ISSN: 1394-7990
Malaysian Journal of Soil Science Vol. 18: 51-60 (2014) Malaysian Society of Soil Science

Effects of Land Use on the Physico-Chemical Properties of Andisols in Mt. Sinabung, North Sumatera, Indonesia

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ABSTRACT

Land use can have an impact on the physical and chemical properties of soils. The aim of this study was to identify and determine changes in soil physics-chemical properties of Andisols under three different land use profiles in the Mt. Sinabung area. These were: natural forest, perennial cropland with low-intensity cultivation, and annual cropland (horticulture) with high-intensity cultivation. Our findings show that differing land use profiles did not change soil classification, solum thickness, and effective depth of the Andisols of Mt. Sinabung. However, intensive cultivation of the Andisols resulted in the top soil having a more intense red colour and increased pH_0 and Al-humus complex.

Keywords: Annual cropland, natural forest, perennial cropland, soil classification, volcanic ash.

INTRODUCTION

The central concept of an Andisol is that of a soil developing in volcanic ejecta (such as volcanic ash, pumice, cinders, lava), and/or in volcaniclastic materials, whose colloidal fraction is dominated by short-range-order materials of Al-humus complexes. Under special environmental conditions, weathering of primary alumino-silicates in parent materials of non-volcanic origin may also lead to the formation of short-range-order minerals; some of these soils are also included in Andisols (Mizota and van Reewijk 1989).

Many Andisols have excellent physical properties that make them highly desirable for a wide range of uses. Chemically, they suffer from high phosphate retention, and may be deficient in K and some micronutrients. Nevertheless, these soils are amongst the most fertile land in the world and are, therefore, very intensively cultivated (Neall 2009). As most of the Andisols in Indonesia are very productive, the soils are intensively cultivated with perennial and annual crops. Because these areas are located more than 700 m above sea level, they are mainly used for dry land agriculture (corn, peanut, cassava, and tuber crops), highland vegetables (potato, carrot, cabbage, etc.), and floriculture (tea, coffe, clove, vanilla) (Tan 2008; Subagyo *et al*. 2000; Fiantis *et al*. 2005).

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Mt. Sinabung, along with the nearby Mt. Sibayak, are active volcanoes in the North Sumatra province and are located on the Karo Highlands, in Karo regency. Mt. Sinabung is Pleistocene-Halocene stratovolcano of andisitic and dasitic composition, located at about 2460 m above sea level. The coordinates of the peak are 3°10’12” N and 98°23’3” E. The recorded eruption in the year 1600 produced lava and ash which became parent materials for Andisols in the vicinity of the Karo regency and the northern part of Langkat regency (Anon 2013).

Studies of Andisols in secondary forest, mixed farm, cinnamon and coffee farms at slope 3–8 %, 8–15 %, 15–25 % and > 25 % indicate that organic matter content, agregate stability and permeability of soils in forest land are higher than in other land usage, while soil bulk density and porosity are lower (Endriani and Zurhalena 2008). The aims of our study were to identify, determine and interpret the properties of Andisols under natural forest, perennial crops and annual crops.

MATERIALS AND METHODS

The study area was located in Kuta Rakyat Village, Naman Teran subregency, Karo regency at the northern slope of Mt. Sinabung, about 90 km from Medan. In this study, three profiles representing lands under different land use profiles were investigated formorphology and physico-chemical characteristics of Andisols in Mt. Sinabung. These were P1 –natural forest; P2 –perennial cultivated land; and P3 – annual cultivated land.

The morphology and physico-chemical characteristics of the three soil profiles were determined based on the field book of Schoeneberger *et al*. (2012). Soil samples were taken from each layer in each profile for soil analysis.

