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The Change of Morphology in Red Acid Soil after Four Years Treatment of Coffee Plantation with Different Weeds Management in a Hilly Area of Lampung, South Sumatra, Indonesia

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Abstract

Research was conducted on the red soils formed from young intermediary to mafic volcanic materials that occupy the hilly areas of South Sumatra, Indonesia within the humid tropical climate. This research was aimed at investigating the influences of different soil cover crops on soil morphology and soil properties after four years treatment as well as examining the probable changes in the soil taxonomy. Three soil profiles were made in the middle of erosion plots after 4 years treatment with different soil cover crops under coffee trees. The treatment plots were ; T-1, keeping the ground bare by hand weeding at two weeks interval (coffee without cover crop); T-2, Coffee with *Paspalum conjugatum* as cover crop and T-3, coffee with natural weeds as cover crops. The soil profiles were described and sampled according to Soil Survey Manual (1993) and Soil Taxonomy Classification System (1998). It was observed that after 4 years, soil surface layer had become thicker and darker than before. Almost all the soil chemical properties in soil surface layer increased, particularly soil pH, organic carbon content, total nitrogen, available P, exchangeable bases, and base saturation. On the other hand, exchangeable Al and Al saturation of soil surface layer decreased. Although several soil characteristics changed during the study period, it was evident that 4 years treatment was too short to change soil taxonomy of the three pedons in sub-group category. In the sub-group category, all pedons were still classified as *Vertic Dystrudepts*. Covering soil surface by natural weeds was able to increase exchangeable bases and base saturation in the sub- surface layer, therefore over a long period of time there will be a possibility of the changing the soil taxonomy from *Vertic Dystrudepts* to *Eutrudepts* in the great soil group category.

Key words : Red Soil, coffee, cover crop, weeds, *Vertic Dystrudepts,* Sumatra

1. Introduction

The term of Red Soil is used to describe soils that have hue of 10 YR until 5 YR, with value and chroma ranging between 2 and 8 (Wiharso, 1996). This type of soil is widely distributed in the tropical regions of the world, including Indonesia. They are formed from many kinds of rocks, both *felsic* and *mafic,* spread over low and high altitudes of undulating mountainous regions with perhumid to semiarid climates (Buurman, 1980). Red soil is associated with acid soils, marginal soils, and infertile soils. According to Soil Classification System in the past, these soils were called Latosol or Lateritic soils (Uehara and Gillman, 1981). Since 1961, red soils in Indonesia had been classified into four, namely ; Red-Yellow Mediterranean, Latosol, Red-Yellow Podzolic, and Lateritic (Buurman, 1980).

Soils that are formed from recent volcanic materials, fluvial, or in the young landscape are generally rich in nutrients and capable of supporting plant growth and animal community, if the availability of water, sunshine, and temperature are not limiting factors. The soils formed by these volcanic materials usually have enough nutrients that can support various plants. However, under humid tropical climate, the soils will be subjected to soil erosion and the soil degradation become fast. Materials left on the landscape are subsurface layer, which are abundant with insoluble materials, hence showed the inability of soils to support sustainable agriculture.

Within the research area, drastic changes in land use from primary forests to cultivated lands without proper soil conservation practices had led to severe land deterioration causing significant soil fertility decline between 1970 and 1990 (Lumbanraja *et al.,* 1998). Improving soil ability to support various plants and sustain agriculture, soils should be managed and maintained through conservation practices such as covering soil by cover crops or weeds. Afandi *et al.* (2002) reported that covering soil by grass (*Paspalum conjugatum*) and natural weeds could decrease runoff and erosion significantly.

This research was aimed to characterize the soil morphology and soil properties of three pedons of red soil in a hilly area under coffee plantation in South Sumatra, Indonesia, after four years of cover cropping management using grass (*Paspalum conjugatum*) and natural weeds. The probable changes in the soil taxonomy with reference to the Soil Taxonomy Classification System (Soil Survey Staff, 1998) were also examined.

