J. Jpn. Soc. Soil Phys.
土壌の物理性
No. 92, p. 3～16 (2003)

Soil Physical Properties under Coffee Trees with Different Weed Managements in a Hilly Humid Tropical Area of Lampung, South Sumatra, Indonesia

AFANDI*, Tumiar Katarina MANIK*, Bustomi ROSADI*, Muhajir UTOMO*, Masateru SENGE**, Tadashi ADACHI*** and Yoko OKI***

* Faculty of Agriculture, University of Lampung, Indonesia, Jl. Sumantri Brojonegoro 1, Bandar Lampung 35145, Indonesia

** Faculty of Agriculture, Gifu University, Gifu, Japan, 1-1 Yanagido Gifu 501-1193, Japan

*** Faculty of Environmental Science and Technology, Okayama University, Japan, 3-1-1 Tsushimanaka Okayama 700-8530, Japan

Abstract

The effects of weed management under coffee trees on soil physical properties were investigated during four-years experiment in Lampung, South Sumatra, Indonesia. The treatments were as follows : coffee without cover crop (clean-weeded plot) ; coffee with *Paspalum conjugatum* as cover crop (*Paspalum* plot) ; and coffee with natural weeds which was dominated by *Clibadia surinamense* (natural weeds plot). Weed management was done every two weeks by clearing all the weeds in clean-weeded plots, and cutting the weeds around the coffee trees with diameter 1 m for the weedy plots (*Paspalum* plot and natural weeds plot). The results showed that a better soil physical condition was achieved when the soil surface under the coffee trees was covered with *Paspalum conjugatum.* The average soil organic-C in the soil profile of Paspalum and natural weeds plots were 32 g/kg and 27 g/kg respectively, which were higher than in clean-weeded plot which had 20 g/kg of organic carbon. A smooth horizon boundary was found in *Paspalum* plot due to the abundance of its roots which was also enhancing soil color more black, and the process of wetting and drying. A strong aggregate stability was found at the *Paspalum* plot as indicated by penetrometer readings as well as water stable aggregate index. Two centimeters thickness of hardpan which was developed at *Paspalum* plot made the water movement from upper layer inhibited during the dry season. The highest porosity was found at *Paspalum* plot (0.64 $m^3 m^{-3}$) followed by natural weeds plot (0.62 $m^3 m^{-3}$) and clean-weeded plot (0.60 $m^3 m^{-3}$). However, the average available water content was not different between *Paspalum* plot and natural weeds plot, and only 0.15 $m^3 m^{-3}$ higher than that of clean-weeded plot. The permeabilities varied among the treatments, and this variance was biggest in the upper layer of *Paspalum* plot.

Key words : soil structure, coffee, weeds, aggregate

1. Introduction

Coffee is one of the main important exported products of Lampung Province, Indonesia, and accounts for about 50% of Indonesian exported coffee (BPD-AEKI, Lampung, 1996 ; Bank Indonesia Bandar Lampung, 2000). The coffee trees are mostly grown in mountainous areas with humid tropical climate, which is characterized by high rainfall, more than 2500 mm/year (Afandi *et al.*, 1999). Due to rainfall pattern and topographic condition, the erosion risk in coffee areas is naturally very high. However, the soil erosion problem is more severe by the

Table 1 Soil properties at the initial stage (1995)

Depth (cm)	pH H_2O	Total-N (g/kg)	Organic-C (g/kg)	CEC (cmol/kg)	Texture (g/g) Sand	Silt	Clay	Bulk density (g/cm^3)
0- 10	4.92	2.6	34.8	13.3	0.25	0.23	0.52	0.96
10- 20	4.89	1.6	18.6	9.9	0.25	0.16	0.59	0.93
20- 35	4.91	0.9	8.9	9.3	0.26	0.13	0.61	0.99
35- 60	4.87	0.7	8.2	8.7	0.26	0.13	0.61	0.93
60-100	4.85	0.6	8.2	8.7	0.28	0.15	0.57	—

mismanagement of land in coffee plantations and cultivated land. In the future, soil erosion from coffee areas will be more serious due to the rapid change of land use type from forest areas to coffee plantations ; in 1970 the forest occupied 57.4% of these areas, which was reduced to 21.4% in 1990. On the other hand, the monoculture plantations (coffee garden) increased from 0% in 1970 to 41.8% in 1990 (Syam *et al.*, 1997).

The use of cover crop under coffee trees is very important to control soil loss and to maintain and improve soil structure. Beneficial effects of plants on improvement of soil structure usually are related to physical action of plant roots and addition of organic matter. Abujamin *et al.* (1983) reported that the use of *Bahia* grass (*Paspalum notatum*) strip and *Bede* grass (*Brachiaria decumbens*) strip could suppress soil erosion to zero, and soil with stable aggregate and higher organic matter content was also achieved. The reduction of soil erosion was also achieved due to the increasing of aggregate stability because of manure application (Utomo, 1989). On the other hand, losing of organic matter as much as 47% occurred in bare condition due to soil erosion for two years (Suwardjo, 1981).

In Lampung areas, Indonesia, there are several ways to manage the cover crop under the coffee trees. Some coffee farmers used high cover crop such as *Gliricidea sepium, Leucaena leucocephala,* and *Pelthoporum pterocarpa* as a shading tree ; however, the most popular technology was "clean-weeded coffee", in which the coffee was grown without high cover crop and by cleaning the entire surface ground cover. In the viewpoint of coffee production, the clean-weeded coffee management, which was applied for many years, had no significant effect on reducing coffee production. However, the current use of more quantities of fertilizers by the farmers is affecting the soil condition. Due to the fact that the surface ground cover under coffee trees (in the form of weeds) could be used as erosion barrier and to improve soil structure, an improvement under the existing technology must be made. An evaluation on rates of change in soil physical properties, especially in the long term, is necessary to conduct the development of soil and water conservation strategies.

A four-years experiment was conducted to evaluate the effects of weed management under Arabika coffee trees on soil physical properties in a hilly tropical area of Lampung, South Sumatra, Indonesia.

