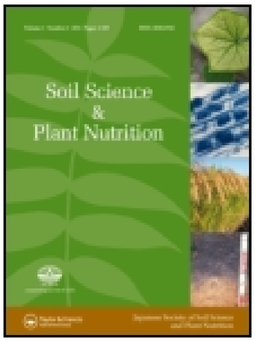

Soil Science and Plant Nutrition

ISSN: 0038-0768 (Print) 1747-0765 (Online) Journal homepage: http://www.tandfonline.com/loi/tssp20

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To cite this article: Abdul Kadir Salam , Yessi Desvia , Edi Sutanto , Tamaluddin Syam , Sutopo Ghani Nugroho & Makoto Kimura (1999) Activities of soil enzymes in different land-use systems in middle terrace areas of Lampung province, South Sumatra, Indonesia, Soil Science and Plant Nutrition, 45:1, 89-99, DOI: 10.1080/00380768.1999.10409326

To link to this article: http://dx.doi.org/10.1080/00380768.1999.10409326

Published online: 04 Jan 2012.

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Soil Sci. Plant Nutr., 45 (1), 89-99, 1999

Activities of Soil Enzymes in Different Land-Use Systems in Middle Terrace Areas of Lampung Province, South Sumatra, Indonesia

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Received June 18, 1998; accepted in revised form October 13, 1998

Changes in the activities of several soil enzymes due to land-use conversion from forests to cultivated lands in the middle terrace areas in Lampung Province, South Sumatra, Indonesia, were monitored. Soil samples were collected from 5 locations in the northern and northeastern regions of Lampung, each comprising several land-use systems (secondary forests, cacao plantations, pineapple plantations, rubber plantations, mixed gardens, cassava fields, corn fields, a rice field, etc.) depending on the distribution of the respective land-use systems at each location. Enzyme assays showed that, with a few exceptions, the activities of acid and alkaline phosphatases, β-glucosidase, and arylsulfatase in the topsoils (0 to 20 cm depth) were higher than, and well correlated with, those in the subsoils (20 to 40 cm depth). Activities of soil enzymes were in general well correlated with the content of total soil nitrogen. No distinct differences in enzymatic activities in soils were observed among the land-use systems. Among the soil enzymes studied, acid phosphatase activity showed a significant relationship only with alkaline phosphatase activity in the topsoils. In contrast, alkaline phosphatase activity showed a significant relation with the other enzymatic activities tested in the topsoils and with arylsulfatase and β-glucosidase activities in the subsoils. Arylsulfatase activity also showed a high correlation with β-glucosidase activity in both topsoils and subsoils.

Key Words: **arylsulfatase, β-glucosidase, phosphatase, soil enzyme, tropical forest.**

Soil enzymatic activity is an important biochemical property to evaluate the soil fertility because of the involvement of several soil enzymes in cycles of nutrients available to crops. Experts in soil fertility have concerned about the decreasing trend of soil enzymatic properties caused by several human activities, including land-use conversion. Land-use conversion changes important soil characteristics that may directly or indirectly affect the activities of soil enzymes, i.e. soil pH (Salam et al. 1998), soil moisture content (Klein and Koths 1980; Baligar et al. 1988), soil temperature (Dash et al. 1981; Moyo et al. 1989; Neal 1990), soil organic matter content (Nannipieri et al. 1980; Baruah and Mishra 1984; Tate III 1984; Baligar et al. 1988; Salam et al. 1998), soil P availability (Pang and Kolenko 1986; Fox and Comerford 1992), types of vegetation, plant roots, and soil microorganisms (Duxbury and Tate III 1981; Frankenberger and Dick 1983; Jha et al. 1992).

The influence of land-use change on the activities of soil enzymes has not been well documented in tropical regions (Jha et al. 1992; Salam et al. 1998). Jha et al. (1992) reported that in Northeast India the activities of soil enzymes such as dehydrogenase, urease, and phosphatase, were higher in less degraded than in more degraded forest soils due to the lower fungal and bacterial populations in more degraded forest soils.