Soil pH was measured in water using a 1:2.5 w/v soil solution ratio. The pH in NaF was measured in a suspension of 1 g soil mixed with a 50 mL 1M NaF solution after stirring for 2 min. The exchangeable bases and cation exchange capacity (CEC) at pH 7 was determined by ammonium acetate method (Van Reeuwijk 2002). Exchangeable aluminium was determined by KCl 1 N extraction method while total soil organic carbon (SOC) was analyzed by Walkley and Black method (van Reeuwijk 2002). pH_0 was determined by the salt titration method of Sakurai (1988). Phosphate retention was determined according to the method of Blakemore (van Reeuwijk 2002) while Oxalic acid Al-extract (Alo), oxalic acid Si-extract (Sio), oxalic acid Fe-extract (Feo), and pyrophosphate Al-extract (Alp) were determined by the method of van Reeuwijk (2002). Total P was determined by $HClO_4$ extraction and available P by Bray II method (van Reeuwijk 2002).

RESULTS AND DISCUSSION

Changes in the Morphology of the Andisols

In this study, the three Andisol profiles represented three landuse profiles: (1) Profile 1–natural forest; (2) Profile 2 –perennial crop, consisting of 18-year-old arabica coffee that was never fertilized; and (3) Profile 3 –under annual crop, consisting of horticultural plants such as potatoes, chilies, or tomatoes which had been continuously cultivated for 30 years. These profiles were located on a volcanic hill in the northern slope of Mt. Sinabung with 3 – 8% inclination. The soils were derived from the same parent materials of andesitic tuff. There were 150 ± 5 m of distance between the profiles. The general condition of the three profiles is found in Table 1.

Soil description and laboratory analyses indicated that the soils in the forest land were Typic Haplud and while the cultivated land, both perennial and annual crops, were Typic Fulvudands (Table 2 and Table 3).

TABLE 1.
Profile description of Sinabung Andisolsunder different land use profiles

Location	:	Kuta Rakyat Village, Naman Teran Sub-regency, Karo Regency, North Sumatera province		
Code	:	Profile 1	Profile 2	Profile 3
Ccoordinate	:	N 03º13′5.0” E 98º23′57.7”	N 03º13′7.66” E 098º24′2.4”	N 03º13′9.2” E 098º23′59.3”
Classification	:	*Typic Hapludand*	*Typic Fulvudand*	*Typic Fulvudand*
Physiography	:	Volcanic hill	Mountainous	Mountainous
Slope characteristics	:	3-8 %	3-8%	3-8%
Elevation	:	1432 m asl.	1439 m asl .	1438 m asl .
Effective depth	:	180 cm	150 cm	165 cm
Land use	:	Forest.	Perennial Crops , Arabica coffe	Annual Crops, Potatoes
Land management	:	No cultivation	Low-intensity cultivation	High-intensity cultivation
Manuring	:		None	Chicken manure and NPK
Parent material	:	Andesitic Tuff Sinabung	Andesitic Tuff Sinabung	Andesitic Tuff Sinabung
Diagnostic Horizon	:	Ochric (0–10 cm), Cambic (10– 87 cm)	Ochric (0–95 cm), Cambic (95–170 cm)	Ochric (0 – 40 cm), Cambic (60–135 cm)
Diagnostic character	:	Andic (10– 134 cm).	Andic (0 – 170 cm).	Andic (0–160 cm).
				

TABLE 2
Characteristics of Andisol profiles under natural forest, perennial crops, and annual cropland

Horizon	Depth (cm)	Soil Color		Structure	Consistency	Boundary
Profile 1 (Forest)						
Oe	0 - 10	5 YR 2/1	Brownish black	crumb	loose	abrupt/wavy
A	10 - 45	10 YR 5/6	Yellowish brown	crumb	loose	diffuse/smooth
AB	45 - 87	10 YR 5/8	Yellowish brown	angular blocky	soft	diffuse/smooth
Bw1	87 - 134	10 YR 6/6	Bright yellowish brown	angular blocky	soft	diffuse/smooth
Bw2	134 - 185	7.5 YR 6/8	Orange	angular blocky	loose	clear/smooth
C	> 185	2.5 YR 6/6	Orange	angular blocky	loose	clear/smooth
Profile 2 (Perennial crops)						
A1	0 - 70	7.5 YR 2/3	Very dark brown	crumb	very friable	diffuse/wavy
A2	70– 95/110	7.5 YR3/2	Brownishblack	crumb	very friable	diffuse/smooth
Bw1	95/110-125	10 YR 6/8	Bright yellowish brown	angular blocky	friable	diffuse/smooth
Bw2	125 – 170	10 YR 7/8	Yellow orange	angular blocky	friable	abrupt/smooth
C	> 170	10 YR 5/6	Yellowish brown	loose	firm	
Profile 3 (Annual crops)						
Ap	0 - 40	5 YR 2/2	Brownish black	crumb	loose	clear/wavy
AB	40 - 60	10 YR 4/6	Brown	angular blocky	very friable	diffuse/smooth
Bw1	60 - 110	10 YR 6/8	Bright yellowish brown	angular blocky	friable	diffuse/smooth
Bw2	110 – 135	10 YR 5/8	Yellowis brown	angular blocky	friable	diffuse/smooth
BC	135 - 175	7.5 YR 5/8	Bright brown	angular blocky	firm	diffuse/smooth
C	>175	10 YR 5/4	Dull yellowish brown	loose	very firm	

