Nutrient Cycling in Agroecosystems **69:** 1–4, 2004.

Note

Effect of weed management in coffee plantation on soil chemical properties

Sarno[1,*], Jamalam Lumbanraja[1], Afandi[1], Tadashi Adachi[2], Yoko Oki[2], Masaharu Senge[3] and Akira Watanabe[4]

*[1]Faculty of Agriculture, University of Lampung, Bandar-Lampung 35145, Indonesia; [2]Faculty of Environmental Science and Technology, Okayama University, Tsushima-Naka, Okayama 700-8530, Japan; [3]Faculty of Agriculture, Gifu University, Yanagido, Gifu 501-1193, Japan; [4]Graduate School of Bioagricultural Sciences, Nagoya University, Chikusa, Nagoya 464-8601, Japan; *Author for correspondence (Fax: +62-72/-702767; E-mail: jur-tanah@maiser.unila.ac.id)*

Received 14 January 2003; accepted in revised form 27 November 2003

Abstract

Coffee plantation in south Sumatra, Indonesia, is developed on the slopes in hilly areas, where soil erosion is a severe problem. Introduction of weed as cover plant has been found to be effective in the reduction of soil erosion. Here the effect of weed management, weeding and coverage with *Paspalum conjugatum* Berg. or natural weeds, on soil chemical properties was investigated. After 4 years, contents of total C, total N, available P, and exchangeable (ex.) Mg in the 0–10 cm and 10–20 cm depth layers were significantly greater in the *Paspalum conjugatum* and natural weed plots than in the weeding plot. In the 0–10 cm layer, ex. K and ex. Ca were also greater in the weed-introduced plots than in the weeding plot. Decrease in soil pH (H_2O) and the increase in ex. Al under coffee plantation were reduced by the coverage with weeds. Thus soil coverage with weeds in coffee plantation on slopes was effective in the maintenance of soil fertility.

Introduction

Red acid soils, widely distributed in Indonesia, have low crop productivity due to low nutrient supplying potential and high soil erosion. Soil erosion is a severe problem, especially in plantation of coffee and fruits developed on the steep slopes of hilly areas, because ca. 2500 mm of annual precipitation occurs in about 4 months of rainy season. To reduce soil erosion, an application of plant mulch (Michels et al. 1995; Buerkert and Lamer 1999) or an introduction of cover plant (Daniels and Gilliam 1996; Robinson et al. 1996; Gilley et al. 2000) is recommended. The use of grass hedge has been reported to reduce soil loss by 50–85% (Daniels and Gilliam 1996; Robinson et al. 1996; Gilley et al. 2000). Afandi et al. (2002, 2003) introduced a gramineous perennial weed *Paspalum conjugatum* Berg. into coffee plantation as cover plant to prevent soil erosion. *Paspalum conjugatum* is widely used in private or public park areas in Indonesia. It grows rapidly with roots produced irregularly from stalks crawling over the ground and making dense rhizomes. Soil erosion was reduced when the land was covered with weeds, and the soil loss during the 4-y period was 4.96 and 0.28 mm in the weeding and *Paspalum conjugatum* plots, respectively (Afandi et al. 2002). Salam et al. (2001) determined enzyme activities in a coffee soil to evaluate the biochemical effect of weeds. They found higher activities of acid phosphatase and β-glucosidase in the *Paspalum conjugatum* plot than in the weeding plot. In this paper, the coverage of coffee soil with weeds is evaluated with respect to the soil chemical properties by comparing them with a weeded soil.

Materials and methods

The field experiment was conducted on a slope with an altitude of 780 m and 15^o gradient in Sumberjaya, Province of West Lampung, Sumatra, Indonesia (105^{o}01′ EL; 04°34′ SL). Soil was classified as Vertic Dystrudepts. The average rainfall was ca. 2500 mm y^{-1} and the average air temperature was 22 °C. Shrubs grew wild at the site before the experiment. They were cut down, the land was cleared without burning, and herbicides were applied. The initial contents of soil total C in the layers of 0–10, 10–20, and 20–30 cm were 33.4, 18.1, and 14.5 Mg ha^{-1}, respectively.