2. Materials and Methods

2.1 Location of study site

The study field is located at Sumber Jaya District, Lampung Province, South Sumatra, Indonesia, with the slope gradient of around 15° and the elevation 735 m above the sea level (Afandi, 2002). According to soil Taxonomy (Soil Survey Staff, 1998), this soil belongs to *Dystrudepts*. Table 1 shows some selected soil properties of initial conditions just after clearing all the weeds and bushes for planting the coffee seedlings.

Table 1 shows that the soil was relatively fertile with high organic matter and nitrogen ;

slightly acid with moderate cation exchange capacity. The average air temperature was low, around 22℃, (Afandi *et al.*, 1999), so the decomposition rate of organic matter was relatively slow, and the soil organic carbon was rather high compared to the other places, in which the elevation is lower and temperature is higher in Lampung. In addition to that, the soil was still relatively virgin. Although the soil was dominated by clay fraction in all depths, the bulk density was very low which indicated the soil was friable and porous.

2. 2 Treatment

The treatments consisted of three plots with 20 m slope length and 8 m width, which adjoined each other and had almost same soil properties of initial conditions as shown in Table 1. The treatments were as follows :

(1) Treatment 1 (clean-weeded plot) : Clean-weeded coffee garden. Soil surface was always keeping bare by hand weeding at two weeks interval. This management is a general practice in this coffee plantation area so it was regarded as the control.

(2) Treatment 2 (*Paspalum* plot) : Coffee garden with *Paspalum conjugatum* as cover crop. Young *Paspalum conjugatum* was transplanted on the experiment plot in November 1995 and February 1996.

(3) Treatment 3 (natural weeds plot) : Coffee garden with natural weeds as cover crop.

The plots were planted with Arabica coffee with planting distance 1.5 m by 2 m on November 1995. Weed management was done every two weeks by clearing all the weeds in the coffee plot (clean-weeded plot), and cutting the weeds around the coffee trees with diameter 1 m for the weedy plots (*Paspalum* plot and natural weeds plot). Before and after the rainy season, the *Paspalum* mats and natural weeds were mowing at 15-cm height. The spray of pesticides and the application of fertilizer have been adopted with the standard usual practice.

2. 3 Measurement of soil properties

a. Profile description

A soil pit was made until 100 cm depth in August 1997 and September 1999. Observation of two years time after planting was selected because the changes in soil physical properties took a long time. The soil color and the size of soil structure were observed based on Japanese Standard Soil Color Charts.

b. Soil physical properties measurement

(a) Penetration resistance (using a cone penetrometer (DAIKI) until 90 cm depth)
(b) Instantaneous soil moisture content (gravimetric method)
(c) Pore size distribution or soil water content at −3.2〜−1585 kPa (centrifuge methods)
(d) Permeability (using thin wall sampler and falling head methods)

Three soil samples were taken for analyzing the parameters of (b), (c), and (d) described above. Permeability and soil water content at various soil moisture potentials at each depth were measured at the end of the experiment in 1999.

c. Changes of some dynamic soil properties

(a) Organic carbon

Organic carbon was evaluated every year. A soil sample from topsoil (0-10 cm depth) was taken in October 1996 (one year after planting), August 1997, August 1998, and March 1999 (before the experiment ended). A composite soil sample was taken from the upper, middle and lower parts of the slope in each plot. Organic carbon was determined using the Walkey-Black Method.

(b) Aggregate stability index

The index of aggregate stability was measured one year after planting until the end of the experiment by the techniques of DeBoodt and DeLeenheer (1958*). About 500 grams of air-dry aggregate was sieved through 8, 4.76, 2.83, and 2 mm sieves (drying sieving). After that, the aggregates from the drying sieving are wetted with water drops until about field capacity ; kept in desiccators for about 12 hours. Wetting sieving process was done afterwards using sieves of 4.76, 2.83, 2, 1, 0.5 and 0.279

mm. Aggregate stability index proposed by DeBoodt and DeLeenheer (1958**) was calculated as follows.

$$AS=\{1/(MWD_{dry}-MWD_{wet})\}\times 100 \quad (1)$$

AS : Aggregate stability index (10^{-2}/mm)

The mean weight diameter (MWD) was calculated with the following equation :

$$MWD_{dry}=[\sum_{i=1}^{n} x_i \times W_i]/W_t \quad (2)$$

x_i : the mean diameter of each size fractions (mm)

W_i : the weight of each fraction (g)

W_t : the total weigh of soil sample (g)

The MWD_{wet} for wetting sieving was also calculated as the above equation (2).

The values found in equation (1) could be classified as follows :

$200 \leqq AS$: extremely stable
$80 \leqq AS < 200$: very stable
$60 \leqq AS < 80$: stable
$50 \leqq AS < 60$: moderately stable
$40 \leqq AS < 50$: less stable
$AS < 40$ not stable

3. Results and Discussion

3. 1 Field observation (soil profile and soil structure)

Field observation of soil profile which was done in 1997, two years after planting, showed that there were very significant changes in the soil profile, especially in upper layer, as shown in Table 2.

The abundance and distribution of weed roots strongly affected the development of soil profile. Due to the fact that *Paspalum* roots distributed almost in the same depth, the border of the soil horizon was smooth (not wavy) in upper layer. The other two treatments had a wavy boundary at upper layer of the soil profile. The type of weeds roots also affected the soil color, especially under dry conditions both directly and indirectly. The abundance of weeds roots in *Paspalum* plot made the soil color brighter under dry conditions due to the effect of root color. However, under wet conditions, both weedy treatments had more black soil color that showed in low chroma, which was an indication of organic matter accumulation.

The soil structures in upper layer of both weedy treatments were more developed than the clean-weeded plot. The basic type of soil structure in all the treatments was angular blocky, however, different in size and field consistency. The soil structure type in clean-weeded plot was fine to medium angular blocky with weak field consistency. The abundance of *Paspalum* roots at upper layer (0–20 cm) yielded a fine to moderate crumb and angular blocky structure, friable but very stable, on the other hand, natural weeds plot also produced stable, medium to very coarse angular blocky structure.