TABLE 3
Physico-chemical characteristics of Andisols under natural forest, perennial and annual crop

Horizon	Depth	Partcle size distribution				Db	pH			pH	pH_0	C- org	Exchangeable Bases				Al	CEC	BS
		sand	silt	clay	Texture		H_2O	KCl	Δ pH	NaF			K	Ca	Mg	Na	Exch.		
	-----cm-----	------% -------				gcm^{-3}							-----------cmol$_c$kg^{-1}-----------						--%-
Profile 1 (Forest)																			
Oe	0 - 10	88	8	4	Sand	0.35	5.65	5.20	-0.45	10.69	4.70	16.64	0.22	2.03	5.29	0.19	1.48	54.1	14.29
A	10 - 45	96	2	2	Sand	0.34	5.37	5.14	-0.23	11.32	4.81	3.36	0.14	1.92	6.19	0.17	1.08	46.0	18.30
AB	45 - 87	96	2	2	Sand	0.36	5.16	5.67	0.51	11.35	5.69	2.98	0.19	2.32	4.66	0.25	0.80	45.2	16.41
Bw1	87 - 134	92	6	2	Sand	0.39	5.36	5.84	0.48	11.10	6.22	0.54	0.15	1.79	4.38	0.25	0.76	28.2	23.32
Bw2	134 - 185	94	4	2	Sand	0.43	5.39	5.80	0.41	11.09	6.02	0.22	0.26	1.74	4.38	0.26	0.88	33.0	20.15
C	> 185	94	4	2	Sand	0.50	5.54	5.57	0.03	11.03	5.10	0.02	0.24	2.22	4.98	0.16	0.88	26.5	28.68
Profile 2 (Perennial crops)																			
A1	0 - 70	90	6	4	Sand	0.39	4.66	4.63	-0.03	11.24	4.29	8.53	0.15	2.21	6.52	0.22	3.04	58.3	15.62
A2	70– 95/110	94	2	4	Sand	0.50	5.13	4.86	-0.27	11.17	4.64	5.24	0.15	2.01	5.50	0.27	0.96	55.8	14.23
Bw1	95/110-125	96	2	2	Sand	0.41	5.12	5.41	0.29	11.22	5.52	1.63	0.14	1.87	6.25	0.26	0.92	40.4	21.12
Bw2	125 – 170	96	2	2	Sand	0.39	5.19	5.66	0.47	11.08	5.98	0.63	0.17	1.68	3.44	0.29	1.04	39.7	14.07
C	> 170	94	2	4	Sand	0.56	5.39	5.62	0.23	11.12	5.64	0.76	0.13	1.88	7.12	0.24	1.32	26.5	35.40
Profile 3 (Annual crops)																			
Ap	0 - 40	90	8	2	Sand	0.46	5.75	5.54	-0.21	11.10	5.46	7.90	0.17	1.58	7.86	0.22	1.24	39.4	24.94
AB	40 - 60	94	2	4	Sand	0.41	4.82	5.19	0.37	11.37	5.24	2.78	0.15	1.65	5.77	0.19	0.88	54.9	14.14
Bw1	60 - 110	94	4	2	Sand	0.39	5.41	5.81	0.40	11.21	6.25	1.87	0.17	1.20	5.94	0.26	0.96	52.9	14.32
Bw2	110 – 135	94	4	2	Sand	0.50	5.67	6.11	0.44	11.23	6.84	0.99	0.14	1.68	5.49	0.27	0.72	30.3	25.03
BC	135 - 175	94	4	2	Sand	0.48	5.48	6.05	0.57	11.27	6.40	0.68	0.13	1.99	3.93	0.26	1.16	34.8	18.14
C	>175	94	4	2	Sand	---	5.40	5.87	0.47	11.03	6.45	0.54	0.19	2.18	5.16	0.25	1.20	25.8	30.18

