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CHANGES IN SOIL MORPHOLOGY AND PROPERTIES UNDER LONG－TERM SOIL MANAGEMENT IN HUMID TROPICAL REGIONS OF LAMPUNG, INDONESIA

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ABSTRACT: A humid tropical climate is characterized by high amounts of rainfall and high temperatures throughout most of the year. It results in elevated rates of soil weathering, soil loss, the leaching of cations, and the oxidation of the organic matter in the soil. The aim of this research was to observe the changes in soil morphology and soil properties due to the differences in soil management over a period of 20 years. Three types of soil management methods were applied, namely, intensive tillage (IT), minimum tillage (MT), and no tillage (NT). Basically, minimum tillage and no tillage are types of conservation tillage (CT). The results showed that, with IT management, the lower content of organic matter in the upper layer of the soil caused the soil to become lighter in color, which was characterized by higher chroma. The soil structure on the top layer of the soil changed from crumbs toward angular blocky. The topsoil was seen to be more friable than when the other two management methods were applied, while the lower layer was denser or more compact. Generally, the chemical properties of the soil with the CT management methods were better than those with the IT method, and those with the NT method were slightly better than those with the MT method.

Keywords: Intensive tillage, Minimum tillage, No tillage, Conservation tillage

1. INTRODUCTION

Technically, the major constraint of producing food in humid tropical regions is the low quality of the soil brought about by the rapid rate of soil degradation, resulting from high temperatures and high amounts of rainfall. Due to the large quantity and high intensity of the rainfall events in these humid tropical regions, soil erosion can potentially reach dramatic levels [1, 2]. Therefore, the soil quality decreases rapidly. The process of the decreasing soil quality, from morphology and physical/chemical properties of the soil, continues at a high rate. In cultivated lands, especially those for food crops and horticulture, the canopy is short and more open, and thus, more conducive to erosion, surface flow, and oxidation. As a result, the color of the soil will be brighter due to the decreased soil organic matter (SOM), soil structure damage, thinning soil surface horizon, and decreasing colloid adsorption of the soil against cations brought about by a reduced source of negative charge which will eventually be more conducive to the occurrence of the cation leaching process. The above conditions occur because, in general, little attention is paid to soil conversation in the existing agricultural cultivation methods or conventional agriculture. This is happening not only in farmlands, but also at plantation companies.

In order to reduce the rate of soil degradation due to high amounts of rainfall and high heat in humid tropical regions, new technologies are appearing that can reduce the rate of soil degradation by minimizing soil tillage (MT) or even eliminating it (NT). Both of these cultivation technologies can be referred to as conservation tillage (CT) or conservation agriculture (CA) because they do not modify the soil layers intensively; therefore, they will not alter or damage the soil structure. Conservation tillage, the most important aspect of conservation agriculture, is thought to take care of the soil health, plant growth, and the environment [3].

Through conservation tillage technology, in addition to not causing too much damage to the soil structure at the top soil, the residue of the harvest that is spread over the soil surface can function as mulch. The presence of mulch above the soil surface is expected to reduce the soil damage due to splash erosion and surface runoff. Plant residue from the previous crop season, which is used as mulch, is important in CT practices. This is not only because of its effectiveness in reducing soil erosion, but also because of its ability to convert the substrate to microbial biomass carbon [4, 5, 6]. In addition, the mulch covering the soil surface is expected to restrain the effects of high temperatures so that the microclimate on the surface layer will not overheat. This will further reduce the rate of oxidation of the soil organic matter. Using mulch, the soil temperature at a depth of 5 cm decreases by 5-9°C and the soil moisture content [7] increases.

The aim of this study is to determine the changes that occurred in the morphology and the properties of the soil after a difference in land management over a period of 20 years.