From the field observation, it was clear that the development of soil structure in upper layer in *Paspalum* plot was more complex than the other two treatments and it seemed to be determined by three processes : mechanical binding of soil aggregates by root action, cementing action by organic matter, as well as the process of wetting and drying of the soil. An observation that was made in the dry season of 1997 showed that the soil in *Paspalum* plot was drier and harder than in the natural weeds plot followed by clean-weeded plot because the abundance of *Paspalum*'s roots consumed more water than the other treatments, so the evapotranspiration in this plot was very high ; however under moist conditions, the aggregate was more friable than natural weeds plot followed by clean-weeded coffee probably because *Paspalum* plot had more organic matter.

As shown in Table 2, some cracks were found in all the profiles with different degrees in length and depth. The main cause of the cracks was the existence of 2 : 1 type clay mineral. Lumbanraja *et al.* (1999) reported that soil in this area contained up to 0.25 g/g of vermiculite-chlorite intergrades, a type of clay mineral that posseses swell-shrink property. However, the degree of cracking was different

Table 2 Soil Profiles two years after planting (observed in August, 1997)

Soil properties	Treatment		
	Clean-weeded plot	*Paspalum* plot	Natural weeds plot
Topsoil			
-Depth (cm)	0～10/15	0～16	0～10/24
-Horizon border	wavy, abrupt	smooth, clear	wavy, abrupt
-Colour			
-Dry	7.5 YR 3/3 (dark brown)	7.5 YR 4/3 (brown)	7.5 YR 3/2 (brownish black)
-Moist	10 YR 3/4 (dark brown)	10 YR 3/2 (brownish black)	10 YR 3/2 (brownish black)
-Stucture			
-Type	Angular blocky	Crumb to Angular blocky	Angular blocky
-Size	Fine to Medium	Very fine to Medium	Medium to very coarse
-Roots system	Coffee roots (less)	*Paspalum* roots (abundant)	Various grass roots (many)
-Cracking	No	Evidence (one cracks)	Evidence (two cracks)
Subsoil-1			
-Depth (cm)	10/15～30	16～37	10/24～35
-Horizon border	diffuse, smooth	smooth, diffuse	smooth, diffuse
-Colour (dry)	7.5 YR 4/4 (brown)	7.5 YR 5/8 (bright brown)	7.5 YR 4/4 (brown)
-Stucture			
-Type	Sub angular blocky	Crumb to Angular blocky	Angular blocky
-Size (dominant)	Medium	Medium	Coarse
-Roots system	Coffee roots (less)	*Paspalum* roots (less)	Various grass roots (many)
-Cracking	No	Evidence	Evidence and filled with soil from above (color 7.5 YR 3/3)
Subsoil-2			
-Depth (cm)	30～50	37～47	35～56
-Horizon border	diffuse, smooth	diffuse, smooth	diffuse, smooth
-Colour (dry)	7.5 YR 5/6 (bright brown)	7.5 YR 5/6 (bright brown)	7.5 YR 5/6 (bright brown)
-Stucture			
-Type	Sub angular blocky	Angular Blocky	Angular blocky
-Size (dominant)	Medium	Fine	Medium
-Roots system	Grass roots (small amount)	Grass roots (less)	Grass roots (many)
-Cracking	Evidence and filled with soil from above (color 7.5 YR 4/4)	Evidence until 70 cm depth	Evidence until 70 cm and filled with soil from above (color 7.5 YR 3/2) and earth-worm casting

Note : Observation was done in dry condition

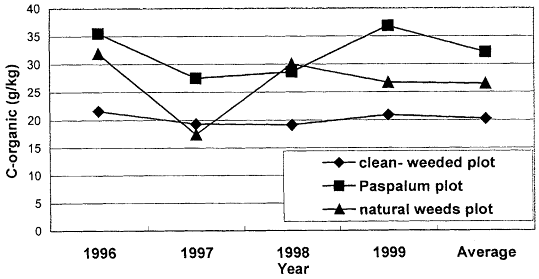

Fig. 1 Changes of organic carbon in topsoil under coffee trees with different weed managements.

among the treatments probably due to the activity of weed roots. In the clean-weeded coffee treatment, the cracks were found in the subsoil; however, in both weedy treatments the cracks were found from the upper layer until the deeper layer. Many cracks were found in the deeper layer of natural weeds plot, which was dominated by woody species known as *Clibadia surinamense* with deep roots. Instead of mineral type discussed above, the existence of root system in this layer enhanced the soil cracking. The roots extracted more water from this depth, and make the process of wetting and drying of the soil proceed at a faster rate. Soil particles and organic matter from the above layer, which made a form like a finger until 70 cm depth, filled the cracks.

Soil profile observation made in 1999 was quite similar to that of 1997, except that the depth of topsoil in *Paspalum* plot (as indicated by the dark soil color) increased from 16 cm to 20 cm. The other soil properties were almost the same.

3. 2 Soil organic carbon (SOC)

The average soil organic carbon (SOC) in *Paspalum* and natural weeds plots were 32.1 g/kg and 26.5 g/kg respectively, which were higher than in clean-weeded plot which has 20.2 g/kg of organic carbon (Fig. 1). The value of SOC in clean-weeded plot was almost constant, probably due to the low soil erosion during four-years of experiment which was around 5.0 mm of soil depth. However, the content of SOC matter in clean-weeded plot decreased compared to the initial stage (Table 1) due to little supply of organic matter under no cover crops. The value of SOC decreased in 1997 due to the long dry season, so the addition of soil organic matter decreased. As reported by Sriyani *et al.* (1999), there was a sharp decrease in the number of weed species due to the long dry season in 1997.

The content of organic carbon was maintained to be as high as initial stage in *Paspalum* plot. *Paspalum conjugatum* is a grass species ; as stated by Tisdall and Oades (1982), organic matter might have accumulated under good pastures because the annual addition of phytomas was greater. The roots of grasses are short-lived, so each-year decomposition of dead roots contributes to the quantity of humified organic matter (Foth, 1978).

