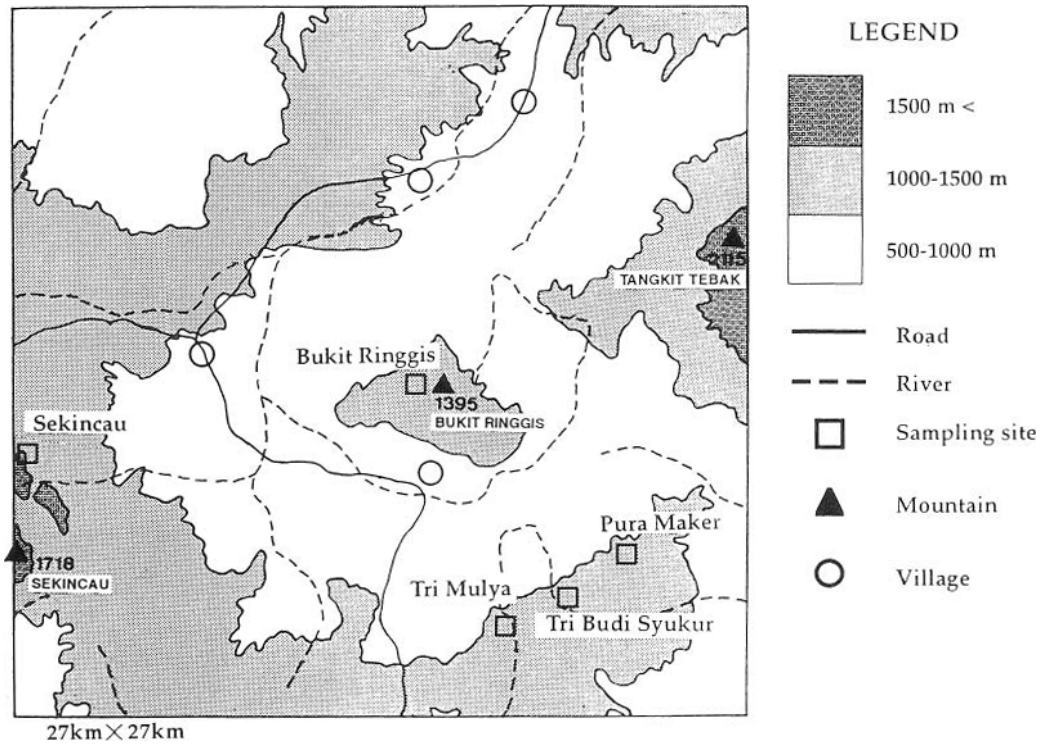

Fig. 1. Map of sampling sites (4°55′ S to 5°10′ S and 104°19′ E to 104°34′ E).

phosphatases), urease, and β-glucosidase. The analyses of phosphatase activities basically followed the method of Tabatabai and Bremner (1969). After stopping the soil microbial activities with toluene, 4 mL of a modified universal buffer (MUB), pH 6.5 (for acid phosphatase measurement) or pH 11 (for alkaline phosphatase measurement) and 1 mL of 0.025 M *p*-nitrophenyl phosphate (*p*-NPP) dissolved in MUB solution with the corresponding pH were added to 1 g of soil sample. The mixture was incubated for 1 h at 30°C. The enzymatic reaction was stopped by the addition of a NaOH solution, followed by the addition of a $CaCl_2$ solution to extract *p*-nitrophenol. The concentration of *p*-nitrophenol was determined with a Shimadzu UV-2200 UV-VIS Recording Spectrophotometer at 400 nm.

The activity of β-glucosidase was determined by the above method but *p*-nitrophenyl-β-D-glucopyranoside (*p*-NPG) was used as a substrate instead of *p*-NPP, and a MUB solution pH 6 was employed.

Urease activity was determined by measuring the amount of urea substrate remaining in the soil system after incubation (Tabatabai 1982). A 5 g (oven-dry equivalent) soil sample and 5 mL of a urea substrate solution (2 mg urea per ml) were incubated at 30°C. The microbial and enzymatic reactions were stopped after a 5 h incubation with the addition of KCl and phenylmercuric acetate solution (PMA). Potassium chloride solution was employed for urea extraction. The amount of remaining urea in the extract was determined after development of a red color using sulfuric acid, phosphoric acid, thiosemicarbazide, and diacetylmonoxime. The concentration of urease was determined by measuring the absorbance of the red color at 527 nm with a Shimadzu UV-2200 UV-VIS Recording Spectrophotometer.

