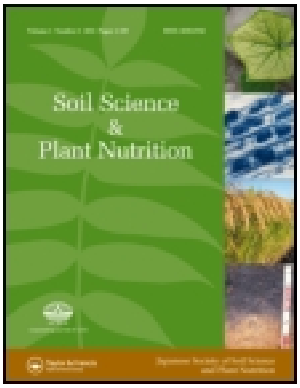

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Activities of Soil Enzymes in Fields Continuously Cultivated with Cassava, Sugarcane, and Pineapple in Middle Terrace Areas of Lampung Province, South Sumatra, Indonesia

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Changes in the activities of soil enzymes (acid and alkaline phosphatases, β-glucosidase, and arylsulfatase) associated with continuous cultivation of cassava, sugarcane, and pineapple were studied in middle terrace areas of Lampung Province, South Sumatra, Indonesia. Soil samples were collected from fields continuously cultivated with cassava for the period ranging from 0 to 10 y, with sugarcane from 0 to 20 y, and with pineapple from 0 to 10 y. Continuous cultivation did not show conspicuous effects on soil pH, and contents of total N, organic C, and available P as well as soil enzymatic activities. However, the changes in the activities of the soil enzymes generally showed a significant relationship with the contents of soil organic C and total N.

Key Words: **cassava, continuous cultivation, pineapple, soil enzymes, sugarcane.**

Although the important role of plant species in affecting the activities of soil enzymes has been demonstrated (Tate III 1987; Fox and Comerford 1992; Sakai and Tadano 1993; Joner et al. 1995), the effects of continuous cultivation of particular plants on the activities of soil enzymes are not well documented.

Since soil enzymes such as phosphatases and arylsulfatase play a major role in the biocycling of P and S (Tabatabai 1982; Tate III 1987), information on the effects of continuous planting of particular crops on the activities of soil enzymes is very important for sustainable management of fields.

Long-term cultivation of fields continuously for particular crops may bring about specific changes in soil chemical properties. High absorption of cations by crops, for example, acidifies rhizosphere soils (Tisdale et al. 1985; Singer and Munns 1987). In general, the activity of phosphatases increases with the increase in soil pH to the optimum pH, and decreases thereafter (Malcolm 1983; Rojo et al. 1990; Salam et al. 1998). Such a dependency of enzymatic activities on soil pH results from the reversible reaction of the ionization and deionization of acidic and basic groups in the active center of the enzymes (Frankenberger and Johanson 1982).

Changes in soil properties such as contents of organic C and total N in soils due to continuous cultivation of particular crops affect the activities of soil enzymes (Nannipieri et al. 1980; Frankenberger and Dick 1983; Baruah and Mishra 1984; Baligar et al. 1988).

As the activities of soil enzymes depend on the nutrient status in soils, specific application of fertilizers for continuous cropping of particular plant may eventually change the activities of soil enzymes. For example, the activity of phosphatases is dependent on the concentration of orthophosphates in soil, and heavy application of phosphatic fertilizers decreased the activity of phosphatase in soils (Pang and Kolenko 1986; Fox and Comerford 1992).

This study was conducted to analyze the effects of continuous cultivation of sugarcane, cassava, and pineapple on the activities of soil enzymes in relation to the changes in some soil chemical properties.

MATERIALS AND METHODS

Soil samples were collected from Ap horizons (0–20 cm) of cassava (*Manihot esculenta*), sugarcane (*Saccharum officinarum*), and pineapple (*Ananas comusus*) fields. The soils were sampled in the center between plant rows. All the fields were located in the northeastern part of Lampung Province, South Sumatra, Indonesia, with soil types of Distropepts. Location of the respective fields is shown in Fig. 1. Ten cassava fields owned by farmers, of which 5 had been cultivated for 1 to 5 y and the other 5 for 6 to 10 y, were selected (10 y was the longest period). They were fertilized at the rates of 250, 125, and 125 kg ha^{-1} as urea, triple superphosphate, and KCl, respectively. Five locations under secondary forests near cassava fields were also chosen as the controls of cassava fields. In each of