2. Materials and Method

The research was conducted in coffee plantation which had been under three different cover cropping management systems since 1995 to 1999 in a hilly area of Sumber Jaya District, Lampung Province, South Sumatra at an altitude of about 800 meters above sea level and 15° gradient.

The detailed treatments were discussed by Afandi *et al.* (2002) and could be summarized as follows :

(1) **Treatment 1 (T-1)** : Clean-weeded coffee. Ground surface was always keeping bare by hand weeding at two weeks interval. This management is a general practice in this coffee plantation area so that this treatment is regarded as a control.

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

(3) **Treatment 3 (T-3)** : Coffee with natural weeds as cover crop.

In each plot, seedlings of Arabica coffee were planted 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 clean-weeded plot (T-1), and cutting the weeds around the coffee tree with diameter 1 m for the weedy plots (T-2 and T-3). Before and after rainy season, the *Paspalum* mats (T-2) and natural weeds (T-3) were mowed at 15-cm height. Application of fertilizer and pesticides had been adopted according to the standard usual practice.

The natural weeds were dominated by *Clibadium surinamense, Ageratum conyzoides, Chromolaena odorata, Melastoma malabatricum, Clidemia hirta, Dicranopteris linearis, Imperata* *cylindrica, Paspalum conjugatum, and Borreria leaves* (Salam *et al.,* 2001).

The treatments were located side by side. Each treatment had two plots with an area of 100 m^2 of 5 m width and 20 m length. One plot was used for soil erosion measurement (undisturbed during four years), and the other plot was used for soil sampling. So each erosion plot was separated by sampling plot. After four years of treatments, a representative soil profile was dug in the middle of soil erosion plot in each treatment plot.

Chemical fertilizers including 200 kg ha^{-1} of urea, 45 kg ha^{-1} of P_2O_5 in the form of $Ca(H_2PO_4)_2$, and 100 kg ha^{-1} of potassium chloride, were applied just after transplanting and then twice a year in April and October.

Soil samples were taken from each horizon for chemical and physical analyses. Soil pH was determined in H_2O and 1 N-KCl at soil to liquid ratio of 1 : 2.5, Organic Carbon (Walkley and Black), total Nitrogen (Kjeldahl), available P (Bray-I), CEC, exchangeable bases extracted by NH_4OAc. at pH 7.0, and exchangeable Aluminum extracted by 1 N-KCl. The soil profiles were described and sampled according to Soil Survey Manual (1993) and Soil Taxonomy Classification System (1998) to determine the morphological processes that occurred in the red soil.

The soil strength in each horizon was measured using hand penetrometer, and repeated 10 times, and the results was the average of the measurements.

3. Results and Discussions

3.1 Morphology and Physico-chemical Properties of Soil

The morphology and physico-chemical properties of the three pedons are relatively similar in terms of their structure, texture, consistence, color and thickness (Table 1). These are, clay texture, blocky to sub-angular blocky shape structure in the surface horizon, crumb structure in the sub-surface and friable in all horizons. However, when soils were observed critically, differences in color, internal drainage, and the thickness of surface horizon were noticed. The soil surface horizon of pedons treated with *Paspalum* grass and natural weeds were found to be thicker than the control. This observation can be attributed to the fact that cover crops are able to decrease run off and erosion (Afandi *et al.,* 2002), therefore useful for soil conservation measures.

Soil color is closely related to parent material, organic carbon content, the intensity of Fe/Al oxidation, age of parent material, and soil moisture condition. The color of soil in surface horizon of pedons (A horizon) that were covered by either *Paspalum* grass or natural weeds was darker than control, due to their organic materials released to the soil. Soil color in the subsoil of *Paspalum* grass and natural weeds plots had red color brighter than clean-weeded coffee plot (control), with that of grass superior to natural weeds plot. Reduction and oxidation (Redox) process in soils affect the stability of iron (Fe) and manganese (Mn) compounds. Soil color can indicate certain moisture condition due to the mobilization of Fe and Mn caused by Redox processes. Generally, the subsoil of three pedons showed enough oxidation and good internal drainage conditions. These phenomena were proved by the high chroma (≥ 4). But, soil colors in the lowest horizon of pedon T-1 (at 81–103 cm depth) and pedon T-3 (at 108–132 cm depth) that reached 2.5 Y showed less oxidative condition and the internal drainage worse than T-2 (at 120–135 cm depth). Among the three pedons, T-1 was the least oxidative compared to others, even though the lowest layer had ever experienced redox reaction in the past as shown by the red mottles (10 YR 5/8).