Analysis of the other soil properties included soil pH, Walkey-and-Black organic carbon, Kjeldahl total N, Bray I extractable P, and cation exchange capacity (CEC). The analyses of all the soil properties were always conducted in triplicate.

Optimum-pH of phosphatase activity in soil. The optimum pH for phosphatase is the pH value at which phosphatase shows the highest activity; an important characteristic of phosphatase because this soil enzyme is fairly pH-dependent. A set of MUB solutions with pH values ranging from 3 to 12 was prepared. The method used for measuring the activity of phosphatase at a particular pH was the same as that described above, except that the pH of the MUB solution was adjusted to the related value. The optimum pH for phosphatase was determined in all the topsoil samples from all the sampling locations. All the measurements were conducted with 2 replications.

RESULTS AND DISCUSSION

1. Soil physico-chemical properties

As shown in Table 1, the elevation of the areas with coffee plantations and that of cultivated lands were lower than that of primary forests and secondary forests at each sampling site.

Soil pH fluctuated from 4.0 to 5.9 in the topsoils and from 4.1 to 5.7 in the subsoils, respectively. No clear differences in the soil pH among the land-use systems were observed in both topsoils and subsoils.

Amounts of organic C, total N, available P, and CEC were generally largest in the soil samples from primary forests, followed by secondary forests and the other two land uses both in the topsoils and subsoils. Although the cultivated lands at Bukit Ringgis, Sekincau, and

Table 1. Sampling sites and chemical properties of soil samples.

Site	Depth	El.[1)]	Dist.[2)]	pH(H_2O)	Organic-C	Total-N	Available-P	CEC
	(cm)	(m)	(m)	(1:2.5)	(g kg^{-1})		(mg kg^{-1})	(cmol(+)kg^{-1})
Bukit Ringgis:								
PF[3)]	0-20	1550	0	4.4	60.4	5.5	4.0	43.2
	20-40			4.8	25.0	2.3	1.5	18.2
SF[3)]	0-20	1400	628	5.4	41.4	3.4	2.1	18.5
	20-40			4.9	21.7	2.0	1.5	13.7
CP[3)]	0-20	1120	1660	4.9	28.5	2.3	1.5	11.4
	20-40			4.9	10.1	1.2	1.0	12.5
CL[3)]	0-20	1100	2160	4.4	15.8	1.7	1.5	12.4
	20-40			4.3	7.5	0.8	0.7	12.2
Sekincau:								
PF	0-20	1620	0	4.0	73.1	6.1	5.6	41.0
	20-40			4.1	32.7	2.5	3.3	22.4
SF	0-20	1440	530	4.8	42.9	3.5	2.1	15.1
	20-40			4.6	24.5	2.4	1.5	16.1
CP	0-20	1240	1550	4.6	30.9	3.3	1.5	13.5
	20-40			4.4	11.2	1.2	1.0	16.0
CL	0-20	1170	2300	5.2	19.3	1.8	1.8	13.9
	20-40			4.1	7.0	0.9	1.0	13.9
Tri Mulya:								
PF	0-20	890	0	5.4	58.0	5.1	3.5	37.6
	20-40			4.9	18.2	2.0	1.3	21.9
SF	0-20	740	335	5.5	38.7	3.2	2.3	24.8
	20-40			5.0	12.5	2.1	2.1	14.8
CP	0-20	490	765	5.4	26.7	2.5	2.8	14.7
	20-40			4.8	7.0	1.3	1.5	11.8
CL	0-20	465	1220	5.2	14.2	1.3	2.1	13.8
	20-40			5.0	5.5	0.7	1.0	12.7
Tri Budi Syukur:								
PF	0-20	1240	0	4.9	30.5	1.8	7.3	18.4
	20-40			5.2	3.8	1.1	5.4	15.3
SF	0-20	985	354	5.9	27.5	3.2	7.3	23.9
	20-40			5.7	10.2	1.4	6.1	20.2
CP	0-20	735	826	5.1	22.6	2.6	7.3	14.4
	20-40			5.4	11.1	1.4	6.9	13.2
CL	0-20	710	1427	4.8	13.3	1.8	6.9	11.7
	20-40			5.6	6.5	0.6	6.5	9.2
Pura Mekar:								
PF	0-20	940	0	5.5	23.3	2.0	8.9	8.2
	20-40			5.3	13.6	1.2	7.3	4.9
SF	0-20	790	381	5.2	30.0	2.9	10.1	8.4
	20-40			5.7	10.7	1.2	6.9	5.9
CP	0-20	540	940	5.6	23.4	2.5	7.3	11.2
	20-40			5.4	11.4	1.4	6.9	9.3
CL	0-20	522	1340	5.3	23.2	2.1	11.1	8.3
	20-40			4.9	8.7	0.9	3.8	6.5