2. MATERIAL AND METHODS

This research was conducted on Reddish Brown Latosol (Udult) derived from young Quarternary andesitic volcanic rock [8]. The study site has an altitude of about 120 m above sea level, with a latitude of 5° 21' 20" S and a longitude of 105° 13' 47" E. The soil at this site was managed for 20 years, starting in 1987, by applying three types of soil management. The first method was intensive tillage (IT), the second was minimum tillage (MT), and the third was no tillage (NT). The cereal-legume-fallow rotation sequences were set each year. The plots for this long-term experiment were four by six meters in size [9]. In the IT plots, prior to planting, the soil was plowed two times to a depth of approximately 20 cm, and all the weeds and previous crop residue were removed. In the MT plots, the soil was plowed lightly to a depth of 0-5 cm using a hoe. In the NT plots, the weeds were sprayed with glyphosate at a dose of 4.8 liters per hectare. In the CT plots (MT and NT), all the dead weeds and previous crop residue were used as mulch to cover the soil surface, while in the IT plots, all the weeds and previous crop residue were removed from the plots [10, 11, 12]. The nitrogen source for the N treatment was 46% urea. Nitrogen fertilizer was applied by hand banding in a row close to the crop. A week after planting, P and K fertilizers were applied as basal fertilizers at rates of 100 kg SP-18 ha^{-1} and 100 kg KCl ha^{-1}, respectively [6].

A soil pit was dug in the middle of each plot. Soil samples were taken and soil profiles were described according to the Soil Survey Division Staff [13]. The soil color was determined by Munsell Soil Color Charts [14]. Disturbed soil samples were taken by the pipette method [15] to analyze the soil texture and the chemical properties of the soil. The chemical properties included the organic carbon content (Walkley and Black), total nitrogen (Kjeldahl), pH in the H_2O at a ratio of 1:2.5 (pH meter), exchangeable bases, soil CEC extracted by 1 N NH_4OAc. at pH 7.0, and exchangeable Al & H extracted by 1 N KCl measured by AAS. An undisturbed soil sample was taken by the core method through a sample ring, 2 inches in diameter, to analyze the bulk density [16]. The soil strength (unconfined compressive strength) in each soil layer was measured using a pocket penetrometer (ELE International).

Table 1 Initial data on physical and chemical properties of soil in study area

Soil properties	Value
Bulk density (g cm^{-3})	0.90
pH H_2O	5.3 - 5.4
Org carbon (%)	1.3 - 1.6
Total N (%)	0.14 - 0.17
Available P (ppm)	17 - 23
CEC ($cmol.kg^{-1}$)	6.3 - 7.32
Ca ($cmol.kg^{-1}$)	0.75 - 0.96
Mg ($cmol.kg^{-1}$)	0.95 - 1.39
K ($cmol.kg^{-1}$)	0.4 - 0.64

The initial data on the physical and chemical properties of the studied soils were available only for the soil surface layer as thick as 20 cm (Table 1). The chemical properties of the soil for 1994 were obtained from Utomo [17, 18], and the bulk density of the soil for 1987 was obtained from Utomo [19, 20, 21]. Data were analyzed by T-test.

3. RESULTS AND DISCUSSIONS

3. 1 Soil Morphology

3. 1. 1 Soil Horizons

From the soil surface to a depth of 150 cm, there is a difference in the number of soil horizons, namely, the IT pedon has six soil horizons, the MT pedon has five soil horizons, and the NT pedon has four soil horizons. A difference is also found in the thickness of the surface horizon where the surface horizon of the IT pedon (18 cm) is thicker than that of either CT pedon (15 cm). This happens because the soil plowing reached a depth of 18 cm for the IT pedon.

3. 1. 2 Soil Color

There is a gradual difference in soil color from the surface horizon where the soil on the IT pedon (7.5 YR 3/4) is slightly lighter than that on the CT pedons (7.5 YR 3/2) which is characterized by higher chroma. Although there is a difference in the soil color, all three pedons belong to the same class of dark brown color (Table 2). The difference in soil color on the surface horizon is due to the difference in the soil organic carbon (SOC) content, where the SOC content on the upper layer of the IT pedon (1.42%) is less than that of the two CT pedons. Between the two CT pedons, the soil C-organic content on the surface horizon on the NT pedon(1.60%) is higher than that of the MT pedon (1.53%).