Three plots of 20 m slope length and 5 m width were prepared as follows, and six-month-old coffee *Arabica* was transplanted with 2 m × 1.5 m spacing in November 1995. Treatment 1 (T-1): ground surface was kept bare by hand-weeding at an interval of four weeks, which is a common management practice followed by native farmers. Treatment 2 (T-2): seeds of *Paspalum conjugatum* Berg. were sowed. The soil coverage reached 100% by May 1996. Treatment 3 (T-3): natural weeds were allowed to grow. Weed species observed in T-3 were described by Sriyani et al. (1999). As basal fertilizer, urea, $Ca(H_2PO_4)_2$, and KCl were applied at the rates of 200 kg ha^{-1}, 45 kg P_2O_5 ha^{-1}, and 100 kg ha^{-1}, respectively, just after transplanting, and then half the amount was applied again every April and October. Each plot was surrounded by 30-cm-high zinc metal sheets. In T-2 and T-3, hand-weeding was conducted for the area within 1 m around each coffee plant to avoid the competition of nutrients between coffee and weeds. Weeds were mowed before and after the rainy season at a height of 15 cm from the soil surface. Biomass of weed roots during the experimental period was in the range of 0.2–0.4, 1.1–2.3, and 0.8–6.1 kg dry weight (dw) m^{-3} in T-1, T-2, and T-3, respectively (Sriyani et al. 1999). That in T-1 was about half compared with the initial time (0.74 kg dw m^{-3}; personal communication).

Soil samples were collected on 1 November 1999 from three lines at 5, 10, and 15 m from the top of each plot. The direction of sampling line was decided to take the length of plot and the influence of erosion into consideration. Three soil profiles were made at each line, and soil was collected from three layers of 0–10, 10–20, and 20–30 cm depth. Bulk density was 1.04 to 1.05 for T-1 soils, 0.87 to 0.94 for T-2 soils, and 0.91 to 1.01 for T-3 soils. Three soil samples collected from the same depth at each line were combined to make a composite sample, then air-dried and sieved ($<$ 2 mm).

Total C and total N concentrations of the soil samples were determined using a NC analyzer, Sumigraph NC-800 (Shimadzu, Japan) after pulverization with a vibration mill (TI-100, Heiko Ltd., Japan). Soil pH was measured in suspensions of soil with deionized water mixed at the ratio of 2.5 mL to 1 g. Available P was extracted with a mixture of 0.03 M NH_4F and 0.1 M HCl according to the Bray-2 method (Shiga and Miyake 1975) and determined using the molybdenum blue method. The cation exchange capacity (CEC) was obtained by titration of the remaining ammonium ion in extract after replacement of cation exchange sites with neutral 1 M ammonium acetate. Exchangeable (ex.) K, Mg, and Ca in the ammonium acetate extract were determined using an atomic absorption spectrophotometer AA 782 (Nippon Jarrell-Ash). The exchangeable Al was determined by the KCl method (Thomas 1982). Particle size distribution of soils was measured by a hydrometer method according to Gee and Bauder (1986).

The variations in soil chemical properties among three samples collected from the same layers at different lines of a plot were small for some cases whilst very large for other cases, and on the whole, they were too large to consider each sample as an average of the plot. Hence, we treated three soil samples from different lines as replications to estimate the differences in soil chemical properties among the plots and layers. Significance of differences was analyzed by ANOVA.

Results and discussion

Soil pH (Table 1) of the 0–10 cm layer was lower in T-1 compared with T-2 and T-3. The initial soil pH was reported to be 4.92, 4.89, and 4.91 for the layers of 0–10 cm, 10–20 cm and 20–30 cm, respectively (Afandi et al. 2002). Hence, soil pH was maintained or increased slightly due to coverage with weeds.

Total C and total N contents (Table 1) were significantly greater in T-2 and T-3 than in T-1 in all the layers, except for those in the 20–30 cm layer between T-1 and T-2. No significant difference was found between T-2 and T-3. Both the accelerated decomposition of soil organic matter in T-1 under no weed conditions and the larger supply of organic matter in T-2 and T-3 may be the causes of the dif-

Table 1. Chemical properties of coffee soils with and without coverage by weeds.