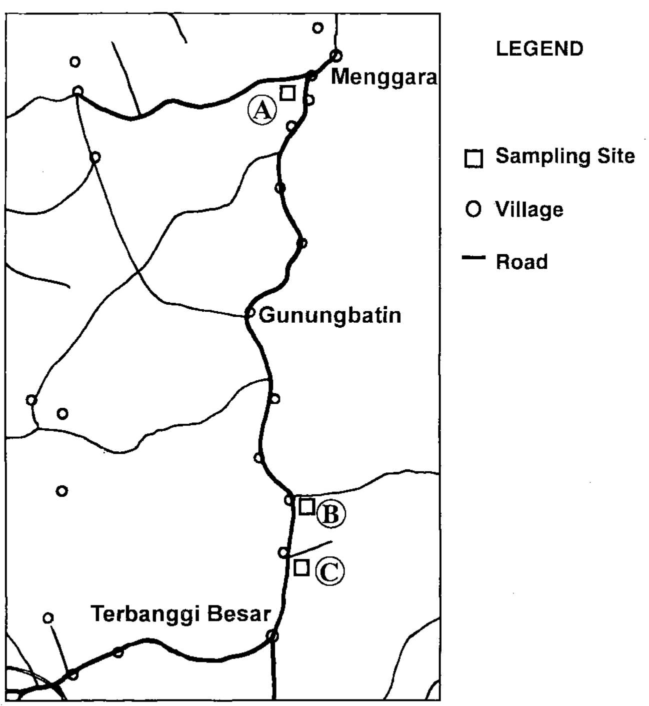

Fig. 1. Map of sampling sites (4°27′ S to 4°55′ S and 105°0′ E to 105°18′ E). Sampling sites: (A) cassava fields in several villages, (B) sugarcane fields, and (C) pineapple fields, respectively.

these fields, soil samples were collected from 5 sampling points at least 200 m apart from each other. The date of soil sampling was February 12, 1997 (about 2 months after planting).

Some of the sugarcane and pineapple fields had been cultivated for about 10 and 20 y, respectively. They belonged to private companies (the total area of both plantations covered several thousand hectares). Sugarcane fields were fertilized with 1,500 to 2,500 kg ha^{-1} of triple superphosphate at the time of opening, and additional 500 kg ha^{-1} of triple superphosphate, 600 to 700 kg ha^{-1} of urea, and 800 kg ha^{-1} of KCl were applied during each cultivation period. Soil samples from sugarcane plantation fields were collected from fields with continuous cultivation for 3, 9, 13, and 20 y (sampled on December 16, 1997, the time between harvest and the next planting), while those from pineapple plantation fields were collected from fields with continuous cultivation of 1, 2, 3, and 4 cycles (the duration of one cycle for pineapple harvest was about 2 and a half years). Pineapple fields were fertilized with 500 kg-N ha^{-1} as urea in the first plantation period and 250 kg-N ha^{-1} in the succeeding plantation periods as well as with 500 to 750 kg ha^{-1} of rock phosphate (from Tunisia; 135 to 200 kg-P_2O_5 ha^{-1}) and 1,000 kg ha^{-1} of KCl during each plantation period. The date of soil sampling was May 3, 1997 (the time between harvest and the next planting). Secondary forests adjacent to the sugarcane fields and newly opened secondary forests near the pineapple plantation fields were selected as controls for the sugarcane and pineapple fields, respectively. At each sampling, soils were collected from 5 sampling points at least 200 m apart from each other.

Soon after sampling, the soils were passed through a 2-mm mesh screen, and thoroughly mixed without drying. Activities of soil enzymes were determined as early as possible after the preparation of soils. Activities of acid and alkaline phosphatases, β-glucosidase, and arylsulfatase were determined by the modified methods of Tabatabai (1982), reported 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. 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. Activity of each enzyme was determined at 30 °C.

A portion of the soil samples was sieved through a 2-mm mesh screen after air-drying for the analyses of soil chemical properties such as soil pH, and contents of organic C, total N, and available P (Bremner and Mulvaney 1982; Nelson and Somners 1982).

RESULTS AND DISCUSSION

1. Changes in soil chemical and enzymatic properties

As shown in Table 1, soil pH and contents of organic C and total N were consistently higher in secondary forests than in cassava fields nearby, and tended to decrease with the duration of cassava cultivation. The content of available P was highest in cassava fields subjected to 1- to 5-y cultivation. The higher content of available P in the fields subjected to 1- to 5-y cultivation may be due to heavy application of P-fertilizers.

Activities of acid phosphatase, β-glucosidase, and arylsulfatase in soils were highest in secondary forests and also tended to decrease with the duration of cassava cultivation (Table 2). The activity of alkaline phosphatase was higher in secondary forests and cassava fields subjected to 1 to 5 y cultivation than in the cassava fields subjected to 6 to 10 y cultivation.

Although consistent changes in the soil chemical properties by continuous cultivation of sugarcane did not show any clear tendency (Table 1), the higher content of available P in the sugarcane fields subjected to 13- and 20-y cultivation reflected the effect of continuous application of P-fertilizers.

Table 1. Selected chemical properties of the soil samples collected from cassava, sugarcane, and pineapple plantation fields (average±SD).