3. 1. 3 Soil Structure

The soil structure on the surface layer of the soil on the two CT pedons has the same shape, that is, crumbs, while that on the IT pedon shows a change toward angular blocky (Table 2). The change is certainly related to the reduced content of soil organic matter (SOM). According to Busari et al. [3], the yearly practice of the no-till system over a long period of time is beneficial to the maintenance and enhancement of the structure and the chemical properties of the soil, most especially the content of soil organic carbon.

3. 1. 4 Soil Consistency

The topsoil on the IT pedon has a more friable consistency than either CT pedon (Table 2), because soil plowing can dismantle chunks of the soil, thereby rupturing the soil aggregates and making them smaller. In the subsoil horizon, the soil consistency in the IT pedon has a thicker layer

Table 2 Morphology of soils under different management methods

Type of tillage	Soil depth (cm)	Soil horizon	Soil color	Soil structure	Soil consistency
IT	0-18	Ap	7.5YR 3/4	Cr-Ab, vF, 2	vfr
	18-27	AB	5YR3/4	Ab, F, 2	fr
	27-54	Bt1	5YR4/4	Ab, M, 2	sf
	54-82	Bt2	5YR4/6	Ab, C, 2	f
	82-128	Bt3	5YR5/6	Ab, M, 2	f
	128-147	Bw	5YR5/8	Ab, M, 2	sf
MT	0-15	Ap	7.5YR3/2	Cr, vF, 2	fr
	15-45	AB	5YR3/4	Ab, F, 2	fr
	45-82	Bt1	5YR4/4	Ab, M, 2	sf
	82-112	Bt2	5YR4/6	Ab, M, 2	f
	112-150	Bt3	5YR5/6	Ab, F, 2	sf
NT	0-15	Ap	7.5YR 3/2	Cr, vF, 2	fr
	15-48	Bt1	5YR4/4	Ab, M, 2	sf
	48-124	Bt2	5YR4/6	Ab, M, 2	sf
	124-168	Bw	5YR5/6	Ab, vF, 2	sf

Ex.: Ab = angular blocky, Cr = crumb, vF = very fine, M = medium, vfr = very frible, fr = friable, sf = slightly firm, f = firm

Table 3 Soil physical properties

Type of tillage	Soil depth (cm)	Soil horizon	Soil strength (Kgf.cm^{-3})	Bulk density (gcm^{-3})	Soil separates (%)		
					Sand	Silt	Clay
IT	0-18	Ap	1.35	0.98	12.4	30.0	57.6
	18-27	AB	1.70	1.13	8.0	23.5	68.5
	27-54	Bt1	2.00	1.18	6.2	13.1	80.7
	54-82	Bt2	3.45	1.32	4.1	12.4	83.5
	82-128	Bt3	4.05	1.34	3.9	8.8	87.3
	128-147	Bw	2.75	1.34	3.8	8.4	87.8
MT	0-15	Ap	1.20	1.04	14.1	27.8	58.1
	15-45	AB	2.10	1.08	7.4	21.4	71.2
	45-82	Bt1	2.40	1.17	5.5	13.5	81.0
	82-112	Bt2	2.75	1.23	4.9	12.3	82.8
	112-150	Bt3	2.30	1.18	4.3	16.4	79.3
NT	0-15	Ap	1.80	1.14	14.2	30.4	55.4
	15-48	Bt1	1.85	1.18	7.3	11.3	81.4
	48-124	Bt2	2.75	1.24	4.2	10.5	85.3
	124-168	Bw	1.95	1.16	3.9	8.4	87.7