We carried out studies to analyze the effects of land use change on the activities of soil enzymes in South Sumatra, Indonesia, and we showed that the activities of phosphatases, β-glucosidase, and urease were higher in most cases in primary and in secondary forests than in coffee plantation lands and crop lands in hilly areas, indicating that the clearing of forests and conversion to coffee plantations and cultivated lands significantly disturbed the soil microbial activities (Salam et al. 1998).

The objective of the current studies was to evaluate the changes in the activities of soil enzymes (acid phosphatase, alkaline phosphatase, β-glucosidase, and arylsulfatase) associated with land-use conversion in the middle terrace areas in Lampung Province, South Sumatra, Indonesia, where cassava and rubber are the dominant crop and plantation plants, respectively.

MATERIALS AND METHODS

Soil samples. Soil samples were collected from 5 locations (Mulyasari, Ujung G. Ilir, Menggala, Tulung Boho, and Panaragan) in the central and northeastern regions of Lampung Province, South Sumatra, Indonesia (Fig. 1); each comprised several land-use

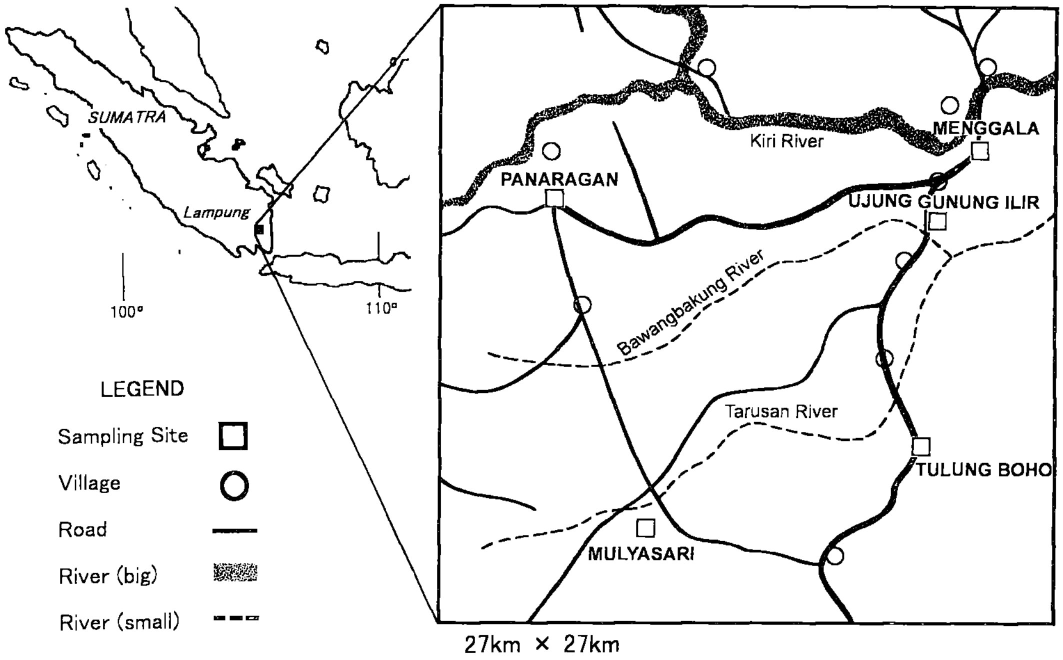

Fig. 1. Map showing the location of the sampling sites (4°25′S to 4°40′S and 105°0′E to 105°15′E).

systems such as secondary forests (including swamps), plantations (cacao, "sengon" [*Albizia falcataria*], rubber, and pineapple), mixed gardens (for plant species, see Table 1) and cultivated lands (such as cassava, rice, and corn). The elevation of the areas shown in Fig. 1 ranged from 135 to 145 m above the sea level. Soil of each location was classified into Inceptisols in the Soil Taxonomy classification system.

Soil samples weighing several hundred grams were collected from 2 sites with respective land-use fields, and were made composite. The soil samples from mixed gardens were collected between major trees. Soil samples were taken at two different depths (topsoil: 0 to 20 cm, and subsoil: 20 to 40 cm) after removing of the litter layer. Soil samples were sieved through a 2 mm mesh screen and thoroughly mixed under moist conditions. Soil samples were stored in a cold room, and the activities of the soil enzymes were measured as soon as practically possible after soil sample collection.

