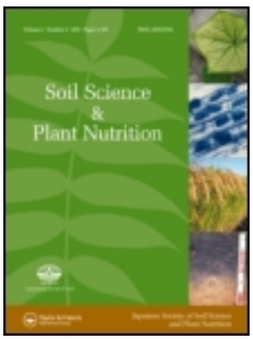

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Soil Enzymatic Activities in a Hilly Coffee Plantation in Lampung Province, South Sumatra, Indonesia, under Plant Cover Management

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The effect of weed cover on the activities of soil enzymes (acid phosphatase, alkaline phosphatase, β-glucosidase, and arylsulfatase) was evaluated in plots established in a coffee plantation field that was located in a hilly area in Lampung Province, South Sumatra, Indonesia. The plots were as follows: plot without cover weed (control plot), plot covered with *Paspalum conjugatum*, and plot covered with the natural vegetation (5 m wide and 20 m long) along a 15° slope. Soil samples were collected from 0 to 20 and 20 to 40 cm depths. The activities of acid phosphatase and β-glucosidase were in general higher in the plots covered with *P. conjugatum* and the natural vegetation. The content of available P was well correlated with the activities of acid phosphatase, β-glucosidase, and arylsulfatase. The decrease in the activities of the soil enzymes in the control plot relative to the plots with plant cover was attributed to a higher degree of soil erosion in the control plot than in the plots with plant cover.

Key Words: **natural vegetation, *Paspalum conjugatum*, soil conservation, soil enzyme, soil erosion.**

Soil erosion is one of the processes that accelerate the degradation of soil fertility in the tropics, particularly in hilly areas with steep slopes. Through this process, the mass of fertile surface soil is carried from upper to lower locations, and due to soil erosion, plant nutrients such as nitrogen, phosphorus, potassium, and other essential elements leak out of the soil with plant growth. Among the soil properties, the decrease in the activities of soil enzymes is seldom considered in the influence of soil erosion on soil fertility. Since soil enzymes play important roles in the cycling of several essential elements in soil-plant systems (Tabatabai 1982; Tate III 1987), it is important to analyze the activities of the soil enzymes from the viewpoint of soil fertility.

Soil enzymes may occur as dissolved and adsorbed entities in soil (Tabatabai and Fu 1992). Dissolved entities may move easily with water through water percolation and/or water runoff, whereas adsorbed entities are firmly fixed and may move only with the soil particles as a result of soil erosion. Hence, soil conservation measures aiming at reducing the magnitude of soil erosion may depress the movements of both essential elements and soil

enzymes. The use of plant cover in soil conservation programs may also stimulate the activities of soil enzymes because plant roots are one of the major enzyme producers (Tate III 1987; Sakai and Tadano 1993; Joner et al. 1995). In addition, the changes in the rhizosphere environment such as temperature, pH, water content, and contents of soil organic matter, total N, and available P may also stimulate or depress the growth and development of enzyme-producing microorganisms and thereby modify the activities of soil enzymes (Pang and Kolenko 1986; Moyo et al. 1989; Neal 1990; Fox and Comerford 1992; Deng and Tabatabai 1996; Salam et al. 1998).

Erosion control by the use of a weed cover is an option for sustainable plantation agriculture developed in hilly areas. In the project entitled "Basic Researches on Developing the Techniques for Sustainable Biological Production in the Regions of Red Acid Soils" supported by the Ministry of Education, Science, Sports and Culture of Japan (1995–1999), experimental plots to estimate the effect of weed cover on erosion control were set up in 1995 in a hilly area under coffee plantations in Lampung Province, South Sumatra, Indonesia, and water run-off and soil erosion were monitored until 1999 (Afandi et al. 1999). In this study, comparison of the soil enzymatic activities (acid and alkaline phosphatases, β-glucosidase, and arylsulfatase) and soil physico-chemical properties among plots with different plant covers was conducted to evaluate the effect of weed cover from the viewpoint of soil microbiology and fertility.