Plant	Years used	pH	Organic C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Av. P ($mg\ kg^{-1}$)
Cassava	S.F. nearby*	4.7±0.1 a**	43.0±9.6 a	2.6±0.9 a	5.03±1.98 a
	1–5 y	4.5±0.4 a	20.0±5.2 b	1.0±0.2 a	24.7±23.2 b
	6–10 y	4.4±0.6 a	12.8±1.3 b	0.8±0.0 a	7.70±2.37 a
Sugarcane	S.F. nearby*	5.1±0.2 a	22.9±0.6 ab	0.8±0.2 a	8.44±2.86 a
	3 y	5.2±0.3 a	18.6±4.9 bc	0.8±0.2 a	7.19±3.67 a
	9 y	4.9±0.3 a	28.3±6.1 a	1.6±0.5 a	8.16±3.10 a
	13 y	5.5±1.1 a	14.6±1.2 c	0.7±0.1 a	23.1±5.61 b
	20 y	4.7±0.2 a	23.1±2.2 ab	0.9±0.2 a	63.6±25.2 c
Pineapple	just opened*	4.6±0.3 a	14.4±2.5 a	0.8±0.2 a	199±19 a
	1st	4.3±0.0 a	12.3±1.2 a	0.7±0.1 a	3.17±2.24 b
	2nd	4.3±0.0 a	12.3±1.2 a	0.7±0.1 a	3.17±2.24 b
	3rd	4.0±0.2 a	15.2±3.6 a	0.8±0.1 a	11.0±7.4 b
	4th	4.0±0.1 a	13.5±2.6 a	0.7±0.1 a	21.5±19.2 b

*See text. **Values not followed by the same letter differ significantly at $p<5\%$ (analysis of variance). Comparison was made separately among the fields of respective plants under different cultivation histories.

Table 2. Activities of some enzymes in the soil samples collected from cassava, sugarcane, and pineapple plantation fields (average±SD).

Plant	Years used	Acid phosph.	Alk. phosph.	β-Glucos.	Arylsulf.
		μg *p*-nitrophenol $g^{-1}\ h^{-1}$			
Cassava	S.F. nearby*	72±26 a**	46±17 a	40±8 a	195±28 a
	1–5 y	56±7 a	50±14 a	30±4 a	32±4 b
	6–10 y	47±2 a	35±5 a	30±2 a	26±5 b
Sugarcane	S.F. nearby*	140±21 a	33±17 a	90±13 a	161±24 a
	3 y	132±16 a	41±10 a	58±18 b	44±13 c
	9 y	142±26 a	128±42 b	74±9 ab	100±28 b
	13 y	82±31 b	36±9 a	51±27 b	43±8 c
	20 y	96±15 b	52±19 a	59±11 b	37±9 c
Pineapple	just opened*	58±3 a	38±4 b	37±14 a	30±1 ab
	1st	51±2 ab	36±11 b	36±3 a	27±5 ab
	2nd	49±2 b	29±5 a	46±1 b	24±2 a
	3rd	55±6 ab	36±3 ab	31±4 a	30±3 ab
	4th	51±3 ab	45±5 c	32±3 a	31±4 b

*See text. **Values not followed by the same letter differ significantly at $p<5\%$ (analysis of variance). Comparison was made separately among the fields of respective plants under different cultivation histories.

Acid and alkaline phosphatase activities were highest in the sugarcane fields subjected to 9-y cultivation (Table 2). The activities of β-glucosidase and arylsulfatase were also the second highest in the sugarcane fields subjected to 9-y cultivation next to the secondary forests. The activities of all the enzymes in the sugarcane fields subjected to 13- and 20-y cultivation were in general lower than those in the fields with a shorter duration of continuous sugarcane cultivation.

Soil pH consistently decreased with the duration of continuous planting of pineapple (Table 1). Changes in contents of organic C, total N, and available P did not show any clear tendency with the year of continuous planting of pineapple. Contents of organic C, total N, and available P were lowest in the pineapple fields of the 2nd cycle (about 5-y continuous planting of pineapple).

Changes with time in the activities of the soil enzymes did not show any clear pattern in the pineapple fields (Table 2). However, it was observed that the activities of acid and alkaline phosphatases and arylsulfatase were lowest in the pineapple fields of the 2nd cycle. In contrast, β-glucosidase showed the highest activity in the fields of the 2nd cycle. The activities of acid phosphatase in the pineapple fields that had been recently cleared from secondary forests tended to be higher than those in the fields with a longer history of pineapple plantation.

These findings indicated that there was no consistent trend in the soil chemical properties and enzymatic activities associated with continuous cultivation of the respective plants tested in the studied areas.

As the season of soil sampling was different among the fields of the respective plants (cassava fields in February, sugarcane fields in December, and pineapple fields in May), direct comparison could not be performed for the effects of continuous cultivation of particular plants on the activities of soil enzymes. However the negligible effect of the kind

Table 3. Correlation coefficients for some chemical and enzymatic properties of the soil samples from cassava, sugarcane, and pineapple plantation fields.