Analysis of activities of soil enzymes and physico-chemical properties. Enzymatic activities in the soil samples were measured for acid and alkaline phosphatases, arylsulfatase, and β-glucosidase. Analyses of phosphatase and β-glucosidase activities followed the methods of Tabatabai and Bremner (1969) with some modifications reported previously by Salam et al. (1998).

Arylsulfatase activity was measured by the following method. A 1 g aliquot of soil sample (<2 mm, oven-dry equivalent) was put into a 50-mL Erlenmeyer flask. The microbial activity was stopped by the addition of 0.25 mL toluene, followed by 4 mL acetate buffer 0.5 M (pH 5.8) and 1 mL of *p*-nitrophenyl sulfate solution 0.025 M (ca. 3.5 mg of *p*-nitrophenol equivalent). After gentle swirling, the mixture was incubated for 1 h at 30°C. A 1 mL aliquot of 0.5 M $CaCl_2$ and a 4 mL aliquot of 0.5 M NaOH solution were then added. Concentration of *p*-nitrophenol in the solution phase was determined with a spectrophotometer at 400 nm wavelength after filtering through a Whatman No. 42 paper (Tabatabai 1982). All the analyses were conducted in triplicate.

Analyses of the physico-chemical properties of the soil samples included soil pH, Walkey-and-Black organic C content, total N content, Bray I extractable P content, exchangeable K content, and cation exchange capacity (CEC) (Bray and Kurtz 1945; Bremner and Mulvaney 1982; Nelson and Somners 1982; Rhoades 1982; Thomas 1982). All the analyses were conducted in duplicate.

RESULTS AND DISCUSSION

1. Physico-chemical properties of soil samples

Physico-chemical properties of the soil samples from every land-use system at each location are shown in Table 1. Soil pH was strongly acidic, ranging from 3.7 to 5.4 for the topsoils and from 3.8 to 5.4 for the subsoils. Land-use changes from secondary forests to mixed gardens, plantation lands for "sengon" and rubber, and cassava fields tended to decrease the soil pH.

Organic C content was generally higher in secondary forest and swamp soils than in the soils from the other land-use systems. "Sengon" plantation lands and cassava fields contained less soil organic C than secondary forests. Organic C content of all the soils ranged from 9 to 37 g kg^{-1} in the topsoils and from 1 to 29 g kg^{-1} in the subsoils. With a few exceptions, the organic C content in the topsoils were higher than that in the subsoils. This trend was in agreement with that of soil CEC, indicating the importance of the content of soil organic matter in determining the soil CEC. Total N contents in soils ranged from 0.6

Table 1. Selected chemical properties of soils in different land-use systems.