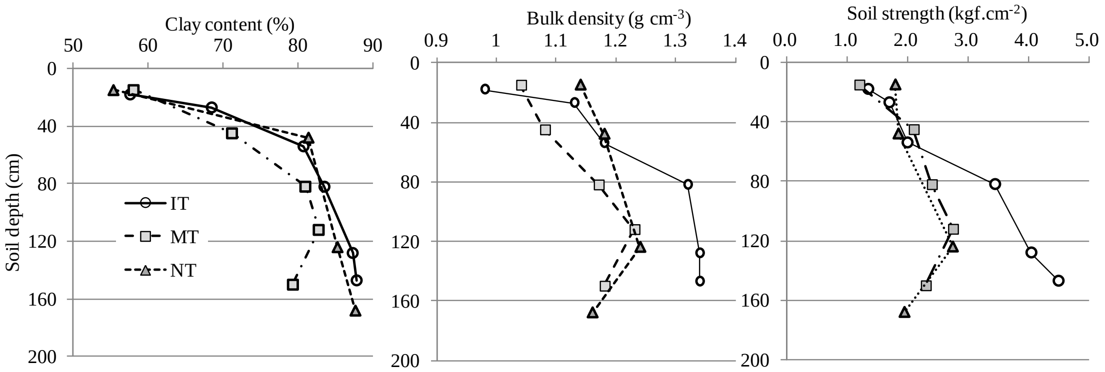

Fig. 1 Clay content, bulk density, and soil strength of the three pedons

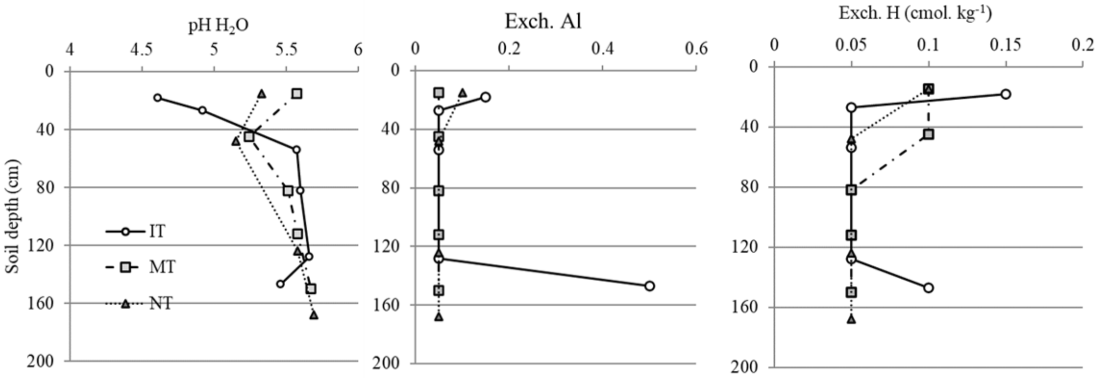

Fig. 2 Soil pH and exchangeable Al and H of the three pedons

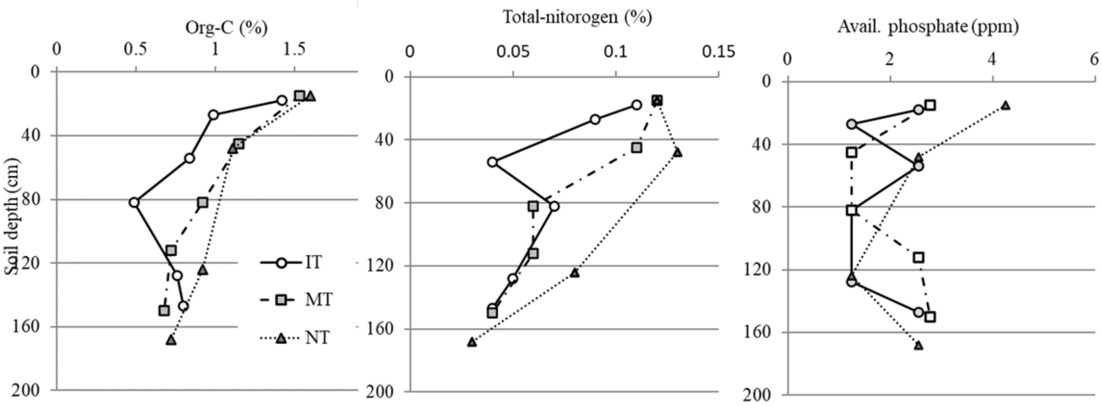

Fig. 3 Organic carbon, total nitrogen, and available phosphate of the three pedons

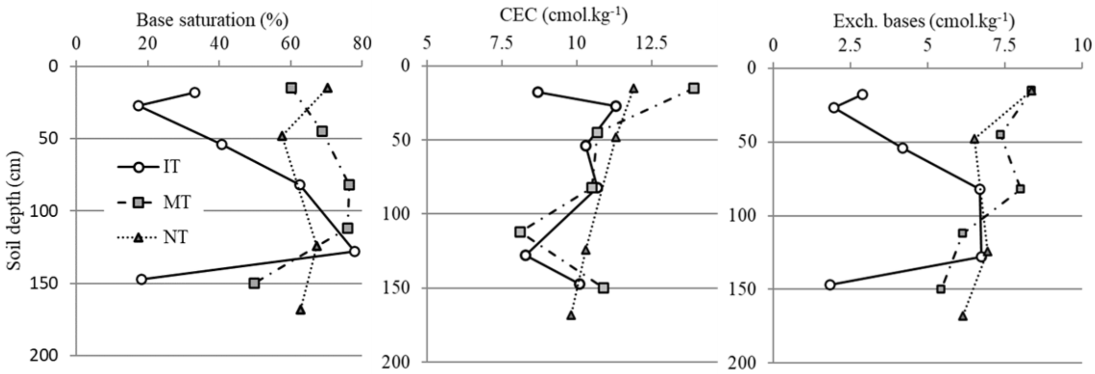

Fig. 4 Soil CEC, sum of exchangeable bases, and base saturation of the three pedons

of firm soil, while the NT pedon has no firm soil consistency (Table 2). The presence of a soil layer that has a firm consistency will inhibit the growth and development of plant roots. The thickness of the firm soil layer on the IT pedon will inhibit the development of plant roots.

3. 2 Physical Properties of Soil

3. 2. 1 Soil Texture

All three pedons belong to the same texture class, that is, clay (Table 3). The contents of the clay particles in the soil surface layers lie in the range of 55-58%, while that at the bottom layer lies in the range of 80-88%. The difference in clay contents is actually found in the second soil layer, where the content of clay on the NT pedon is much higher than those on the other two pedons. This may occur because of the more open topsoil on the IT pedon, as a result of the intensive soil tillage, which can promote the leaching process of the clay particles running more intensively than on the NT pedon. Therefore, the clay content in the second layer of the IT pedon is the lowest.

3.2.2 Bulk Density

The IT pedon, which has more open soil on the surface layer due to the low bulk density (BD) and no mulch, causes the penetration of rain water to be greater. Such conditions are conducive to the leaching of clay particles. In addition, more open soil without mulch and greater macro pore space on the soil surface layer cause better aeration, so that the exchange of air and the heat from sunlight are allowed to penetrate the deeper layers of the soil. This can cause the adhesiveness of stronger granules; consequently, the consistency of the soil becomes firmer (Table 2) and the BD value becomes higher (Table 2 and Fig. 1). Compared with the initial condition, all the treatments bring about an increase in the BD value, but the increasing BD in the no-tillage system is higher than that in the other two systems. This is because the fewest modifications were made to the soil body.

3. 2. 3 Soil Strength

In line with the soil texture, the BD, and the soil consistency, the higher clay content causes the BD value to increase and the soil consistency to become stronger. This, in turn, will cause the soil strength to also become stronger. Figure 1 shows that the soil strength in the lower layer of the IT pedon is stronger than that of the CT pedons. The stronger soil strength will further inhibit the growth and development of plant roots.