Although there are different colors (matrix or mottles) in subsoil among the three pedons, it is too early to conclude that those differences were caused during four years of study. Conceptually, a biological process or vegetation plays an important role in soil formation over a long-term period. In a more detailed analysis,

Table 1 Morphology and Soil Physical Properties of Three Pedons under Different Cover Crop Management Systems

Plot	Soil Depth (cm)	Horizon	Matrix Color	Soil Structure	Soil Separates (kg/kg)			Texture	Soil Strength kPa	Consistence	Mottles / Crack	Roots
					Sand	Silt	Clay					
T-1	0–10	A	Dark Brown 10 YR 3/3	Sab, f, 1	0.253	0.262	0.485	C	245.2	fr	Crack	md-few, f-m
	10–32	AB	Yellowish Brown 10 YR 5/6	Sab, f-m, 1	0.254	0.132	0.614	C	230.5	fr	Crack	f-cm
	32–81	Bw1	Strong Brown 7.5 YR 5/6	Cr, vf, 1	0.277	0.131	0.592	C	171.6	fr	Crack	f-few
	81–103	Bw2	Light Yellowish Brown 2.5 Y 6/4	Cr, vf, 1	0.254	0.121	0.625	C	147.1	fr	10 R 5/8, sdk	f-very few
T-2	0–15	A	Dark Greyish Brown 10 YR 3/2	b, vf, 1	0.396	0.181	0.423	C	230.5	fr	Crack	md-few, f-m
	15–40	AB	Yellowish Dark Brown 10 YR 4/6–5/6	ab, f-m, 1	0.318	0.120	0.562	C	264.8	fr	Crack	f-cm
	40–85	Bw1	Strong Brown 7.5 YR 5/6	Cr, vf, 1	0.293	0.136	0.571	C	220.6	fr	Crack	f-few
	85–120	Bw2	Yellowish Red 5 YR 5/6	Cr, vf, 1	0.212	0.123	0.665	C	205.9	fr	Crack	f-very few
	120–135	Bw3	Yellowish Red 5 YR 5/6 & Brownish Yellow 10 YR 6/6	b, vf, 1	0.175	0.134	0.691	C	240.3	fr		—
T-3	0–13	A	Dark Greyish Brown 10 YR 3/2	b, f, 1	0.333	0.221	0.446	C	181.4	fr	Crack	md-cm, f-m
	13–48	AB	Yellowish Brown 10 YR 5/6	Sab, f-m, 1	0.294	0.131	0.575	C	240.3	fr	Crack	md-few, f-cm
	48– 92	Bw1	Yellowish Strong Brown 7.5 YR 5/6–10 YR 5/6	Cr, vf, 1	0.312	0.143	0.545	C	264.8	fr	Crack	f-few
	92–108	Bw2	Strong Brown to Yellowish Red 7.5 YR 5/6–5 YR 5/6	Cr, vf, 1	0.237	0.121	0.642	C	250.1	fr		f-very few
	108–132	Bw3	Strong Brown and Olive Yellow 7.5 YR 5/6 & 2.5 Y 6/6	b, f, 1	0.221	0.131	0.648	C	210.8	fr		f-very few

Ex : b=blocky, ab=angular blocky, sab=sub angular blocky, Cr=crumb, C=Clay, fr=friable, Crack, f=fine, md=medium, cm=common, m=many.

the concept of biosequence needs thorough discussion in order to understand the uniformity of parent material in a land unit. Influences of soil cover crop on morphology and soil properties are more significantly shown in soil surface layer, particularly, color, thickness of soil surface layer, soil chemical properties, such as pH, organic carbon content, total nitrogen, available P, exchangeable bases, exchangeable Al, base saturation and Al saturation (Table 2).