MATERIALS AND METHODS

Experimental plots were established in November 1995 in Sumberjaya, West Lampung, South Sumatra, Indonesia (735 m above the sea level). At the time of plot preparation, every plot was cleared by spraying herbicide (Glyphosate). Each plot was 5 m wide and 20 m long along a 15° slope facing the north, and it had been cultivated with coffee plants (planting space 1.25×2 m^2) since December 1995. Plots prepared were as follows: plot without plant cover (control), plot covered with *Paspalum conjugatum*, and plot covered with natural vegetation. Six-month old seedlings of Arabica coffee were transplanted in December 1995. At the same time, seedlings of *P. conjugatum* were transplanted to the *P. conjugatum* plot. The plot with the natural vegetation was left fallow for the recovery of the natural vegetation. The control plot was manually weeded twice a month. Spot hand-weeding over an area of 0.5 m around a coffee tree was also performed in the plots with plant cover twice a month. *P. conjugatum* and the natural vegetation were mowed at a height of 15 cm twice a year before and after the rainy season.

P. conjugatum was selected because it was locally available and grew easily. Dominant species in the natural vegetation plot included *Chromolaena odorata, Clibadium surinamense, Clidemia hirta, Imperata cylindrica, Melastoma affine, Mikania micrantha, and P. conjugatum* (Oki et al. 1999).

The soil at the plot site was Tropohumults with the following characteristics at the time of plot establishment (0 to 20 cm): sand 25%, silt 23%, and clay 52%; pH 4.9, total N 2.6 g kg^{-1}, organic C 34.8 g kg^{-1}, and CEC 13.3 cmol(+) kg^{-1}. Soil samples (0 to 20 cm and 20 to 40 cm) were collected four times, i.e. in July 1996, November 1997, June 1998, and June 1999, from two sites (30 cm apart from each other) at 5, 10, and 15 m from the upper border of each plot, and mixed. The sites for soil sampling were more than 50 cm apart from the coffee plants. The soil samples were passed through a 2 mm mesh screen without drying. A portion of the soil samples was air-dried, screened through a mesh 2 mm in diameter, and mixed

thoroughly for the analysis of the contents of soil organic C, total N, available P, and pH.

The activities of the soil enzymes were analyzed soon after the collection of the soil samples. The soil enzymes for which the activities were determined included acid and alkaline phosphatases, β-glucosidase, and arylsulfatase. The activities of the soil enzymes were measured at 30°C using the method of Tabatabai (1982). All the analyses were conducted in triplicate. Contents of organic C, total N, and available P, and soil pH were determined using conventional methods (Bremner and Mulvaney 1982; Nelson and Somners 1982).

RESULTS

Changes in soil chemical properties

Changes in the moisture content and soil chemical properties in the respective plots as a result of different management for soil conservation are presented in Table 1.

Moisture content ranged from 32 to 44% in the topsoil and from 38 to 51% in the subsoil, respectively, and it was significantly lower in the topsoil than in the subsoil in every plot ($p<0.001$). In addition, the moisture content was lower in the natural vegetation plot than in the other plots in the topsoil ($p<0.05$), while such a difference in moisture content was not observed in the subsoil. Soil pH and contents of soil organic C and total N in the *P. conjugatum* and the natural vegetation plots in the top part were higher than those in the control plot ($p<0.01$ for the *P. conjugatum* plot and $p<0.05$ for the natural vegetation plot). The effect of plant cover on the soil chemical properties was also observed for the soil pH and contents of soil organic C and total N in the subsoil in the *P. conjugatum* plot ($p<0.001$), and for the soil pH and organic C content in the natural vegetation plot ($p<0.001$). Thus, the effect of plant cover on the soil chemical properties was detectable to a 40 cm depth. All the chemical properties in the subsoil showed a good correlation with those in the topsoil, with correlation coefficients of 0.705*** for the pH, 0.639*** for the organic C content, 0.575*** for the total N content, and 0.576** for the available P content (*$p<0.05$, **$p<0.01$, ***$p<0.001$).

Distance from the upper border affected the moisture content in soil, and the values were significantly higher at the higher position (5 m) than at the lower position (15 m) ($p<0.05$). The effect of the distance was also found to affect the soil chemical properties for the soil samples collected from the control and the natural vegetation plots, but not for the samples from the *P. conjugatum* plot. Contents of soil organic C, total N, and available P were in general higher at the lower position than at the higher position in the control and the natural vegetation plots. These observations indicated the beneficial effect of land cover with *P. conjugatum* on the prevention of soil erosion.