3. 3 Soil Chemical Properties

3. 3. 1 Soil pH and Potential Soil Acidity

The pH of the soil surface layer on the IT pedon is lower than that of the two CT pedons, while the soil pH of the NT pedon is lower than that of the MT pedon (Fig. 2). This is related to the exchangeable Al & H on the IT pedon that are higher than those on the two CT pedons. The Al cation is the soil acidity potential that is able to release H^+ into the soil solution, which consequently causes the soil to become more acidic.

3. 3. 2 Soil Organic Carbon and Total Nitrogen

Up to a depth of 100 cm, the soil organic-C content of the IT pedon is lower than that of either CT pedon, while the total-N content of the IT pedon is lower from the soil surface to a depth of 60 cm (Fig. 3). The data on the soil's organic-C content on the surface horizons of the three pedons indicate that the CT treatment is more capable of conserving the soil organic matter content in the soil surface layer than the IT treatment. Meanwhile, between the two CT treatments, it is seen that the NT treatment can conserve more soil organic matter content in the soil surface layer from loss through erosion, leaching, or oxidation processes. Between the two CT pedons, the soil organic-C content on the surface horizon of the NT pedon (1.60%) was higher than that of the MT pedon (1.53%). The presence of mulch as a soil cover enabled the prevention of the loss of soil nitrogen through evaporation, the decomposition of soil organic matter, or the leaching process.

3. 3. 3 Available Phosphate

Figure 3 shows that the available phosphate of the NT pedon is higher than that of the IT and MT pedons. As a static element in the soil body, phosphates are generally more stable and are usually lost through surface runoff and soil erosion, although water-soluble phosphates could be lost through the leaching process. The absence of any destructive treatment to the soil surface layer allows the NT system to better protect the soil from phosphate loss through surface runoff, erosion, or the leaching process compared to the IT or MT system.

3. 3. 4 Soil CEC, Exch. Bases & Base Saturation

Figure 4 shows that the IT pedon has soil CEC, a sum of exchangeable bases, and base saturation that are less than those of the CT pedons. Both CT pedons have the same sum of exchangeable bases, while the soil CEC of the MT pedon is higher than that of the NT pedon. Therefore, the base saturation of the NT pedon is a little higher than that of the MT pedon. Natural weeds can take nutrients from the deeper layers through the roots and bring them to the canopy of the plant. Then, through the process of dead weed decomposition, nutrients will be released to the topsoil. The longer the nutrient cycles become, the higher the nutrients of the surface layer contents will be compared to the lower layers. The contribution of nutrients through the weed cycle can then be utilized by the main plant. Covering the soil surface with natural weeds and their residue at a coffee plantation was shown to increase the organic carbon content, total nitrogen, soil pH, CEC, and exchangeable calcium, as well as to decrease the exchangeable Al and Al saturation in the soil surface horizon [22]. Therefore, the CT system can reduce the loss of soil and SOM, which can also contribute to the plant nutrients and simultaneously improve the chemical properties of the soil.

4. CONCLUSION

The results of the present study have shown that the lower content of soil organic matter in the upper layer of the IT pedon caused the soil color to become lighter, which was characterized by higher chroma. The soil structure on the top layer of the IT pedon changed from crumbs toward angular blocky. The topsoil of the IT pedon was more friable than that of the other two pedons, while the lower layer was denser or more compact, as was shown by the higher BD, stronger soil strength, and very thick firm soil layer. Generally, the chemical properties of the CT pedon soil were better than those of the IT pedon soil, and those of the NT pedon soil were slightly better than those of the MT pedon soil, particularly at the soil surface layer. Finally, conservation tillage over a long period was seen to improve the CEC, the sum of exchangeable bases, and the base saturation of the soils.

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