Generally, cover crops have the capability to improve chemical properties of soil surface layers (Wiharso, Afandi and Senge, 2001). The content of organic carbon, total nitrogen, available P, exchangeable bases, and pH of soil surface layer in both grass and natural weed plots, were higher than control plot, while exchangeable Al and Al saturation decreased.

Accumulation of organic matters and exchangeable bases in soil surface horizon of coffee plantation treated with grass (T-2) or natural weed (T-3) show that bases in the form of nutrients had been translocated from subsoil to various tissues of cover crops through roots, and these bases and organic matter were later returned into the soil surface after decomposition. Bases returned to the soil surface in this manner retarded the loss of exchangeable bases by leaching and retarded the development of soil acidity, hence the pH values were higher in T-2 and T-3 compared to T-1. *Paspalum* grass and natural weeds in this research had total biomass larger than control (Sriyani *et al.,* 1999), hence its ability to de-

Table 2 Soil Chemical Properties of Three Pedons under Different Cover Crop Management Systems

Plot	Soil depth (cm)	Hor	pH		C-Org (mg/kg)	T-N (mg/kg)	Avail. P Bray I (mg/kg)	CEC 7	Exchangeable Bases cmol(+) kg^{-1}				Σ Exch. Bases	BS 7 (%)	ECEC	Exch. Al	Al sat (%)
			H_2O	KCl					Ca	Mg	K	Na					
T-1	0-10	A	4.29	3.74	22.7	1.9	3.09	17.3	3.70	1.98	0.26	0.05	5.99	34.6	8.99	3.00	33.4
	10-32	AB	4.25	3.69	9.0	0.9	1.03	16.1	3.44	1.98	0.21	0.04	5.67	35.2	7.92	2.25	28.4
	32-81	Bw1	3.92	3.65	2.9	0.5	—	18.1	2.81	1.35	0.12	0.02	4.30	23.8	7.85	3.55	45.2
	81-103	Bw2	3.96	3.63	2.9	0.4	—	26.4	3.96	1.56	0.10	0.01	5.63	21.3	9.52	3.85	40.9
T-2	0-15	A	4.57	3.88	26.1	2.2	19.98	16.2	7.02	6.46	0.47	0.10	14.05	86.7	15.50	1.45	9.4
	15-40	AB	4.11	3.68	9.6	1.0	1.89	16.6	3.70	1.04	0.13	0.02	4.89	29.5	7.89	3.00	38.0
	40-85	Bw1	3.76	3.42	3.7	0.6	—	16.8	2.55	1.02	0.12	0.02	3.71	22.1	6.81	3.10	45.5
	85-120	Bw2	3.92	3.60	4.0	0.4	—	17.3	2.17	1.04	0.10	0.02	3.33	19.2	7.38	4.05	54.9
	120-135	Bw3	3.90	3.57	2.7	0.3	—	24.8	1.91	1.04	0.09	0.01	3.05	12.3	8.05	5.00	62.1
T-3	0-13	A	4.80	3.83	29.0	2.4	8.14	19.8	7.53	4.08	0.27	0.07	11.95	60.4	12.60	0.65	5.2
	13-48	AB	4.38	3.73	9.2	0.9	2.01	14.7	4.47	2.71	0.17	0.04	7.39	50.3	10.59	3.20	30.2
	48-92	Bw1	4.02	3.74	2.7	0.4	—	13.3	2.68	1.35	0.14	0.03	4.20	31.6	7.40	3.20	43.2
	92-108	Bw2	4.01	3.75	2.3	0.4	—	14.1	1.66	1.35	0.09	0.01	3.11	22.1	6.76	3.65	54.0
	108-132	Bw3	4.00	3.74	1.5	0.3	—	38.0	1.65	1.33	0.09	0.01	3.08	8.1	7.13	4.05	56.8

CEC 7＝CEC by 1 N NH4OAc at pH 7.0. cmol(+)kg^{-1} ; BS 7＝ΣExch. Bases/CEC 7×100% ; ECEC (Effective CEC)＝ΣExch. Bases＋Exch. Al, cmol(+)kg^{-1} ; Al Sat. (Al Saturation)＝Exch. Al/ECEC×100%.

crease soil erosion significantly (Afandi *et al.,* 2002). This is also supported by the thicker soil surface layer of both grasses and natural weeds plots compared to the control.