[1)]: Elevation of sampling sites from sea level; [2)]: Distance from Primary Forest's sampling site; [3)]: PF primary forests, SF secondary forests, CP coffee plantations, CL cultivated lands

Tri Mulya, and those at Tri Budi Syukur and Pura Mekar were upland fields and paddy fields, respectively, no significant differences in the soil physico-chemical properties were observed between them. The contents of organic C, total N, available P, and CEC in the topsoil samples were well-correlated with those in the subsoil samples with correlation

coefficients (r) 0.882** for organic C, 0.863** for total N, 0.864** for available P, and 0.826** for CEC, respectively (**significant at 1% level).

As the sites for coffee plantations and cultivated lands were located at lower positions in the same toposequence compared with the respective primary and secondary forests (Table 1), the original values of these parameters at the time of deforestation were estimated to have been higher at these sites than (or at least comparable to) those of the respective primary and secondary forests.

These findings, therefore, suggested that clearing of primary and secondary forests and their conversion to coffee plantations and cultivated lands stimulated the decomposition of soil organic matter and probably accelerated the soil erosion due to the increase in soil temperature, soil tillage and the decrease of plant debris input.

2. Soil enzyme activities

Topsoils. The activities of soil enzymes at all the locations for different land-use systems are shown in Table 2. The mean relative enzymatic activities in the secondary forests, coffee plantations, and cultivated lands are presented in Table 3 by giving those in the primary forests a value of 1. It was evident that with a few exceptions the enzymatic activities were all highest in primary forests followed by those in secondary forests, and that the enzymatic activities in the coffee plantations and cultivated lands were very low compared

Table 2. Activities of soil enzymes under respective land use systems.

	Acid phosphatase[1]		Alkaline phosphatase[1]		β-Glucosidase[1]		Urease[2]	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Bukit Ringgis								
PF[3]	371±16	129±1	157±0	13±0	169±12	29±3	185±21	89±26
SF[3]	269±2	247±6	63±14	40±3	98±3	33±3	152±18	111±9
CP[3]	166±13	94±4	29±3	13±1	110±2	23±3	59±5	0±0
CL[3]	185±1	137±3	34±2	15±1	123±1	26±8	56±6	17±2
Sekincau								
PF	1092±173	427±8	N.D.[4]	349±76	158±1	38±0	206±7	95±7
SF	419±19	387±9	220±11	190±25	79±5	39±9	138±7	88±1
CP	352±9	89±5	209±13	33±3	142±4	26±0	166±1	77±7
CL	238±6	72±5	153±0	14±0	73±1	19±4	108±9	63±12
Tri Mulya								
PF	211±17	112±1	255±28	72±0	289±31	44±3	262±2	66±6
SF	109±1	85±3	159±1	43±1	96±3	29±2	123±4	60±2
CP	158±13	105±0	40±0	18±1	52±2	31±3	80±5	62±2
CL	159±6	85±8	44±3	15±0	83±5	25±0	83±0	47±1
Tri Budi Syukur								
PF	209±29	68±0	103±5	52±9	107±14	40±3	190±35	4±0
SF	178±6	122±4	172±4	105±15	87±3	42±1	190±35	139±37
CP	188±15	93±3	84±8	44±1	81±8	30±1	86±37	4±0
CL	180±9	52±6	83±6	27±1	73±0	17±0	8±0	0±0
Pura Mekar								
PF	203±18	91±13	154±14	55±10	71±9	34±1	63±0	49±11
SF	239±7	88±9	178±4	43±1	110±6	35±1	178±18	90±5
CP	129±5	49±0	56±0	32±1	39±4	21±0	139±10	86±2
CL	114±16	50±2	82±1	31±1	68±2	32±2	113±9	46±10

[1]: in μg p-nitrophenol g^{-1} h^{-1}, [2]: in μg urea g^{-1} h^{-1}, [3]: PF Primary forests, SF Secondary forests, CP Coffee plantations, CL Cultivated lands, [4]: Not determined.