Soil properties	pH	Org.-C	Total-N	Avail. P	Ac. phos.	Alk. phos.	β-Gluc.	Arylsulf.
Top right values for overall and bottom left values for cassava soil samples:								
pH		0.180	0.046	−0.003	0.542**	0.121	0.499**	0.294*
Organic-C	0.323		0.853**	−0.116	0.476**	0.438**	0.348**	0.738**
Total-N	0.210	0.971**		−0.142	0.260*	0.475**	0.110	0.632**
Available P	0.563*	−0.174	−0.275		−0.138	−0.058	−0.164	−0.196
Acid phosph.	0.072	0.898**	0.934**	−0.243		0.489**	0.794**	0.538**
Alk. phosph.	−0.023	0.605*	0.545*	−0.031	0.526*		0.369**	0.307*
β-Glucosidase	0.292	0.790**	0.786**	−0.287	0.575*	0.516*		0.550**
Arylsulfatase	0.374	0.887**	0.859**	−0.278	0.670**	0.348	0.832**	
Top right values for sugarcane and bottom left values for pineapple soil samples:								
pH		−0.347	−0.183	−0.245	0.009	−0.157	0.005	−0.025
Organic-C	−0.022		0.644**	−0.030	0.479*	0.527**	0.379	0.351
Total-N	0.410*	0.438*		−0.196	0.455*	0.837**	0.189	0.241
Available P	0.416*	0.071	0.007		−0.480*	−0.152	−0.273	−0.443*
Acid phosph.	0.117	0.542**	0.481*	0.350		0.407*	0.550**	0.582**
Alk. phosph.	−0.166	0.482*	0.296	0.196	0.348		0.233	0.235
β-Glucosidase	−0.308	0.419*	0.241	0.176	0.444*	0.722**		0.731**
Arylsulfatase	0.329	0.049	0.269	−0.251	0.147	−0.152	−0.167	

* and ** Significant at 5% and 1% levels, respectively.

of plant on the enzymatic activities described before agreed well with the previous findings (Salam et al. 1999) that no distinct differences in enzymatic activities in soils were observed among the land-use systems (secondary forests, cacao plantations, pineapple plantations, rubber plantations, mixed gardens, cassava fields, corn fields, a rice-field, etc.) in the central and northeastern regions of Lampung Province.

Although it was reported that the activities of soil enzymes readily decreased by cultivation of soils (Jha et al. 1992; Salam et al. 1998), the present results showed that only arylsulfatase activity decreased due to continuous cultivation of cassava and sugarcane (Table 2). In addition, unlike the contents reported by Pang and Kolenko (1986) and Fox and Comerford (1992), the high contents of phosphate in soils did not result in appreciably high activities of phosphatases (Table 3).

In general, the changes in the contents of soil organic C and total N seemed to be responsible for the changes in the activities of the soil enzymes in the fields cultivated continuously with particular plants.

2. Relationships between activities of soil enzymes and chemical properties

As shown in Table 3, among the soil chemical properties investigated, the content of organic C showed a highly significant correlation with the content of total N within the fields of any plant ($r=0.438^*$ to 0.971^{**}). The content of organic C in soils showed the most positive correlation with the activities of nearly all kinds of soil enzymes irrespective of the type of plant cultivated ($r=0.605^*$ to 0.898^{**} in the cassava fields, $r=0.351$ to 0.527^{**} in the sugarcane fields, and $r=0.419^*$ to 0.542^{**} in the pineapple fields, excluding arylsulfatase).

The content of total N in soils also showed a positive correlation with the activities of all the soil enzymes tested in the cassava fields ($r=0.545^*$ to 0.934^{**}), with the activities of acid and alkaline phosphatases in the sugarcane fields ($r=0.455^*$ and 0.837^{**}, respectively), and with that of acid phosphatase in the pineapple fields ($r=0.481^*$). Activities of soil enzymes under several land-use systems were also found to be in general well correlated with the content of total N (Salam et al. 1999).

Statistical evaluation of all the data indicated that the activities of the soil enzymes were well correlated with each other ($r=0.307^*$ to 0.794^{**}). In addition, significant relations were found between the activities of acid phosphatase and the other enzymes in the cassava ($r=0.526^*$ to 0.670^{**}) and sugarcane ($r=0.407^*$ to 0.582^{**}) fields. In the previous study on the activities of soil enzymes in several land-use systems, acid phosphatase activity showed a significant relationship only with alkaline phosphatase activity, while alkaline phosphatase activity also showed a significant relation with the activities of β-glucosidase and arylsulfatase (Salam et al. 1999). The activities of β-glucosidase also showed a positive correlation with those of arylsulfatase in the cassava fields ($r=0.832^{**}$) and in the sugarcane fields ($r=0.731^{**}$).

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