3. 3 Penetrometer resistance

The penetrometer data, especially in upper layer, gave a very different result when measuring was done in dry and rainy season as shown in Fig. 2, and which supported our profile observation. It seemed that the behavior of soil water in each treatment influenced these results because the soil water content mainly determined the penetrometer resistance.

In the dry season measurement, a very compact and hard surface layer ($>25\ \mathrm{kgf/cm^2}$) approximately at 2 cm depth was found in *Paspalum* plot. Although it was not as hard as in *Paspalum* plot, the penetrometer resistance in natural weeds plot was also higher than clean-weeded plot. Field observation showed that at upper layer the soil condition was drier in weedy plots compared to clean-weeded plot because the weedy plots consumed more water than clean-weeded plot. Furthermore, penetrometer resistances in whole layer were higher in weedy plots than in clean-weeded plot, which showed that the soil conditions of weedy plots were dry compared to clean-weeded plot due to the soil water uptake of weed roots especially in dry season as shown in Fig. 3 described later.

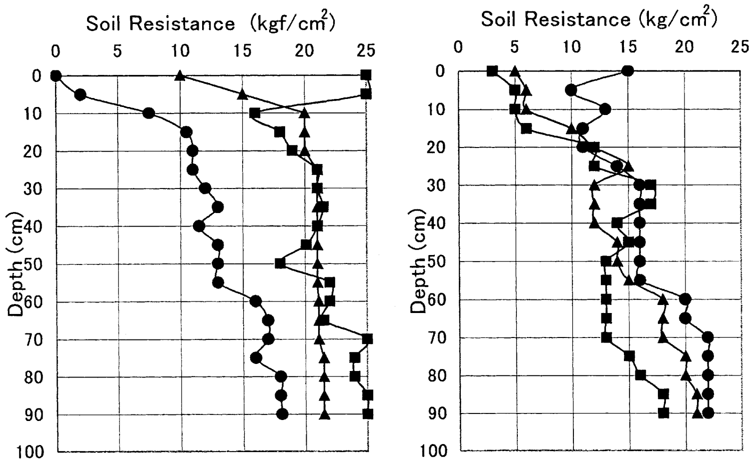

Fig. 2 Soil resistance measured by penetrometer under dry condition (left : October, 1999) and moist condition (right : January, 1997).
(● : clean-weeded plot ; ■ : *Paspalum* plot ; ▲ : natural weeds plot)

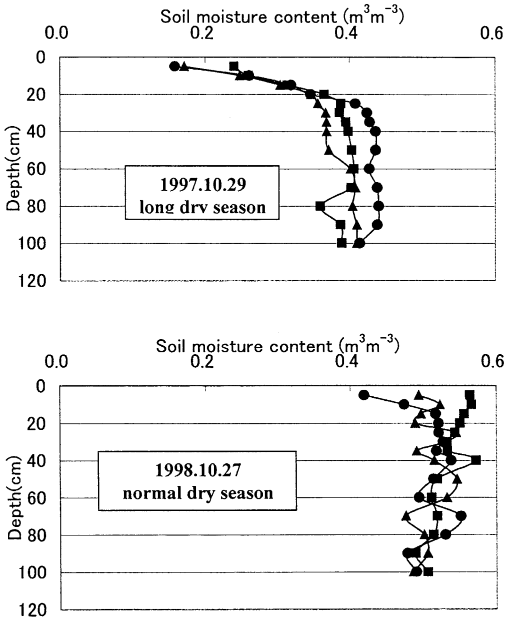

Fig. 3 Soil moisture content under coffee trees with different weed managements.
(● : clean-weeded plot ; ■ : *Paspalum* plot ; ▲ : natural weeds plot)

Observation which was done in the rainy season (Fig. 2) showed that the penetration resistance in *Paspalum* plot was less than 5 kgf/cm^2 in the upper layer, and in natural weeds plot and clean-weeded plot the values were 5 kgf/cm^2 and 15 kgf/cm^2 respectively. This data showed that the soils in *Paspalum* and natural weeds plots were wetter and retained more water in upper layer during rainy season, so the soil would be more friable.

3. 4 Instantaneous soil water content

The profiles of soil water content during long dry season in 1997 and normal dry season in 1998 are shown in Fig. 3. Soil moisture content in this figure is the average of three soil samples at each depth.

Both observations showed that *Paspalum* plot could retain higher soil water content in the upper layer, whereas during the long dry season in 1997, the clean-weeded plot held more soil water content in the lower layer (20–100 cm). In normal dry season in 1998, the soil water content in the deeper layer of each plot was almost the same.

It seems that the above phenomenon was related to the soil surface condition as indicated by the soil resistance shown in Fig. 2. At *Paspalum* plot, the evapotranspiration was found to be higher during the dry season, hence the soil surface became hard and about 2 cm of hardpan was developed. As a consequence, during the dry season the water move-

Table 3 Effects of weed management under coffee trees on solid, porosity and water content at various pF (1999)

Treatment	Depth (cm)	Solid ($m^3 m^{-3}$)	Porosity ($m^3 m^{-3}$)	Water content −3.2 kPa ($m^3 m^{-3}$)	−10 kPa	−32 kPa	−1585 kPa
Clean Weeded Coffee	5	0.410	0.590	0.494	0.468	0.445	0.352
	15	0.400	0.600	0.546	0.537	0.530	0.442
	25	0.394	0.606	0.550	0.541	0.535	0.445
	35	0.394	0.606	0.575	0.567	0.558	0.456
	Average	0.400	0.601	0.541	0.528	0.517	0.424
Coffee +*Paspalum*	5	0.356	0.644	0.500	0.366	0.343	0.223
	15	0.335	0.665	0.509	0.489	0.471	0.361
	25	0.357	0.643	0.572	0.542	0.527	0.421
	35	0.374	0.626	0.578	0.553	0.541	0.439
	Average	0.356	0.645	0.540	0.488	0.471	0.361
Coffee+ Natural Weeds	5	0.379	0.621	0.521	0.502	0.481	0.361
	15	0.350	0.650	0.407	0.392	0.374	0.256
	25	0.385	0.615	0.507	0.498	0.489	0.384
	35	0.410	0.590	0.544	0.539	0.531	0.437
	Average	0.381	0.619	0.495	0.483	0.469	0.360

ment from the upper layer was inhibited, and the roots of Paspalum as well as natural weeds would took water from the deeper layer.