Land use	Soil layer	pH	Organic C g kg^{-1}	Total N g kg^{-1}	Exch. K mg kg^{-1}	Av. P mg kg^{-1}	CEC cmol(+) kg^{-1}
A. Mulyasari							
Secondary forest	topsoil	5.2	36.6	0.7	73.4	3.5	14.3
	subsoil	5.0	17.8	1.4	42.8	1.5	6.5
Rubber	topsoil	5.0	20.9	1.2	38.4	5.3	12.5
	subsoil	4.6	12.7	1.8	29.7	8.1	7.3
“Sengon”[a]	topsoil	4.4	11.7	0.8	29.5	9.0	5.6
	subsoil	4.2	8.3	0.6	19.0	2.4	5.4
Mixed garden[c]	topsoil	4.5	21.4	1.3	58.1	9.9	6.8
	subsoil	4.6	16.1	1.1	45.0	0.9	6.9
Cassava	topsoil	4.3	9.0	0.6	8.42	1.8	4.9
	subsoil	4.1	17.6	0.6	19.0	11.0	5.0
Cassava and corn	topsoil	4.5	13.8	0.8	29.5	11.0	5.7
	subsoil	4.6	10.0	0.7	13.7	5.7	5.5
Paddy rice	topsoil	4.4	13.4	0.8	8.42	9.8	5.1
	subsoil	4.7	6.5	0.6	13.7	2.1	4.1
B. Ujung G. Ilir							
Secondary forest	topsoil	4.5	24.8	1.3	50.5	6.0	7.3
	subsoil	4.5	14.8	0.7	8.42	1.8	6.1
Swamp	topsoil	3.9	25.7	2.5	256	1.4	23.2
	subsoil	4.4	9.3	0.9	103	1.0	20.4
“Alang-alang”[b]	topsoil	4.9	19.6	1.3	61.1	6.8	3.0
	subsoil	4.6	12.4	0.6	19.0	4.1	4.5
Cassava	topsoil	4.4	25.1	1.3	29.5	9.8	7.2
	subsoil	4.3	11.7	0.7	13.7	4.9	4.0
C. Menggala							
Secondary forest	topsoil	5.1	23.8	1.1	51.5	2.6	8.5
	subsoil	5.4	17.6	1.5	34.1	0.8	8.1
Rubber	topsoil	4.3	26.7	1.2	36.2	2.9	8.8
	subsoil	4.7	17.3	1.1	29.7	0.8	8.2
Cacao	topsoil	5.1	30.3	1.0	86.5	3.2	8.9
	subsoil	5.1	29.1	1.4	68.9	3.2	12.2
“Sengon”[a]	topsoil	4.0	15.3	1.0	3.9	5.8	4.7
	subsoil	4.4	2.8	0.4	3.9	2.1	3.7
Mixed garden[c]	topsoil	4.8	25.7	0.9	62.4	3.2	9.6
	subsoil	4.9	20.0	1.5	42.8	1.5	10.9
Cassava 1 (newly open)	topsoil	5.4	29.8	0.8	68.9	3.5	8.4
	subsoil	5.5	23.6	2.8	73.4	1.5	6.5
Cassava 2	topsoil	3.7	15.3	1.0	15.6	5.8	8.1
	subsoil	3.9	8.3	1.1	3.9	3.5	5.9
D. Tulung Boho							
Secondary forest	topsoil	4.8	24.9	1.3	62.4	11.3	25.9
	subsoil	4.8	6.2	1.3	31.2	5.8	4.5
Swamp	topsoil	3.9	19.4	3.2	74.1	6.5	7.7
	subsoil	3.8	10.4	1.8	15.6	4.3	4.5
Pineapple	topsoil	4.0	11.8	1.3	3.9	3.5	2.7
	subsoil	3.9	9.0	0.3	3.9	1.0	4.7
“Sengon”[a]	topsoil	4.4	16.7	1.1	31.2	15.5	2.7
	subsoil	4.2	6.2	0.4	3.9	1.3	2.3
Mixed garden[c]	topsoil	4.0	10.4	0.6	42.9	1.0	3.1
	subsoil	4.3	9.7	0.5	3.9	5.0	3.9

Table 1. Continued.

Land use	Soil layer	pH	Organic C g kg^{-1}	Total N g kg^{-1}	Exch. K mg kg^{-1}	Av. P mg kg^{-1}	CEC cmol(+) kg^{-1}
Cassava	topsoil	4.1	13.2	0.8	62.4	7.3	4.7
	subsoil	4.1	17.3	1.0	31.2	7.3	4.7
Corn	topsoil	4.7	9.7	0.8	23.4	25.9	1.7
	subsoil	4.3	1.4	0.2	3.9	2.8	3.7
E. Panaragan							
Secondary forest	topsoil	4.7	15.3	1.3	31.2	5.8	1.3
	subsoil	4.2	4.9	0.6	3.9	2.8	3.1
Rubber	topsoil	4.1	13.2	0.9	3.9	2.8	2.7
	subsoil	3.8	5.6	0.6	3.9	6.1	2.7
Mixed garden 1[c]	topsoil	4.2	13.9	1.5	31.2	6.1	6.5
	subsoil	4.2	3.5	0.3	15.6	5.8	4.5
Mixed garden 2[c]	topsoil	4.3	16.7	1.1	3.9	6.1	7.9
	subsoil	4.4	4.2	0.6	3.9	5.8	4.3
Cassava	topsoil	3.8	12.5	0.6	23.4	5.8	3.3
	subsoil	4.2	4.9	0.6	3.9	2.8	2.9