Changes in soil enzymatic activities

Although the activities of alkaline phosphatase and arylsulfatase were not different among the plots, those of acid phosphatases and β-glucosidase were higher in the *P. conjugatum* and the natural vegetation plots than in the control plot (Table 2).

The activities of acid and alkaline phosphatases and β-glucosidase were significantly higher in the topsoil than in the subsoil ($p<0.001$). The activities of the soil enzymes in the topsoil were well correlated with those in the subsoil ($r=0.960$***, 0.691***, 0.726***, and 0.383* for acid phosphatase, alkaline phosphatase, β-glucsidase, and arylsulfatase, respectively).

Table 1. Changes in some soil chemical properties in hilly coffee plots under different soil conservation techniques.

Distance from the top plot border (m)	Layer	Moisture content (%)				pH				Org. C (g kg^{-1})				Total N (g kg^{-1})				Avail. P (mg kg^{-1})		
		1996	1997	1998	1999	1996	1997	1998	1999	1996	1997	1998	1999	1996	1997	1998	1999	1997	1998	1999
Control																				
5	top	41	43	37	42	4.46	5.20	4.86	3.76	22.3	14.7	16.4	21.1	1.7	1.3	1.1	1.8	6.40	1.34	3.52
	sub	46	43	43	48	4.51	4.29	4.60	4.36	21.7	19.3	11.0	16.9	1.7	1.0	0.7	1.2	4.67	1.34	4.15
10	top	41	38	46	41	4.44	4.00	5.11	3.49	14.6	23.1	21.2	21.1	1.3	1.8	1.5	1.5	6.05	2.78	2.78
	sub	44	41	46	47	4.43	3.87	4.87	4.27	12.1	11.7	13.8	7.8	1.0	0.9	0.8	1.1	4.67	0.10	3.48
15	top	37	36	39	37	4.33	3.84	5.06	3.64	27.9	20.1	19.8	20.5	2.2	1.8	1.4	1.8	7.46	1.34	4.26
	sub	43	41	46	45	4.34	4.10	4.74	3.63	17.0	13.1	18.4	5.9	1.5	1.0	1.3	1.3	6.05	2.06	2.15
P. conjugatum																				
5	top	34	44	38	38	5.06	4.59	5.78	4.04	34.7	29.1	28.9	50.0	2.7	2.3	1.1	2.4	5.36	2.06	5.00
	sub	51	48	41	46	5.03	4.33	5.39	4.46	28.8	22.1	21.5	26.6	2.3	2.0	1.2	1.8	5.36	2.78	4.83
10	top	38	39	36	40	5.10	4.94	6.01	3.87	36.9	30.5	29.3	29.2	2.7	1.3	2.2	2.7	4.67	1.34	3.52
	sub	41	43	40	42	5.13	4.66	5.14	4.89	32.2	26.1	25.1	26.9	2.6	2.0	1.7	1.9	4.67	1.34	3.11
15	top	32	33	41	37	5.04	4.68	6.53	3.66	35.0	22.8	27.6	31.1	2.3	1.5	1.6	2.3	4.67	5.00	3.52
	sub	40	45	44	45	5.29	4.57	4.99	4.53	31.6	23.1	24.0	27.5	2.3	1.8	1.7	1.3	5.36	2.06	3.48
Natural vegetation																				
5	top	41	42	39	42	5.47	4.60	5.23	4.14	28.8	17.1	28.9	23.0	2.2	1.3	1.8	2.1	4.67	2.78	3.52
	sub	42	46	40	45	5.28	4.71	5.05	5.22	22.9	21.4	19.1	17.8	2.0	1.5	1.2	1.1	4.67	1.70	5.52
10	top	36	38	40	38	5.28	4.58	5.43	3.97	34.1	12.4	32.9	26.7	2.5	1.3	2.1	2.4	5.36	6.53	3.52
	sub	38	41	46	42	5.37	4.47	5.22	4.56	29.7	11.4	9.2	20.6	2.2	1.1	0.9	1.4	4.67	1.34	2.81
15	top	37	37	38	39	5.15	3.99	5.59	4.68	32.8	22.8	28.3	30.5	2.5	1.7	1.8	2.7	5.36	2.78	5.76
	sub	43	44	43	51	5.03	4.33	5.28	4.91	21.4	13.4	12.4	23.8	1.7	0.8	1.0	1.3	5.36	2.42	2.81

Table 2. Changes in activities of some soil enzymes in hilly cofffee plots under different soil conservation techniques.