3. 5 Solid and soil water content

The composition of three phases of soil is presented in Table 3. The soil was clayey (clay >0.51 g/g as shown in Table 1) with high organic matter, so naturally the total porosity was very high. The average total porosity ranged from 0.601 $m^3 m^{-3}$ to 0.645 $m^3 m^{-3}$. The highest porosity was found at *Paspalum* plot (0.645 $m^3 m^{-3}$) followed by natural weeds plot (0.619 $m^3 m^{-3}$) and clean-weeded plot (0.601 $m^3 m^{-3}$). As a consequence, the solid phases of *Paspalum* and natural weeds plot were lower than that of clean-weeded plot. It is interesting to note that the existence of cover crop, especially at *Paspalum* plot, has changed the solid-pore composition although the change was very small.

The existence of *Paspalum* and natural weeds also affected the water contents of −3.2, −10, −32 and −1585 kPa as shown in Table 3. The water contents at −3.2, −10, and −32 kPa were lower in *Paspalum* and natural weeds plot than clean-weeded plot and as a result the amount of big pore as shown in Fig. 4 at both weedy plots were higher because those porosities were higher. Both weedy plots had aeration pore (water content between saturated and −3.2 kPa) as much as 75–107% higher than clean-weeded plot ; for macro pore (water content between saturated and −10 kPa), the range was 86–115% higher ; and for coarse pore (water content between saturated and −32 kPa) was 79–107% higher. Because the total porosity was highest at *Paspalum* plot, the macropore and coarse pore were found to be highest for this treatment. The coarse pore in *Paspalum* plot was higher as much as 107% and 16% than clean-weeded plot and natural weeds plot respectively.

The main function of large pores is an avenue for infiltration and drainage of water. The aeration pore would transmit water during saturated condition. The macro and

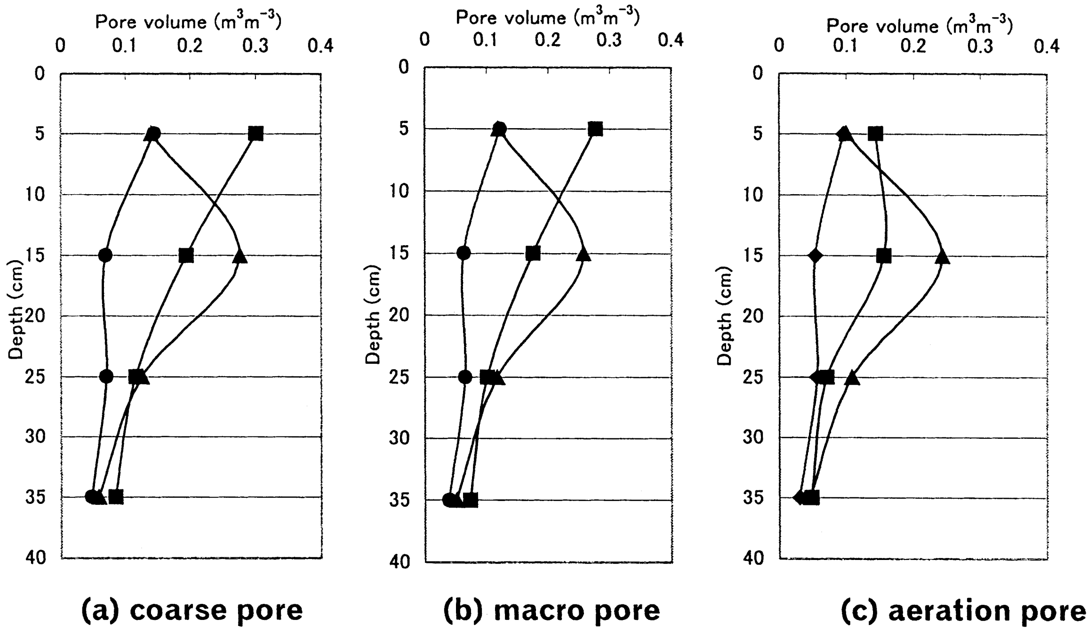

Fig. 4 Effects of different weed managements on pore composition (1999).
(● : clean-weeded plot ; ■ : *Paspalum* plot ; ▲ : natural weeds plot)

coarse pore which included aeration pore could transmit and drain water during infiltration. Macro pore could cause to drain gravitational water quickly and coarse pore could cause to drain gravitational water slowly. Thus the number of these pores will affect surface runoff as well as soil erosion. During the process of drainage under a saturation condition, the water in aeration pore will be empty initially, and as a consequence the natural weeds plot which had higher aeration pore would be drier first, followed by *Paspalum* plot. In case of wet condition (water content between saturated and field capacity), the *Paspalum* plot which had highest coarse and macro pore would infiltrate water faster than the other treatments.

The average available water content (water content between −32 and −1585 kPa) for each treatment was almost the same, i.e. 0.093 $m^3 m^{-3}$, 0.110 $m^3 m^{-3}$ and 0.109 $m^3 m^{-3}$ for clean-weeded, *Paspalum* and natural weeds plot respectively. The existence of weeds had decreased the value of permanent wilting point (−1585 kPa), however, at the same time the value of field capacity (−32 kPa) also decreased simultaneously, therefore the available water content did not change. This situation is shown in Fig. 5.

The distribution and activity of roots in each treatment has strongly influenced the amount of large pore in each depth as shown in Fig. 4. The abundance of *Paspalum* roots in the upper layer made this plot to have bigger large pores than the other two treatments, however, as the roots decreased with depth, the number of pores also decreased. On the other hand, at 15 cm depth, the highest big pores were found at natural weeds plot due to the abundance of root system in this depth of natural weeds plot. As the roots system decreased with depth, the amount of large pores became similar.