[a] "Sengon," *Albizia falcataria*. [b] "Alang-alang," *Imperata cylindrica*. [c] Cassava, coffee, pineapple, coconut, banana, and mango at Mulyasari; cempedak (*Actocarpus kemando*), rubber, banana, and mango at Menggala; jack fruit, kapok, mango, coconut, and kinang (*Areca catechu*) at Tulung Boho; and cempedak, mango, kinang, and jack fruit for mixed garden 1 and cempedak, mango, kinang, jack fruit, banana, and kapok for mixed garden 2 at Panaragan, respectively.

to 3.2 g kg^{-1} in the topsoils and from 0.2 to 2.8 g kg^{-1} in the subsoils. Total N contents in soils did not show any conspicuous trend in relation to the land-use systems in the study areas.

The amount of exchangeable K ranged from 4 to 256 mg kg^{-1} in the topsoils and from 4 to 103 mg kg^{-1} in the subsoils. The amount of exchangeable K was lower in rubber plantation lands and cassava fields than in secondary forests. The amount of soil available P ranged from 1 to 26 mg kg^{-1} in the topsoils and from 1 to 11 mg kg^{-1} in the subsoils. The differences in available P contents were considered to be due to P-fertilization, but no general tendency was observed in relation to the land-use systems except for the increasing tendency in "sengon" plantation lands. The CEC was generally low, ranging from 1.3 to 25.9 cmol(+) kg^{-1} for the topsoils and 2.7 to 20.4 cmol(+) kg^{-1} for the subsoils. In the "sengon" plantation the CEC value tended to decrease.

Table 2 shows the correlation coefficients between the respective physico-chemical properties in the topsoils and in the subsoils. Total N content did not show a significant relation with total organic C content in the topsoils, suggesting that different types of organic materials had accumulated in fields with different land-uses. Except for the content of available P, no significant relationships were observed in the subsoils.

Except for the contents of total N and available P, other soil chemical properties in the subsoils showed a good correlation with those in the topsoils, with correlation coefficients of 0.820*** for pH, 0.635*** for organic C content, 0.833*** for exchangeable K content, and 0.614*** for CEC, respectively.

2. Soil enzymatic activities

Topsoils. The activities of acid and alkaline phosphatases, arylsulfatase, and β-glucosidase for every land-use system at each location are shown in Tables 3 to 6.

Table 2. Correlation coefficients among soil physico-chemical properties (upper-right in topsoils and lower-left in subsoils).

	pH	Total org. C	Total N	Exch. K	Av. P	CEC
pH	–	0.599***	−0.247	0.088	0.074	0.204
Total organic C	0.606***	–	0.208	0.511**	−0.281	0.609***
Total N	0.600***	0.663***	–	0.534**	−0.080	0.354
Exchangeable K	0.584***	0.629***	0.611***	–	−0.231	0.651***
Available P	−0.347	−0.085	−0.097	−0.245	–	−0.183
CEC	0.379*	0.468**	0.353	0.856***	−0.289	–

Significance at *5%, **1%, and ***0.1% levels.

Table 3. Activity (±SE) of acid phosphatase in different land-use systems (μg p-nitrophenol g^{-1} h^{-1}).

Land use	Soil layer	Mulyasari	U.G. Ilir	Menggala	Tulung Boho	Panaragan
Secondary forest	topsoil	96±0	286±13	39±1	105±19	151±24
	subsoil	14±0	243±0	22±1	84±10	96±5
Swamp	topsoil		262±16		335±0	
	subsoil		206±13		200±19	
"Alang-alang"[a]	topsoil		219±0			
	subsoil		186±5			
Rubber	topsoil	222±18		171±17		96±5
	subsoil	104±6		117±12		59±10
Cacao	topsoil			28±2		
	subsoil			25±0		
"Sengon"[b]	topsoil	164±6		175±9	110±0	
	subsoil	136±7		73±0	73±0	
Pineapple	topsoil				140±0	
	subsoil				120±0	
Mixed garden 1	topsoil	133±0		29±1	168±0	188±20
	subsoil	113±7		22±1	140±0	96±14
Mixed garden 2	topsoil					168±0
	subsoil					113±0
Cassava 1	topsoil	171±12	237±3	202±12	151±33	168±19
	subsoil	127±1	187±7	197±6	120±0	124±5
Cassava 2	topsoil			140±0		
	subsoil			44±29		
Cassava and corn	topsoil	128±3				
	subsoil	117±0				
Corn	topsoil				96±5	
	subsoil				56±5	
Paddy rice	topsoil	129±7				
	subsoil	105±3				