Layer	Treatment[a]	pH (H_2O)	Total C ($Mg\ ha^{-1}$)	Total N ($Mg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	CEC ($kmol_c\ ha^{-1}$)	Exchangeable cation ($kg\ ha^{-1}$) K	Mg	Ca	Al
0–10 cm	T-1	4.50 e	29.9 b	2.20 b	13.3 b	174 a	15.2 bc	3.0 d	11.0 d	25.0 a
	T-2	4.94 bc	37.6 a	2.84 a	14.9 b	167 a	23.0 a	12.0 bc	22.7 bc	7.7 cd
	T-3	5.23 a	39.4 a	2.90 a	32.5 a	177 a	18.1 ab	19.7 a	43.5 a	3.3 d
10–20 cm	T-1	4.49 e	19.1 c	1.52 cd	3.9 ef	154 a	12.4 cde	2.6 d	9.5 d	25.9 a
	T-2	4.63 de	27.2 b	2.15 b	6.6 d	156 a	13.7 bcd	8.4 c	15.9 cd	12.3 bc
	T-3	5.10 ab	30.1 b	2.30 b	10.8 c	164 a	13.4 bcde	14.9 b	31.5 b	5.4 cd
20–30 cm	T-1	4.53 e	11.9 d	1.03 e	2.0 f	146 a	11.2 cde	2.5 d	7.4 d	26.4 a
	T-2	4.78 cd	15.8 cd	1.33 de	3.1 ef	150 a	8.9 de	4.7 d	10.9 d	19.4 ab
	T-3	4.63 de	20.8 c	1.71 c	5.1 e	176 a	7.9 e	10.7 bc	28.9 b	22.5 a

Values not followed by the same letter differ significantly ($P < 0.05$). [a] T-1, weeding; T-2, coverage with *Paspalum conjugatum* Berg.; T-3, coverage with natural weeds.

Table 2. Particle size distribution of coffee soils with and without coverage by weeds.

Layer	Treatment[a]	Sand (%)	Silt (%)	Clay (%)
0–10 cm	T-1	43.5 a	19.3 abc	37.1 ab
	T-2	44.2 a	20.9 ab	35.0 ab
	T-3	43.7 a	22.7 a	33.6 b
10–20 cm	T-1	43.2 a	13.4 bc	43.4 ab
	T-2	42.5 a	18.6 ab	39.1 ab
	T-3	39.8 a	19.1 ab	41.2 ab
20–30 cm	T-1	38.2 a	10.4 c	48.4 a
	T-2	41.5 a	14.0 bc	44.5 ab
	T-3	36.8 a	17.3 abc	46.0 ab

Values not followed by the same letter differ significantly ($P < 0.05$); [a]T-1, weeding; T-2, coverage with *Paspalum conjugatum* Berg.; T-3, coverage with natural weeds.

ferences in total C and total N. The applicability of the latter to the lower layer (20–30 cm) was supported by the differences in root biomass, which were 18, 17, 92, and 135 g dw m^{-2} on average for the initial soil, T-1, T-2, and T-3, respectively (Sriyani et al. 1999, and personal communication).

The available P (Table 1) was also greater in T-2 and T-3 than in T-1 in the upper two and all three layers, respectively. Higher activities of acid and alkali phosphatases in the topsoil (0–20 cm), subjected to the same treatments as T-2 and T-3 compared to the topsoil of the weeding plot (Salam et al. 2001) agreed with our results.

The CEC values did not differ significantly among the samples (Table 1). Although soil texture also did not vary among the samples (Table 2), the proportion of clay fraction showed an opposite trend of total C content (Table 1). This was conspicuous between the 20–30 cm layer of T-1 with the highest clay percentage and lowest C content among the samples and the 0–10 cm layer of T-3 with the lowest clay percentage and highest C content. Since the turnover time of soil organic matter is expected to be longer in a smaller particle size fraction (Balesdent 1996), the closer relationship of total C to the proportion of silt fractions ($r = 0.617^{***}$) than to that of clay fraction suggests the low stability of organic matter in the Sumberjaya coffee soil.