3. 6 Aggregate stability

It is very interesting to note that the pattern of aggregate stability in each plot (Fig. 6) is almost similar to the pattern of organic carbon, which indicated that organic matter has a very important role in stabilizing the soil aggregate. The fact that the values of aggregate stability

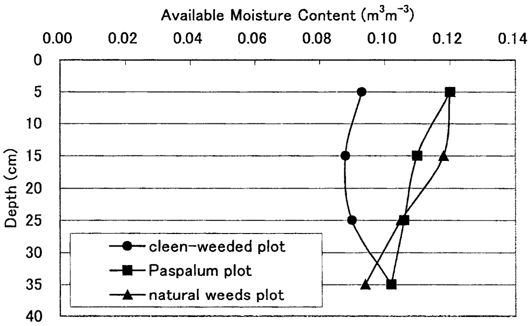

Fig. 5 Effects of different weed managements on available water content (1999).

at clean-weeded plot were almost unchanged during four-year duration of the experiment, which supported this argument. The aggregate stability at weedy plots was higher than clean-weeded plot, both in topsoil and subsoil.

The higher aggregate stability both in *Paspalum* and natural weeds plots was mostly related to development of soil structure through the action of weed roots. In the last year observation, *Paspalum,* which possessed the highest organic matter content, had the highest aggregate stability. Instead of the existence of organic matter, field observation also showed that a mechanical binding by root hair of *Paspalum* was also responsible for increasing aggregate stability.

The other process that was also responsible for the development of soil structure was intermittent wetting and drying processes. The treatments gave different response to wetting process due to rainfall events and drying process occurred by evapotranspiration events. Fig. 7 shows the dynamics of soil moisture suction measured by self-recorded tesiometer after rainfall events. As shown in Fig. 7, at 5 cm depth, *Paspalum* absorbed water and the soil become saturated very quickly due to a rainfall event. However, when this plot started to dry, the water in upper layer depleted faster than the other treatments. A similar process occurred at natural weeds plot at 25 cm depth, because many cracks were found in this depth due to the quick wetting and drying process.

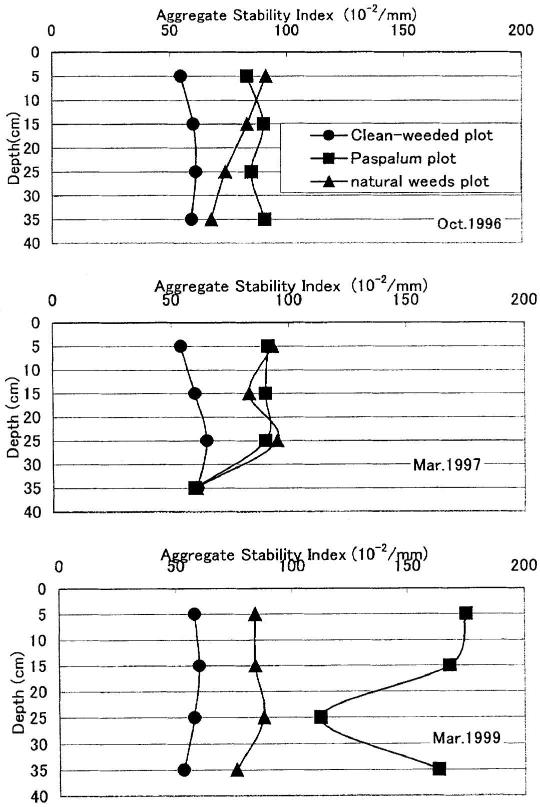

Fig. 6 Aggregate stability under coffee trees with different weed managements measured in different years.

The development of the cracks would promote soil structure development.

3.7 Permeability

Three soil samples were taken by cylindrical samplers 10 cm in height at each depth of 5, 15, 25, and 35 cm for analyzing permeability. All data of the permeabilities at every depth are plotted in Fig. 8.

The maximum and minimum permeability values were found at the same depth (10 cm depth) of *Paspalum* plot, i.e. 1.1×10^{-1} cm/s and 2.7×10^{-4} cm/s respectively. The great variation in these data was due to several reasons, such as the properties of the soil to shrink and swell and the existence of surface crust (about 2 cm thick) in *Paspalum* plot. A thin hardpan with about 2 cm thickness was found in the soil surface of *Paspalum* plot ; however, the hard-

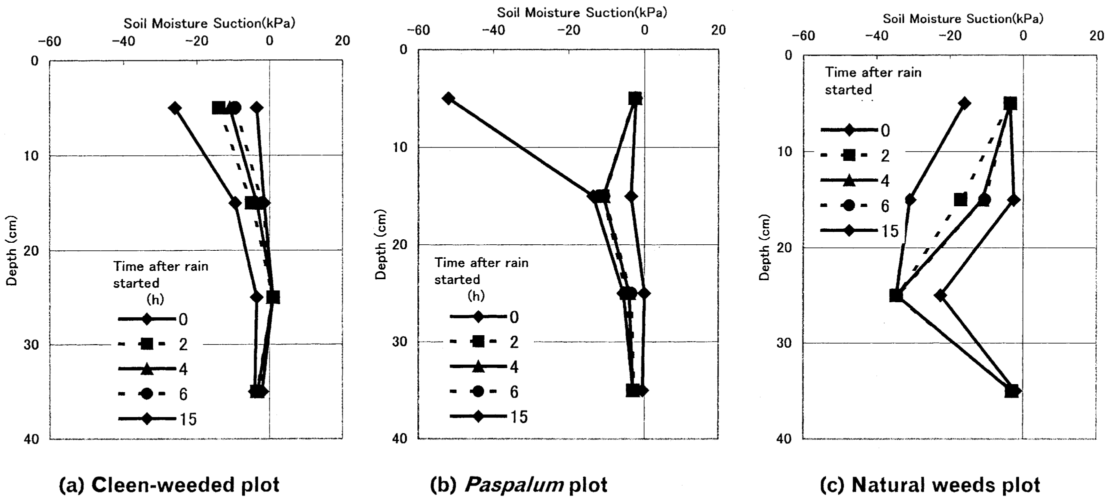

Fig. 7 Dynamics of soil moisture suction in each plot (April 6–7, 1996).

pan had not totally covered the soil surface. The hard pan, which was developed due to surface crust, had made the lowest value of permeability at *Paspalum* plot ; part of the soil surface, which was not covered with the surface crust, had a very high permeability. Such a combination of two permeability values would give a good effect on preventing soil erosion, because the hard surface crust would have a strong aggregate stability, and at the same time, the surface runoff water would enter into the soil profile at a much faster rate. Surface crust also occurred in natural weeds and clean-weeded plot, but not as hard as in *Paspalum* plot.