[a] "Alang-alang," *Imperata cylindrica.* [b] "Sengon," *Albizia falcataria.*

Acid phosphatase (Table 3): As in the case of the previous report, in hilly areas of this province (Salam et al. 1998), the activities of acid phosphatase were higher in the topsoils than in the subsoils. The activity of acid phosphatase ranged from 28 to 335 μg p-nitrophenol g^{-1} h^{-1} in the topsoils. The activity was slightly lower than that in hilly areas in the province (109 to 1,092 μg p-nitrophenol g^{-1} h^{-1}; Salam et al. 1998). Depending on the location, the highest activities were observed in different land-use systems. The activity of acid phosphatase in rubber plantation lands and cassava fields was generally high. These findings indicated that the conversion of forests to plantation lands and cultivated fields did

Table 4. Activity (±SE) of alkaline phosphatase in different land-use systems (μg *p*-nitrophenol g^{-1} h^{-1}).

Land use	Soil layer	Mulyasari	U.G. Ilir	Menggala	Tulung Boho	Panaragan
Secondary forest	topsoil	146±6	69±0	65±12	154±20	113±19
	subsoil	78±6	37±3	27±6	89±14	62±24
Swamp	topsoil		126±7		433±40	
	subsoil		96±15		293±26	
"Alang-alang"	topsoil		62±1			
	subsoil		54±0			
Rubber	topsoil	70±6		36±6		46±0
	subsoil	32±0		19±6		32±0
Cacao	topsoil			70±6		
	subsoil			57±12		
"Sengon"	topsoil	34±0		73±0	39±10	
	subsoil	32±1		32±0	32±10	
Pineapple	topsoil				39±0	
	subsoil				29±5	
Mixed garden 1	topsoil	27±6		49±12	35±5	69±14
	subsoil	19±6		44±6	32±10	35±5
Mixed garden 2	topsoil					86±19
	subsoil					35±5
Cassava 1	topsoil	26±1	51±4	53±6	39±0	52±0
	subsoil	33±1	36±1	36±6	32±0	32±0
Cassava 2	topsoil			66±19		
	subsoil			46±0		
Cassava and corn	topsoil	26±0				
	subsoil	13±4				
Corn	topsoil				29±5	
	subsoil				12±0	
Paddy rice	topsoil	80±7				
	subsoil	28±0				

not decrease the acid phosphatase activity in this region, in contrast to the results of the previous survey in hilly areas in the province (Salam et al. 1998).

Alkaline phosphatase (Table 4): Except for the secondary forests of Mulyasari, Menggala, and Tulung Boho, the activity of alkaline phosphatase was in general lower than the activity of acid phosphatase, and the activity in the topsoils was higher than that in the subsoils. This observation was in good agreement with a report showing that the activity of alkaline phosphatase decreased with soil depth (Zhang et al. 1996). Lower activity of alkaline phosphatase than that of acid phosphatase may be due to the acidic properties of the soils studied (Table 1). The activity of alkaline phosphatase in the topsoils ranged from 26 to 433 μg *p*-nitrophenol g^{-1} h^{-1}, values similar to those recorded in hilly areas in the province (29 to 255 μg *p*-nitrophenol g^{-1} h^{-1}; Salam et al. 1998). The activities of alkaline phosphatase in the secondary forests and swamps were in general higher than those in the rubber plantation lands and cassava fields.

Arylsulfatase (Table 5): The activity of arylsulfatase ranged of 32 to 641 μg *p*-nitrophenol g^{-1} h^{-1}. As in the case of the acid phosphatase activity (Table 3), different land-use systems showed the highest activities depending on the location.