Table 3. Relative values of enzymatic activities under secondary forests, coffee plantations, and cultivated lands.

Soil Enzyme	Secondary Forests		Coffee Plantations		Cultivated lands	
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Acid phosphatase						
Bukit Ringgis	0.73	1.92	0.45	0.73	0.50	1.06
Sekincau	0.38	0.91	0.32	0.21	0.22	0.17
Tri Mulya	0.52	0.76	0.75	0.94	0.75	0.76
Tri Budi Syukur	0.85	1.79	0.90	1.36	0.86	0.76
Pura Mekar	1.18	0.97	0.64	0.54	0.56	0.56
Alkaline phosphatase						
Bukit Ringgis	0.40	3.05	0.18	1.02	0.22	1.11
Sekincau	N.D.	0.54	N.D.	0.10	N.D.	0.04
Tri Mulya	0.62	0.60	0.16	0.24	0.17	0.21
Tri Budi Syukur	1.67	2.03	0.81	0.86	0.81	0.52
Pura Mekar	1.16	0.78	0.36	0.58	0.53	0.56
β -glucosidase						
Bukit Ringgis	0.58	1.16	0.66	0.78	0.73	0.91
Sekincau	0.50	1.05	0.90	0.70	0.46	0.51
Tri Mulya	0.33	0.66	0.18	0.70	0.29	0.57
Tri Budi Syukur	0.81	1.07	0.76	0.76	0.68	0.42
Pura Mekar	1.54	1.05	0.56	0.62	0.96	0.95
Urease						
Bukit Ringgis	0.82	1.25	0.32	0.00	0.30	0.19
Sekincau	0.67	0.92	0.81	0.81	0.52	0.66
Tri Mulya	0.47	0.91	0.31	0.95	0.32	0.72
Tri Budi Syukur	1.00	40.9	0.45	1.00	0.04	0.00
Pura Mekar	2.83	1.84	2.21	1.77	1.79	0.94
Mean±(standard error)						
Acid phosphatase	0.61±0.31	1.06±0.54	0.51±0.23	0.63±0.43	0.48±0.25	0.55±0.33
Alk. phosphatase	0.96±0.57	1.17±1.10	0.38±0.30	0.47±0.39	0.43±0.30	0.41±0.41
β -Glucosidase	0.63±0.47	0.83±0.19	0.51±0.27	0.59±0.06	0.52±0.26	0.56±0.24
Urease	0.96±0.95	1.23±0.43[1)]	0.68±0.80	0.75±0.63	0.50±0.69	0.42±0.39

Relative values under different land uses when a value of 1 was assigned to the topsoils and subsoils of the primary forests, respectively.

[1)]: The relative value obtained from Tri Budi Syukur was not included.

N.D.: Not determined (see text).

with those of primary forests (Table 2). The higher relative enzymatic activities in cultivated lands at Tri Budi Syukur and Pura Mekar compared with the respective enzymatic activities at Bukit Ringgis, Sekincau, and Tri Mulya were estimated not to be due to the difference in the land-use type (paddy fields vs. upland fields) but due to the properties of the locations, because similarly higher enzymatic activities were also found at the former locations in coffee plantations (Table 3). No clear difference in enzymatic activities was detected between cultivated lands planted with upland crops and paddy rice. Thus, in the lands under agricultural practices after clearing of the primary and secondary forests the enzymatic activities did not recover to the levels found in the forests, indicating the important role of forests in preserving the soil enzymatic properties. The activities of the soil enzymes in the coffee plantations and cultivated lands were not significantly different in the most cases. The most drastic decrease in enzymatic activity in the topsoils after the conversion of primary forests to other land uses was observed for alkaline phosphatase (Table 3). The alkaline phosphatase activity in the primary forest in Sekincau was not determined due to serious

interference by the color development originating from soil organic matter, which will be discussed later.