Distance from the upper plot border (m)	Layer	Acid phosphatase (μg *p*-nitrophenol g^{-1} h^{-1})				Alkaline phosphatase (μg *p*-nitrophenol g^{-1} h^{-1})			β-Glucosidase (μg *p*-nitrophenol g^{-1} h^{-1})			Arylsulfatase (μg *p*-nitrophenol g^{-1} h^{-1})		
		1996	1997	1998	1999	1997	1998	1999	1997	1998	1999	1997	1998	1999
Control														
5	top	130	123	77	107	36	44	44	123	38	67	458	54	48
	sub	119	73	60	109	19	47	24	76	36	67	23	34	71
10	top	91	277	82	108	74	70	29	127	49	66	206	60	72
	sub	72	211	69	93	57	68	22	81	26	44	282	65	45
15	top	197	268	100	125	91	76	41	140	58	101	206	74	90
	sub	187	226	80	106	31	83	28	59	30	41	241	72	91
P. conjugatum														
5	top	221	322	105	145	104	45	45	157	113	117	97	108	149
	sub	234	281	79	126	74	28	30	100	56	63	21	138	157
10	top	252	272	108	135	95	50	59	188	123	131	496	150	91
	sub	224	251	104	121	82	26	36	107	52	63	292	168	143
15	top	244	281	145	147	61	36	56	147	90	104	428	115	119
	sub	274	233	125	112	27	31	23	66	51	36	182	175	94
Natural vegetation														
5	top	303	271	107	156	36	55	54	168	75	129	165	134	143
	sub	284	251	83	122	27	30	26	191	48	60	139	74	148
10	top	286	286	126	158	27	71	50	103	83	92	160	206	150
	sub	296	190	103	140	6	58	28	83	41	56	251	72	133
15	top	317	299	177	159	61	39	49	159	89	108	185	219	211
	sub	295	277	122	121	44	69	32	95	33	62	89	105	112

Table 3. Correlation coefficients among soil enzymatic activities and chemical properties in a hilly coffee plantation under different soil conservation techniques.

Soil properties	Acid phosphatase	Alkaline phosphatase	β-Glucosidase	Arylsulfatase
Topsoils (0–20 cm)				
Moisture content	−0.263	0.121	−0.220	−0.449*
pH	−0.015	−0.067	−0.126	−0.164
Organic C	0.163	0.187	0.138	−0.005
Total N	0.251	0.170	0.113	−0.190
Available P	0.605**	0.249	0.507**	0.469**
Acid phosphatase		0.405*	0.768**	0.430*
Alkaline phosphatase			0.364	0.198
β-Glucosidase				0.581**
Subsoils (20–40 cm)				
Moisture content	−0.171	0.202	0.058	−0.520**
pH	0.086	0.114	−0.176	−0.078
Organic C	0.385*	−0.059	0.233	0.185
Total N	0.568**	0.045	0.313	0.266
Available P	0.722**	−0.207	0.581**	0.380
Acid phosphatase		0.165	0.717**	0.471*
Alkaline phosphatase			−0.076	−0.057
β-Glucosidase				0.285

* and ** indicate significance at 5% and 1% levels, respectively.

The activities of the soil enzymes were different depending on the distance from the upper border. And the activities of all the enzymes in the control plot were, with a few exceptions, lower of the 5-m position than in the 15-m position (significantly different between the 5-m and 15-m positions for acid phosphatase and β-glucosidase at the level of $p<0.05$). In contrast, the activities of these enzymes in the *P. conjugatum* plot were in many cases lower in the 15-m position than in the 5-m position.