β-Glucosidase (Table 6): The activity of β-glucosidase in the topsoils ranged from 19 to 385 μg *p*-nitrophenol g^{-1} h^{-1}, values similar to those observed in hilly areas in the

Table 5. Activity (±SE) of arylsulfatase in different land-use systems (μg *p*-nitrophenol g^{-1} h^{-1}).

Land use	Soil layer	Mulyasari	U.G. Ilir	Menggala	Tulung Boho	Panaragan
Secondary forest	topsoil	116±13	32±0	158±5	335±18	641±18
	subsoil	79±28	5±0	117±5	209±54	248±36
Swamp	topsoil		178±5		386±18	
	subsoil		113±10		261±18	
"Alang-alang"	topsoil		195±10			
	subsoil		56±5			
Rubber	topsoil	151±15		86±10		227±13
	subsoil	110±14		56±5		172±13
Cacao	topsoil			154±10		
	subsoil			134±0		
"Sengon"	topsoil	83±5		210±0	112±18	
	subsoil	25±10		57±0	27±6	
Pineapple	topsoil				66±0	
	subsoil				40±0	
Mixed garden 1	topsoil	161±10		161±10	142±0	470±13
	subsoil	123±24		89±23	115±0	125±0
Mixed garden 2	topsoil					285±17
	subsoil					244±12
Cassava 1	topsoil	202±0	175±9	147±10	142±12	210±0
	subsoil	83±5	46±0	113±10	61±6	104±6
Cassava 2	topsoil			129±6		
	subsoil			108±12		
Cassava and corn	topsoil	154±20				
	subsoil	110±14				
Corn	topsoil				40±0	
	subsoil				19±6	
Paddy rice	topsoil	124±5				
	subsoil	62±5				

province (39 to 289 μg *p*-nitrophenol g^{-1} h^{-1}; Salam et al. 1998). As in the case of the acid phosphatase and arylsulfatase activities, different land-use systems showed higher activities depending on the location.

Subsoils.

Acid phosphatase (Table 3): The activity of acid phosphatase in the subsoils ranged from 14 to 243 μg *p*-nitrophenol g^{-1} h^{-1}. The activity of acid phosphatase in the subsoils was linearly related to the activity in the topsoils ($r=0.877^{***}$).

Alkaline phosphatase (Table 4): The activity of alkaline phosphatase in the subsoils ranged from 12 to 293 μg *p*-nitrophenol g^{-1} h^{-1}, with the highest values being recorded in a swamp at Tulung Boho and the lowest in a corn field at Tulung Boho. The activity of alkaline phosphatase in the subsoils was well-correlated with the activity in the topsoils ($r=0.974^{***}$).

Arylsulfatase (Table 5): The activity of arylsulfatase in the subsoils ranged from 5 to 261 μg *p*-nitrophenol g^{-1} h^{-1}, with the highest value being recorded in a swamp at Tulung Boho and the lowest in a secondary forest at Ujung G. Ilir. The activity of arylsulfatase in swamps was higher than in the other land use systems. The activity in the subsoils was also correlated with that in the topsoils ($r=0.769^{***}$).

β-Glucosidase (Table 6): The activity of β-glucosidase in the subsoils which ranged from 21 to 207 μg *p*-nitrophenol g^{-1} h^{-1} was well correlated with that in the topsoils ($r=$

Table 6. Activity (±SE) of β-glucosidase in different land-use systems (μg *p*-nitrophenol g^{-1} h^{-1}).

Land use	Soil layer	Mulyasari	U.G. Ilir	Menggala	Tulung Boho	Panaragan
Secondary forest	topsoil	163±6	19±0	155±18	244±12	201±12
	subsoil	48±0	33±1	100±12	197±5	150±24
Swamp	topsoil		46±1		385±72	
	subsoil		27±2		207±12	
"Alang-alang"	topsoil		35±5			
	subsoil		24±5			
Rubber	topsoil	87±6		87±6		129±6
	subsoil	53±6		48±0		91±0
Cacao	topsoil			176±0		
	subsoil			138±18		
"Sengon"	topsoil	35±9		142±0	129±18	
	subsoil	23±1		74±0	74±0	
Pineapple	topsoil				129±18	
	subsoil				74±0	
Mixed garden 1	topsoil	87±6		125±24	99±0	210±0
	subsoil	48±0		91±12	91±0	78±6
Mixed garden 2	topsoil					176±0
	subsoil					78±6
Cassava 1	topsoil	44±0	46±2	95±6	184±0	167±0
	subsoil	26±0	31±5	78±6	159±12	82.5±12
Cassava 2	topsoil			154±6		
	subsoil			125±0		
Cassava and corn	topsoil	36±2				
	subsoil	24±1				
Corn	topsoil				125±12	
	subsoil				74±0	
Paddy rice	topsoil	26±2				
	subsoil	21±2				