The ex. cation contents differed between the plots. The effect of weed introduction was more remarkable on ex. Mg. In the upper two layers, ex. Mg contents in T-2 and T-3 were 3.2–4.0 and 5.7–6.6 times as large as those in T-1, respectively. In the 0–10 cm layer, ex. Ca was also greater in T-3 followed by T-2 and T-1, while a significant difference in ex. K content was detected only between T-2 and T-1. A portion of ex. cations associated with soil organic matter in T-1 may have been lost following the decomposition of soil organic matter. As the growth of coffee plants was better in T-2 than in T-3 (Sriyani et al. 1999), larger absorptions of P, Mg, and Ca by native vegetation in T-3 than by *Paspalum conjugatum* in T-2, followed by their return to soil, is a possible mechanism leading to the differences in contents of available P and ex. Mg and Ca, as well as pH, between T-2 and T-3.

The opposite trend of ex. bases was observed for ex. Al. The ex. Al contents in the 0–10 and 10–20 cm layers were much lower in T-2 and T-3 than in T-1. Ex. Al in T-2 and T-3 increased with soil depth, and the difference from T-1 was insignificant in the layer 20–30 cm. These results suggested that the ex. Al content in the upper soil could be reduced by the introduction of weeds in comparison with the conventional soil management, which may be associated with the retardation of decomposition of soil organic matter and the maintenance of ex. cations.

Based on the present results, it was concluded that the introduction of weed as cover plant to coffee on slopes was effective in maintenance of chemical properties of soil. The suppression of coffee growth in the weed-introduced plots could not be avoided in the present experiment, which was indicated by the ratio of canopy area T-1:T-2:T-3 = 6:3:2 (Sriyani et al. 1999). Hence, improvement is required to guarantee the initial growth of coffee plant, e.g., delaying the seeding of *Paspalum conjugatum* or keeping bare in a larger area around coffee plant than the present study.

Acknowledgements

This research was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science, Sports and Culture of Japan (No. 09NP0901) and from the Japan Society for the Promotion of Science (No. 12574013).

References

Afandi, Manik T.K., Rosadi B., Utomo M., Senge M., Adachi T. and Oki Y. 2002. J. Jpn. Soc. Soil Phys. 91: 3–14.

Afandi, Manik T.K., Rosadi B., Utomo M., Senge M., Adachi T. and Oki Y. 2003. J. Jpn. Soc. Soil Phys. 92: 3–16.

Balesdent J. 1996. Eur. J. Soil Sci. 47: 485–493.

Buerkert A. and Lamers J.P.A. 1999. Plant Soil 215: 239–253.

Daniels R.B. and Gilliam J.W. 1996. Soil Sci. Soc. Am. J. 60: 246–251.

Gee G.W. and Bauder J.W. 1986. In: Klute A., Cambell G.S., Nielsen D.R., Jackson R.D. and Mortland M.M. (eds), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, 2nd ed. American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 383–411.

Geiger S.C., Manu A. and Bationo A. 1992. Soil Sci. Soc. Am. J. 56: 172–177.

Gilley J.E., Eghball B., Kramer L.A. and Moorman T.B. 2000. J. Soil Water Cons. 55: 190–196.

Michels K., Sivalumar M.V.K. and Allison B.E. 1995. Field Crops Res. 40: 101–110.

Robinson C.A., Ghaffarzadeh M. and Cruse R.M. 1996. J. Soil Water Cons. 51: 227–230.

Salam A.K., Afandi, Sriyani N. and Kimura M. 2001. Soil Sci. Plant. Nutr. 47: 695–702.

Shiga H. and Miyake M. 1975. In: Editing Committee for Dojo Yobun Bunsekiho (ed.), Dojo Yobun Bunsekiho (in Japanese). Yokendo, Tokyo, pp. 245–248.

Sriyani N., Oki Y., Suprapto H., Susanto H., Lubis A.T., Adachi T. and Senge M. 1999. In: Weeds and Environmental Impact. Proceeding I(B) of the 17th Asian-Pacific Weed Science Society Conference, Bangkok, Thailand, November 22–27, 1999, pp. 759–763.

Thomas G.W. 1982. In: Page A.L., Miller R.H. and Keeney D.R. (eds), Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, 2nd ed. American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 159–165.