Relationships between soil physico-chemical properties and soil enzymatic activities

Relations between the soil physico-chemical properties and soil enzymatic activities are indicated in Table 3. In the topsoil, only the content of available P showed a positive correlation with the activities of acid phosphatase, β-glucosidase, and arylsulfatase. On the contrary, the activity of acid phosphatase showed a correlation with the contents of organic C, total N, and available P in the subsoil. Moisture content showed a negative correlation with the activity of arylsulfatase in both the topsoil and subsoil. The activity of acid phosphatase showed a significant correlation with the other enzymatic activities tested in the topsoil, and with the activities of β-glucosidase and arylsulfatase in the subsoil, respectively.

DISCUSSION

Enzymes in plant roots play an important role in the supply of soil enzymes (Tabatabai 1982; Tate III 1987). Different plants supply different amounts of enzymes to the soil systems. As the activities of acid phosphatase and β-glucosidase were higher in the *P. conjugatum* and the natural vegetation plots than in the control plot, enzymes from plant roots and the stimulation of microbial activity by cover plants seemed to have contributed to the increase in the activities of these soil enzymes.

Soil erosion may be another factor that induced the differences in the activities of soil enzymes among the plots. The total water runoff recorded in three rainy seasons (1996–1998) at the lower border of the plots amounted to 284, 7, and 114 mm in the control, *P. conjugatum*, and the natural vegetation plots, respectively (Afandi et al. 1999). The total amount of soil erosion during the period was also lowest in the *P. conjugatum* plot (0.4 Mg ha^{-1}), followed by the natural vegetation and control plots (3.9 and 32.2 Mg ha^{-1}, respectively) (Afandi et al. 1999). As shown in Table 1, the contents of organic C and total N in soil were lower at the 5-m position than those at the 15-m position in the control and natural vegetation plots, which suggested the remarkable effect of soil erosion on their contents in these plots. In contrast, no difference in the contents of organic C and total N in soil between the 5-m and 15-m positions from the top border of the plot was observed in the *P. conjugatum* plot. Activities of soil enzymes were reported to show a good correlation with the contents of organic C and total N in soil (Tate III 1984; Baligar et al. 1988; Salam et al. 1998, 1999a, b). The present experiment showed that the activities of the soil enzymes were lower at the 5-m position than at the 15-m position in the control plot, whereas such a difference in enzymatic activities was not observed in the *P. conjugatum* plot. These findings also suggested that the higher activities of the soil enzymes in the *P. conjugatum* plot could be ascribed partly to a lower degree of soil erosion in this plot. However, the relations of the contents of organic C and total N with the activities of the soil enzymes were not statistically significant (Table 3), presumably due to the seasonal and interannual variations of soil conditions such as moisture content, because their relations were significant on many sampling occasions in the topsoil: e.g. in 1996* (organic C and total N) and 1999* (total N)

for acid phosphatase, in 1997** (organic C), 1997* (total N), and 1999* (total N) for alkaline phosphatase, in 1997* (organic C), 1998* (organic C), and 1999* (total N) for β-glucosidase, and in 1998** (organic C), 1998* (total N), and 1999* (total N) for arylsulfatase ($*p<0.05$, $**p<0.01$; data not shown). However, no direct correlation of the enzymatic activities with the moisture content was detected in any of the plots in the topsoil.

Recently, it has been suggested that the extraction of *p*-nitrophenol with $CaCl_2$ and NaOH from the soil that was used in the present experiment (Tabatabai 1982) was incomplete in compared with the extraction with ethanol from McIlvaine buffer (phosphate/citric acid buffer; Hayano 1973) (Ishizuka 2000). Ishizuka (2000) also reported a lower recovery of *p*-nitrophenol from soils with a high organic content. Although we did not analyze the recovery percentage of *p*-nitrophenol from the soil used, as the purpose of the present study was to compare the soil enzymatic activities among the plots under different plant covers originally with the same organic matter content, the effect of plant cover on the soil enzymatic activities was not considered to be affected by the extraction method to the degree that the method made the purpose of study ambiguous.

In conclusion, the present experiment showed that erosion control by weed cover not only enabled to maintain high activities of soil enzymes such as acid phosphatase and β-glucosidase, but also enabled to preserve the soil chemical properties related to soil fertility. Thus, the use of plant cover was considered to be a promising management method for sustainable plantation agriculture in hilly areas in terms of soil biology and fertility as well as of agricultural engineering.

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