Table 7. Correlation coefficients of soil enzymatic activities with some soil chemical and enzymatic properties.

Soil property	Acid phosphatase	Alkaline phosphatase	Arylsulfatase	β-Glucosidase
		Topsoils		
pH	−0.3401	−0.1047	−0.0769	−0.1242
Organic C	−0.0302	0.2342	−0.1137	0.0467
Total N	0.5919***	0.7757***	0.3713*	0.4260*
Exchangeable K	0.2372	0.2929	−0.0159	−0.0171
Available P	−0.0738	−0.0811	−0.1669	−0.0048
CEC	0.0624	0.3215	0.0353	0.1179
		Subsoils		
pH	−0.1671	−0.2037	−0.0556	−0.1267
Organic C	−0.0328	0.0097	−0.1221	−0.0041
Total N	0.0319	0.3488	0.2914	0.3031
Exchangeable K	0.0878	0.1410	0.0503	−0.0437
Available P	0.0705	0.0221	0.2611	0.1210
CEC	0.0335	0.1194	−0.0182	−0.1420

Significance at * 5%, ** 1%, and *** 0.1% levels.

Table 8. Correlation coefficients among activities of soil enzymes (upper-right in topsoils and lower-left in subsoils).

	Acid phosphatase	Alkaline phosphatase	Arylsulfatase	β-Glucosidase
Acid phosphatase	—	0.443*	0.152	−0.026
Alkaline phosphatase	0.267	—	0.443*	0.698***
Arylsulfatase	−0.068	0.534**	—	0.577***
β-Glucosidase	−0.239	0.543**	0.630***	—

Significance at * 5%, ** 1%, and *** 0.1% levels.

0.884***). The activity of β-glucosidase in "sengon" lands, and corn and rice fields was among the lowest.

3. Relationships between physico-chemical properties and enzymatic activities

As shown in Table 7, there was no significant relationship between the physico-chemical properties and respective enzymatic activities in the topsoils and in subsoils except for a significant correlation of total soil N content in the topsoils with all the soil enzyme activities measured. These findings were markedly different from the previous observations in hilly areas of the province, where acid phosphatase and β-glucosidase activities showed significant relationships with the amounts of soil organic C and total N in the topsoils (Salam et al. 1998). CEC values in the topsoils also showed a significant correlation with the activities of β-glucosidase and urease there. This phenomenon may be due to the fact that the differences in these parameters among the land-use systems were small in relation to those reported in the hilly areas in the previous paper based on the low fertility of the secondary forests in the study areas (Salam et al. 1998).

Acid phosphatase activity showed a significant relationship only with alkaline phosphatase activity in the topsoils (Table 8). In contrast, alkaline phosphatase activity showed a significant relation with all the enzymatic activities measured in the topsoils and with arylsulfatase and β-glucosidase activities in the subsoils. Arylsulfatase activity showed a very high correlation with β-glucosidase activity in both topsoils and subsoils (Table 8).

Acknowledgments. These studies were conducted within the framework of the sub-project entitled "Basic Researches on Developing the Techniques for Sustainable Biological Production in the Regions of Red Acid Soils" under the main project named "Basic Research on Environmentally-Sound Biological Production Technology Development in Eastern Asia" supported by the Grant-in-Aid for Creative Basic Science from the Ministry of Education, Science, Sports and Culture of Japan. We thank Professor Satohiko Sasaki, Leader of the Project, and Professors Saburo Tamura and Yasuo Takai, coordinators of the Project, for their encouragement.

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