As shown in Table 4, all the enzyme activities except for alkaline phosphatase in the topsoils were well-correlated with organic-C and total-N contents at 5% significance levels. The presence of more abundant organic matter may have stimulated the development of the soil-enzyme-producing microorganisms (Tate III 1984; Jha et al. 1992). On the contrary, there was no correlation between available-P contents in soil and any enzymatic activities tested. The CEC showed a significant correlation only with urease and β-glucosidase. These observations indicate that the maintenance of the organic matter content in soil is important to preserve the soil enzymatic activities.

Subsoils. The subsoils from all the sampling sites showed lower enzymatic activities compared with the respective activities in topsoils (Table 2). The activities of the soil enzymes tested were similar between the primary forests and secondary forests except for some cases, while the activities were lower in the coffee plantations and cultivated lands than in primary forests and secondary forests at many locations. Thus, the decrease in enzymatic activities reached a 40 cm depth in the areas under coffee plantations and cultivated lands. In contrast to the enzymatic activities in the topsoils, only the activities of acid and alkaline phosphatases showed a significant correlation with the soil organic-C content in the subsoils (Table 4). The close relationship between the enzymatic activity in the topsoils and that in the subsoils was only observed for acid phosphatase (r was 0.809** for acid phosphatase, 0.577 for alkaline phosphatase, 0.430 for β-glucosidase, and 0.609 for urease).

3. Optimum pH for phosphatase activities in different land-use systems

The activity of phosphatase as a function of pH is depicted in Fig. 2 for soils from all the sampling sites. The curve for the primary forest of Sekincau is not given due to the abnormal phosphatase activity. The high organic matter content in this soil (Table 1) interfered with the determination of the phosphatase activity. Trasar-Cepeda and Gil-Sotres (1987) showed that the method for the determination of phosphatase activity used in this experiment (Tabatabai and Bremner 1969) was not suitable for soils containing a high level of organic matter. The MUB, particularly in the case of high pH values, dissolves a large amount of organic matter, which interferes with the absorbance measurement of the yellow color of p-nitrophenol.

The activity of phosphatase in soils increased from pH 3 with the increase in soil pH to a maximum value and then decreased to an asymptotic value at high pH. Such an enzyme

Table 4. Correlation coefficients between soil chemical properties and enzymatic activities.

	Acid phosphatase	Alkaline phosphatase	β-Glucosidase	Urease
Topsoils				
Organic-C	0.716*	0.584	0.671*	0.734*
Total-N	0.692*	0.620	0.678*	0.721*
Available-P	-0.072	0.023	-0.230	0.066
CEC	0.563	0.442	0.708*	0.664*
Subsoils				
Organic-C	0.823**	0.716*	0.404	0.529
Total-N	0.711*	0.611	0.516	0.542
Available-P	-0.260	0.053	0.101	-0.064
CEC	0.496	0.516	0.414	0.357

* and **: significant with 5% and 1% levels, respectively.