Note: Db: bulk density; CEC: cation-exchange capacity;BS: Base saturation

Field observations showed the soil profile in the forest area to have O horizon of litter material of 10 cm thickness, followed by A horizon and Bw horizon. Soils under the perennial crops and annual crops areas did not have O horizon, but the top soil began with A horizon in the soil profile under perennial crops and Ap horizon in soil profile under annual crops. The three soil profiles had similar solum thickness and an effective depth of more than 100 cm.

Different land use patterns have changed the Andisols colour in the upper layer. In a forest area without cultivation, the A horizon soil had a Hue of 10 YR. In the perrenial crops area, soil color of the A horizon was more red with a Hue of 7.5 YR, and in the annual crops area, which was cultivated intensively, the soil color of the A horizon was even more red with a Hue of 5.0 YR. Land cultivation has turned the topsoil colour to red. The colour change in the topsoil was probebly caused by cultivation. Extensive soil tillage and greater exposure to the sun oxidized the iron in the soil causing the soil to become more red. Oxidized soil iron which is associated withthe mineral shematite, goethite and ferrihydrite exhibits a more red colour which increases from 10 YR to 5 YR (Schwertmann and Taylor 1989).

Changes in the Chemical Properties of Andisols

Soil organic C content in the top layer has been affected significantly by land cultivation. Land under more intensive cultivation showed the biggest decrease in soil organic C. As land under annual crops is under intensive cultivation, it has resulted in a loss of a higher amount of organic C content compared to perennial cropland, which is less intensively cultivated. Forest land which was not cultivated had the highest amount of organic C.

pH_0 defines the pH where the net variable surface charge is zero ($\sigma v- = \sigma v+$). Land cultivation has affected the pH_0 value of the Andisols with soil solum (A, B and C horizons) under annual crops having higher pH0 values than soil solum under forest and perennial crops. The higher pH_0 value in land under annual crops is due to intensive cultivation which causes the soil organic carbon to decrease. As the pH_0 value of soils is influenced by soil organic C content, one way of lowering pH_0 would be to increase the organic matter content of the soil (Uehara and Gillman 1981). Removal of organic matter through intensive cultivation has led to remarkably high pH_0 values (Utami and van Ranst 2002; Shamshuddin and Anda 2008). The relationship between pH_0 and organic carbon content in soil solum is shown in *Figure 1*. It is seen that the pH_0 decreases linearly as organic carbon increases.

Table 4 shows that the amount of available P in the three profiles is very low– less than 8 mg kg^{-1}. Also, it can be seen that total P as P_2O_5 ranges from low to very high, at 0.023 – 0.208 %. Therefore, it can be concluded that P retention value in these soils is very high, more than 85%, fitting the definition of Andisols. This indicates that land cultivation did not significantly change the natural characteristics of the Andisols, such as P retention and low availability of P.

TABLE 4
Physico-chemical characteristic of Andisols under forest, perennial crops and annual crop (continued)