Soil surface horizon of both grass and natural weed plots contain organic carbon higher than control, with natural weeds plot having the highest value. But the highest percentage of organic carbon from natural weed plot did not have corresponding values of exchangeable bases and available P. Exchangeable bases and available P in the surface layer of natural weed plot was lower than that of grass.

Table 2 showed that the use of *Paspalum* grass and natural weeds can increase exchangeable bases and base saturation, especially in the surface layer (A horizon). The increasing exchangeable bases and base saturation by *Paspalum* grass were more concentrated in soil surface layer, while that of natural weeds increased those properties down to the sub-layer. Although the natural weeds plot contains exchangeable bases less than grasses in soil surface horizon, its exchangeable calcium was higher than the rest.

This phenomenon showed that in *Paspalum* plot as well as in natural weeds plot, Al saturation was decreased and the pH was increased in the surface horizon. Yearly observation which was made from 1996 to 1999 also showed that the soil pH and organic matter in *Paspalum* plot and natural weeds plot were higher than in control plot up to 40 cm depth (Salam *et al.,* 2001). Probably the main reason of this phenomenon arised from the abundant of organic matter in *Paspalum* as well as natural weeds plot. The average content of soil organic carbon from 1996 to 1999 in *Paspalum* plot and natural weeds plot was 32.1 g/kg and 26.5 kg respectively where in control plot it was 20.2 g/kg (Afandi *et al.,* 2003).

3.2 Soil Classification

Morphology of the observed soils was almost similar to the soil morphology in lowland areas in Lampung, Indonesia, in which the observed soils are dominated by halloysite (Lumbanraja, Syam, Sarno and Wada, 1999).

The three pedons have deep solum and thin soil surface layers with weak structure, therefore belong to *ochric epipedon.* Due to the absence of clay film in the sub surface horizon as well as soils having CEC of more than 16 cmol(+)kg^{-1}, it indicates that the three pedons belong to the cambic horizon as their diagnostic horizon. According to Soil Survey Staff (1998), those pedons are classified as *Inceptisol* in the order category. Those pedons do not have aquic conditions within 50 cm of the mineral soil surface, but they have udic moisture regime, therefore soils are classified as *udepts* in the sub-order category. In the great soil group category, the three pedons are classified as *Dystrudepts,* because they do not have sulfuric horizon, duripan, fragipan, free carbonate, and a base saturation of 60% or more in one or more horizons at a depth between 25 and 75 cm from the mineral soil surface.

The natural weeds plot (T-3) had a base saturation of 50.17% between 25 and 75 cm depth that satisfies the approximate requirement by *Eutrudepts* (≥60%). It can therefore be deduced that when coffee plantation is properly managed with natural weeds, base saturation is likely to increase within 25–75 cm depth of the sub surface horizon. So, there is a possibility of the changing soil class in great group category from *Dystrudepts* to *Eutrudepts.*

Although clay minerals near this research area (Rigis Hill) are dominated by halloysite, 1 : 1 type of clay mineral, but soils still have enough amount of chlorite, vermicullite and smectite (Lumbanraja, Syam, Sarno and Wada, 1999), therefore soils have ability to swell and shrink. This phenomenon is shown by crack of 5 mm or more width and 30 cm or more length in a depth of less than 125 cm from soil surface in each soil profile. Beside, soils do not have lithic contact within 50 cm from soil surface and *mollic* or *umbric epipedon.* Based on the discussions above, the three pedons are classified as *vertic dystrudepts* in sub group category, although the slickensides or wedge-shape aggregates were not found.