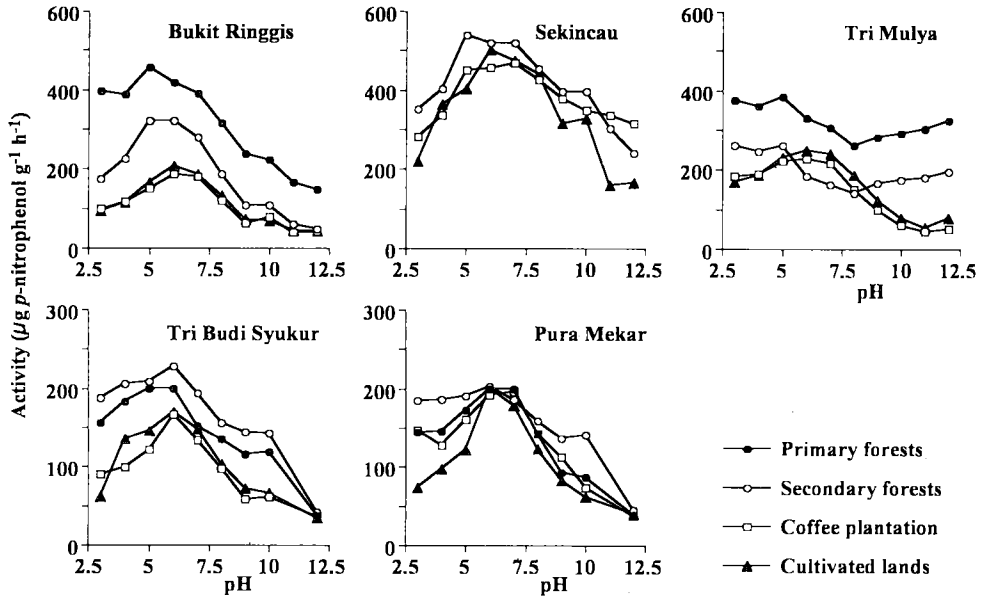

Fig. 2. Activity of soil phosphatase as a function of soil pH.

pH profile is due to the reversible reaction that involves ionization and deionization of acidic and basic groups in the active center of the enzyme-protein (Frankenberger and Johanson 1982). The optimum pH of phosphatase for maximum activity shifted in most cases to higher values by forest clearing and conversion to other land-uses. Soils of Bukit Ringgis showed this phenomenon most obviously; the optimum pH for the primary forest was about 5.0, and it shifted to about 5.5 for the secondary forest, and to 6.3 and 6.0 for the coffee plantations and the cultivated lands, respectively.

As the soil pH did not show any particular tendency after forest clearing, the mechanism of the shifting of the optimum pH associated with forest conversion to other land-use systems remains to be elucidated. Soil microorganisms that controlled the phosphatase activities in each land-use system might have been different and required different optimum pH for maximum phosphatase production. Another possibility is that the differences in plant species growing on each land-use system may have given the greater impact, assuming that plant roots were the main phosphatase producers.

4. Estimation of the decrease in enzymatic activities by forest clearing

Syam et al. (1997) estimated the land-use change from 1978 to 1990 of an area 27 km × 27 km covering our sampling locations using land use maps. Table 5 summarizes their estimation.

Using this information, the decreases in the respective enzymatic activities from 1978 to 1984 and 1990 in the uppermost 0–20 cm layers and underlying 20–40 cm layers of the study area (27 km × 27 km) were estimated based on Tables 3 and 5, assuming that the relative values in Table 3 could be applied to the other locations in the study area (Table 6). As the enzymatic activities in grasslands were not determined in the present studies, they were postulated in the calculation to lie the midway between those in secondary forests and cultivated lands for upland crops, because grasslands were derived from the repeated use of

Table 5. Changes in percentage of respective land use systems from 1978 to 1990.

Land use type	1978	1984	1990
1. Residential areas	1.03	1.70	2.20
2. Paddy fields	2.92	5.02	5.35
3. Upland fields (crops and vegetables)	2.20	1.07	0.12
4. Upland fields under shifting cultivation	4.81	0.33	0.00
5. Plantation lands (monoculture)	20.83	41.77	41.11
6. Plantation lands (mixed)	0.93	0.95	19.26
7. Dense forests (primary forests)	32.60	21.39	12.72
8. Underbrush forests (secondary forests)	16.20	10.79	18.05
9. Ponds	0.03	0.01	0.07
10. Grasslands	18.44	16.98	1.12

Table 6. Estimated decrease (%) of the activities of soil enzymes from 1978.

Soil enzyme	from 1978 to 1984		from 1978 to 1990	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm
Acid phosphatase	8	8	14	12
Alkaline phosphatase	12	12	20	18
β-Glucosidase	8	8	14	13
Urease	4	6	7	6

secondary forests for shifting cultivation with a cycle too short for regeneration, leaving vast areas of infertile grasslands (Syam et al. 1997).

The estimated decreases in enzymatic activities from 1978 in the uppermost 0–20 cm layers ranged from 4 to 12% in 1984 and 7 to 20% in 1990, respectively, while those in the underlying 20–40 cm layers ranged from 6 to 12% in 1984 and 6 to 18% in 1990. The alkaline phosphatase activity decreased most by land use change, followed by that of acid phosphatase and β-glucosidase, while the urease activity slightly decreased. Thus, although the period considered in Table 6 was only 12 y, it was demonstrated that the impact of land-use change contributed to a pronounced deterioration of the soil enzymatic activities until the 40 cm depth.

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