As shown in Fig. 8, there was a tendency in all treatments that the permeability values were lower at the upper soil and increased at 10–30 cm depth, and decreased in the lower part. The existence of surface crust was responsible for lower permeability at the upper layer, and with increasing depth below plow layer (15–20 cm depth), the soil tended to be more compact and hence the permeability decreased.

3. 8 General discussion

The above discussion proved that the soil cover in the form of weeds could change the soil physical properties. The process was quite different between grass weeds like *Paspalum* sp. and woody weeds like *Clibadia* sp. in natural weeds due to the different root system. Some processes involved addition of organic matter, evapotranspiration, and mechanical binding. *Paspalum* is a grass type of weed, and its roots are short-lived so each-year decomposition of dead roots would contribute to the quantity of humified organic matter. The root hair of *Paspalum* could also bind the soil particles mechanically, and if transpiration occurred, the soil released its water and became harder and much more stable. The fact that soil in *Paspalum* plot gave a quicker response in wetting and drying at the upper layer also proved that the abundance of *Paspalum*'s roots affected aggregate development. The fast process of wetting and drying enhanced the formation of cracks and aggregates. In case of natural weeds, the wetting and drying process occurred in deeper layer, and materials from the above layer would fill the crack.

The results of the above process were that *Paspalum* plot had much organic matter with stable aggregate stability and higher large pores. Some soil properties in clean-weeded

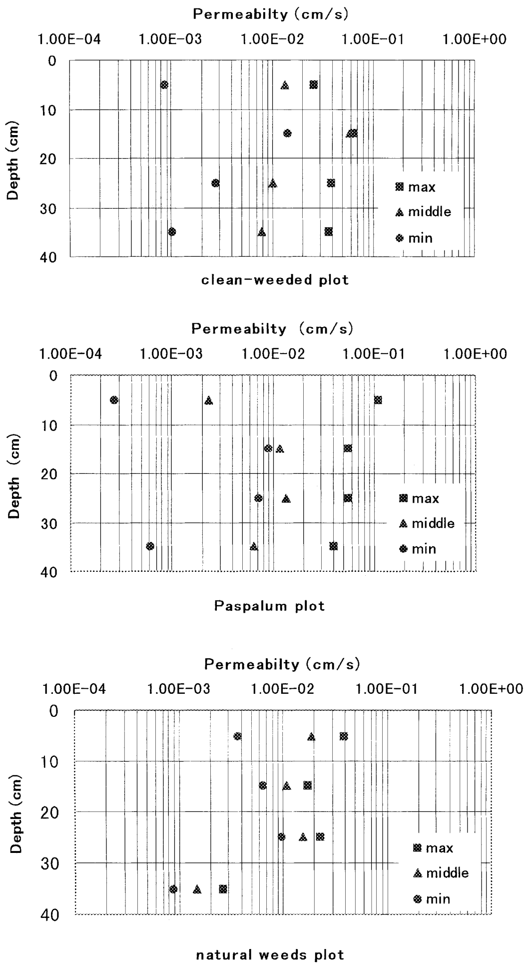

Fig. 8 Effect of weed management under coffee trees on soil permeability (1999).

plot were almost constant during four years, probably because less soil erosion occurred and the decomposition rate of organic matter was slow due to low average temperature (22℃). The soil properties in natural weeds plot were between the other two treatments. A fingering appeared in natural weeds plot which consisted of materials from the above layer.

From the viewpoint of soil conservation, the use of *Paspalum conjugatum* as cover crops gave many beneficial effects for protecting soil erosion. Stable aggregates would make the soil strong enough against rainy drop, and high coarse pore would enhance infiltration rate, so runoff would be less. As discussed by Afandi *et al.* (1999), the soil loss and runoff from *Paspalum* plot was very low and reached zero in the third and fourth years of the experiment. However since the process of wetting and drying was quicker as this grasses consumed more water, the use of *Paspalum* was not as good as natural weeds, from the viewpoint of water conservation. In natural weeds plot, cracking which occurred in the deeper layer would make the infiltration water flow into deeper layer, so natural weeds was better than *Paspalum* from the viewpoint of water conservation.

4. Conclusion

The existence of weeds under coffee trees as a cover crop has improved some soil physical properties, such as the increasing of soil organic carbon, aggregate stability, porosity, big pore (macro, coarse, and aeration pore), and decreasing the permanent wilting point. The average soil organic carbon (SOC) in *Paspalum* and natural weeds plots were 32.1 g/kg and 26.5 g/kg respectively, which were higher than in clean-weeded plot which was relatively constant (20.2 g/kg) during four years of experiment. A thin (about 2 cm thick) hardpan, which developed at the soil surface in *Paspalum* plot, has influenced some soil physical properties, such as the penetrometer resistance, aggregate stability, instantaneous soil water content, and great variation in permeability values. The highest porosity and large pores (macro, coarse, and aeration pore) were found at *Paspalum* plot followed by natural weeds plot and clean-weeded plot. The available water content was not different between *Paspalum* plot and natural weeds plot, and only 0.18 m^3 m^{-3} higher than that of clean-weeded plot, because the values of field capacity and permanent wilting point were small simultaneously at both weedy treatments.

Reference

Abujamin, S., A., Adi and Kurnia, U. (1983) : Permanent grass strip as one of soil conservation methods. Soil and Fertilizer Research News, Center for Soil Research, Ministry of Agriculture, Indonesia, **1** : 16–20 (in Indonesian).