3.3 The Coffee Growth

Although the existence of weeds could be positive effect on the soil, however, in short term, it could suppress the coffee growth performance. The control plot where the conventional weed management applied gave the best performance of coffee growth as shown in plant height, canopy diameter and coverage. As reported by Afandi *et al.* (2002), the weeds had suppressed the coffee height at *Paspalum* plot about 40% and at natural weed plot about 30%. The canopy diameter was also suppressed as much as 57% at *Paspalum* plot and 54% at natural weeds plot.

Sriyani *et al.* (2000) also reported that the yield reduction of coffee beans in weedy plots in 1999 was 40% at *Paspalum* plot and 75% at natural weed plot compared to clean-weeded plot.

3.4 Conclusion

Covering soil surface by crops or weeds for four years was able to conserve soils in hilly area of South Sumatra and improved soil morphology as well as soil chemical properties. Surface layer of soils treated with grasses and natural weeds became thicker and darker than before. Almost all soil chemical properties in soil surface layer increased depending on the type of treatment. Thus, grasses plot had thicker soil surface as well as higher available P, exchangeable bases, Mg, K, Na, and base saturation than natural weeds. On the other hand, natural weeds increased organic carbon content, total nitrogen, soil pH, CEC, exchangeable calcium, as well as decreased exchangeable Al and Al saturation in soil surface horizon. It can be deduced from the study that, since natural weeds were able to increase exchangeable bases and base down to the sub-surface layer, the soil class could possibly change from *Dystrudepts* to *Eutrudepts* in the great soil group category.

Even though several soil characteristics changed, they were not enough to distinguish soil nomenclature of three pedons in sub group category. All pedons had vertic property in sub group category, hence classified as *Vertic Dystrudepts.*

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インドネシア・南スマトラ丘陵傾斜地コーヒー園において4年間の異なった被覆植物の導入が赤色酸性土壌に与える土壌形態学的変化

アファンディ*・ディディン　ウィハルソ*・千家正照**・
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要　　旨

熱帯湿潤気候であるインドネシア・南スマトラ丘陵地に広がる火山灰性の赤色土壌を対象に研究を実施した。一般に火山灰性由来の土壌は植物の生育を支持するのに必要な栄養分を十分に保持している。しかし，赤色土壌はもろく，長期間温暖で湿潤な気候の影響を受けると表層土壌は溶解性栄養分とともに河川に流失する。この研究の目的は，赤色土壌に異なる被覆植物を4年間導入することによって土壌の形態学的・理化学的特性に及ぼす影響とSoil Taxonomy上の分類で起こりうる変化について検討することにある。各試験区は次の通りである。T-1 : 被覆植物のないコーヒー園（2週間に1回の頻度で雑草を除草し地表面を裸地状態に維持した），T-2 : *Paspalum conjugatum* の植物によって地表面を被覆したコーヒー園，T-3 : 自然植生の雑草で地表面を被覆したコーヒー園。Soil Survey Manual と Soil Taxonomy Classification System にしたがって土壌断面を記述し土壌試料をサンプリングした。4年間の被覆植物による処理後，表層土壌はより厚く色調が暗くなることが観測された。また，表層土壌の大半の化学的特性，とくに土壌pH，有機態炭素，全窒素，有効態P，交換性塩基，塩基飽和度が増加した。一方，表層土壌の交換性Al，Al飽和度は減少した。このように試験期間中に土壌の特性は変化したが4年間の処理ではSoil Taxonomyによる亜群の分類を変化させることができず，全ての土壌が *Vertic Dystrudepts* となった。しかし，自然植生の雑草で被覆すると下層土の交換性塩基と塩基飽和度が増加するため，長期間経過するとSoil Taxonomy上の分類が *Vertic Dystrudepts* から Eutrudepts に変化する可能性が示された。

キーワード : 赤色土壌，コーヒー，被覆植物，雑草，*Vertic Dystrudept*，スマトラ

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