Horizon	Depth	P available	P retention	P_2O_5 total	Oxalate extract			Pyrophosphate Al extract	Alo +½Feo
					Al	Si	Fe		
	----cm----	--ppm--	----------	----------	----------	----------	%	----------	----------
Profile 1 (Forest)									
Oe	0 – 10	5.92	85.81	0.169	2.90	2.28	0.41	0.54	3.10
A	10 – 45	1.67	99.20	0.023	2.90	0.45	0.38	0.60	3.09
AB	45 – 87	1.13	99.44	0.034	4.53	1.70	0.27	0.60	4.66
Bw1	87 – 134	1.67	98.19	0.034	4.38	1.43	0.41	0.44	4.58
Bw2	134 – 185	1.40	99.20	0.023	1.30	1.33	0.45	0.42	1.52
C	> 185	1.13	95.04	0.066	1.73	0.63	0.51	0.55	1.98
Profile 2 (Perennial crops)									
A1	0 – 70	5.92	96.64	0.208	2.55	0.56	0.60	0.51	2.83
A2	70– 95/110	4.18	97.42	0.096	2.40	0.51	2.28	0.57	2.65
Bw1	95/110-125	1.13	98.70	0.023	2.40	0.67	2.40	0.54	2.74
Bw2	125 – 170	1.13	99.20	0.048	1.80	0.29	2.40	0.51	1.95
C	> 170	1.40	98.44	0.117	2.88	0.66	1.95	0.68	3.21
Profile 3 (Annual crops)									
Ap	0 – 40	2.50	94.22	0.181	2.95	0.20	2.85	0.73	3.05
AB	40 - 60	1.40	98.95	0.041	3.28	0.14	1.93	0.73	3.35
Bw1	60 – 110	1.40	98.44	0.023	3.73	0.22	1.38	0.54	3.84
Bw2	110 – 135	1.13	98.70	0.142	2.43	0.32	0.95	0.44	2.59
BC	135 – 175	1.13	98.70	0.096	3.15	0.17	1.13	0.57	3.23
C	>175	1.40	97.94	0.089	3.10	0.32	1.15	0.70	3.26

Selective dissolution methods in which Al, Si, and Fe were extracted by oxalic acid (Al_o, Si_o and Fe_o) are considered to represent the sum of Al, Si, and Fe in organic complexes, in non crystaline hydrous oxides and in allophane and imogolite; and Al extracted by pyrophosphate (Al_p) served as proxy for Al organic complexes (Soil Survey Staff 1999). The results of the selective dissolution study showed that land cultivation only changed the Al_o and Al_p contents. Al_o accumulated in the middle layer of the forest land while in the cultivated land, it was distributed in all layers. Intensive cultivation resulted in high Al_p content which accumulated in the top layer, while for land underforest, it resulted in low Al_p.

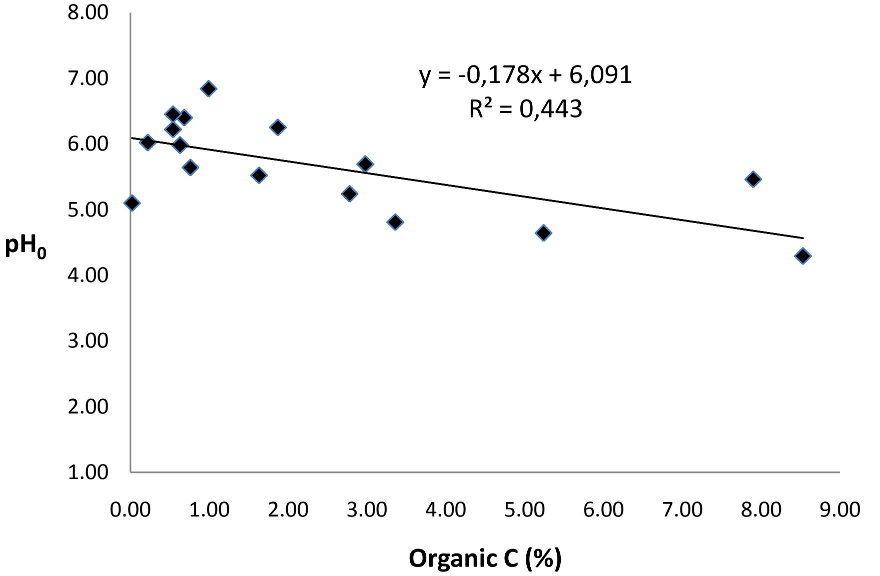

Figure 1: Relationship between pH_0 and organic carbon

CONCLUSION

Diffrent type of landuse, that is natural forest, perennial crops and annual crops, did not change the solum thickness, effective depth, P retention, total P and P available content of the Andisols. Intensive cultivation of the Andisols caused the colour of the top soil to become more red, increased pH0 value and Al-humic complex, but decreased organic carbon.

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