Afandi, Gafur, A., Swibawa, I. G. and Purnomosidhi, P. (1999) : Baseline Biophysical Information about the Tulang Bawang watershed area, North Lampung. Proceeding of the Management of Agrobiodiversity in Indonesia for Sustainable Land Use and Global Environment Benefits. ASB–Indonesia Report No. **9**, Bogor, Indonesia : 76–192.

Afandi, T.K. Manik, B. Rosadi, M. Utomo, M. Senge, T. Adachi and Y. Oki : Soil Erosion under Coffee Trees with Different Weed Managements in Humid Tropical Hilly Area of Lampung, South Sumatra, Indonesia. Journal of the Japanese Society of Soil Physics (in print).

Bank Indonesia Bandar Lampung (2000) : Financial Economic–Monetary Statistics for Lampung Province Region. Bank Indonesia Bandar Lampung : 25.

BPD–AEKI Lampung (Indonesian Association of Coffee Exporter Lampung Branch)(1996) : Experience of Marketing and the Prospect of Lampung Coffee, Roadshow of Technology of Arabica coffee development in Western Lampung, Liwa, Western Lampung, January : 16–38 (in Indonesian).

DeBoodt, M. and DeLeenheer, L. (1958*) : Propotion pour l'evalution de la stabilitie des aggregates sur le terrain. Proc. Int. Symp. Soil Structure, Ghent, Belgium : 234–241.

DeBoodt, M. and DeLeenheer, L. (1958**) : Determination of aggregate stability by the change in mean weight diameter. Intern. Symp. On Soil Structure. Medelingen Landbouwhogeschool, Gent (Belgium) **24** : 290–399.

Foth, F.D. (1978) : Fundamentals of Soil Science. Wiley, New York.

Lumbanraja, J., Syam, T., Nishide, H., Mahi, A.K., Utomo, M., Sarno and Kimura, M. (1998) : Deterioration of soil fertility by land use changes in South Sumatra, Indonesia, from 1970 to 1990. Hydrological Process **12** : 2003–2013.

Soil Survey Staff (1998) : Keys to Soil Taxonomy 8^{th} : p. 173. United States Department of Agriculture, Washington D.C.

Sriyani, N., Suprapto, H., Susanto, H., Lubis, A.T. and Oki, Y. (1999) : Weeds Population Dynamics in Coffee Plantation Managed by Different Soil Conservation Techniques. Proc. of International Sem. Toward Sustainable Agriculture in Humid Tropics Facing 21^{st} Century. Bandar Lampung, Indonesia, September 27–28 : 513–520.

Suwardjo(1981) : The role of plant debris for soil and water conservation in annual farm land. Ph.D. desertation Bogor Agriculture University, Bogor, Indonesia. (in Indonesian).

Syam, T., Nishide, H., Salam, A.K., Utomo, M., Mahi, A.K., Lumbanraja, J., Nugroho, S.G. and Kimura, M. (1997) : Land use change in a hilly area of south Sumatra, Indonesia (from 1970 to 1990). Soil Sci. Plant Nutr., **43** (3) : 587–599.

Tisdall, J.M. and Oades, J.M. (1982) : Organic matter and water–stable aggregates in soils. Journal of Soil Science **33** : 141–163.

Utomo, W.H. (1989) : Soil Conservation in Indonesia, A Record and Analysis. Rajawali Press, Jakarta (in Indonesian).

インドネシア・南スマトラ・ランポンの熱帯湿潤丘陵地コーヒー園における雑草管理の違いが土壌の物理性に与える影響

アファンディ*・ツマイア　カタリナ　マニク*・ブストミ　ロサディ*・ムハジル　ウトモ*・千家正照**・足立忠司***・沖　陽子***
* ランポン大学農学部
** 岐阜大学農学部
*** 岡山大学環境理工学部

要　　旨

インドネシア・南スマトラのランポンにおいて，コーヒー園の雑草管理が土壌の物理性に与える影響を明らかにするために，4 年間の実験を行った。試験区は，⑴地表面の雑草を完全除草したコーヒー園（除草区），⑵被覆植物として *Paspalum conjugatum* で地表面を被覆したコーヒー園（*Paspalum* 区），⑶*Clibadia surinamense* が優先種である自然植生の雑草で地表面を被覆したコーヒー園（自然雑草区）である。雑草管理は 2 週間に 1 回の頻度で行った。除草区では地表面の雑草を完全に除去し，*Paspalum* 区と自然雑草区ではコーヒー樹周囲の直径 1m の範囲を除草した。コーヒー樹下の地表面を *Paspalum* で被覆すると土壌の物理性が改善される結果を得た。*Paspalum* 及び自然発生した雑草で被覆した試験区における土壌中の有機態炭素量は，それぞれ 32 g/kg, 26 g/kg と除草区の 20 g/kg より大きい。*Paspalum* 区の土壌断面では *Paspalum* の根群によって土壌の色が濃くなり，湿潤と乾燥のプロセスによって，層位の境界が鮮明になっていた。コーンペネトロメータの測定値や団粒の安定化度が示すように *Paspalum* 区の土壌は団粒の安定性が大きい。*Paspalum* 区の表層では厚さ 2 cm の硬いパンが発生し，乾季に表層からの水分移動を妨げていた。間隙率は *Paspalum* 区が 0.64 $m^3\,m^{-3}$ と最も大きく，次いで自然雑草区（0.62 $m^3\,m^{-3}$），除草区（0.60 $m^3\,m^{-3}$）の順であった。しかしながら，有効水分量は *Paspalum* 区と自然雑草区の間に大きな相違がなく，除草区と比較しても 0.18 $m^3\,m^{-3}$ 程度大きいのみであった。試験区間の透水係数は大きくばらつき，とくに *Paspalum* 区の表層において変動が大きかった。

キーワード：土壌構造，コーヒー，雑草，団粒

受稿年月日：2001 年 11 月 7 日
受理年月日：2002 年 7 月 8 日