Tropical Volcanic Soils From Flores Island, Indonesia

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ABSTRACT

Tropical Volcanic Soils from Flores Island, Indonesia (Hikmatullah and K Nugroho): Soils that are developed in tropical region with volcanic parent materials have many unique properties, and high potential for agricultural use. The purpose of this study is to characterize the soils developed on volcanic materials from Flores Island, Indonesia, and to examine if the soils meet the requirements for andic soil properties. Selected five soils profiles developed from andesitic volcanic materials from Flores Island were studied to determine their properties. They were compared in their physical, chemical and mineralogical characteristics according to their parent material, and climatic characteristic different. The soils were developed under humid tropical climate with ustic to udic soil moisture regimes with different annual rainfall. The soils developed from volcanic ash parent materials in Flores Island showed different properties compared to the soils derived from volcanic tuff, even though they were developed from the same intermediary volcanic materials. The silica contents, clay mineralogy and sand fractions, were shown as the differences. The different in climatic conditions developed similar properties such as deep solum, dark color, medium texture, and very friable soil consistency. The soils have high organic materials, slightly acid to acid, low to medium cation exchange capacity (CEC). The soils in western region have higher clay content and showing more developed than of the eastern region. All the profiles meet the requirements for andic soil properties, and classified as Andisols order. The composition of sand mineral was dominated by hornblende, augite, and hypersthenes with high weatherable mineral reserves, while the clay fraction was dominated by disordered kaolinite, and hydrated halloysite. The soils were classified into subgroup as Thaptic Hapludands, Typic Hapludands, and Dystric Haplustands.

Keywords: Andisols, andic soil properties, Flores Island, volcanic materials

INTRODUCTION

In Indonesia, the volcanic soils have a total area of 5.4 millions ha or 2.9% of the total Indonesia archipelago (Subagjo *et al*. 2004), whereas in the world the soils occupy about 0.84% of the earth's surface (Leamy, 1984; Takahashi and Shoji 2002). The volcanic soils have widely distributed along a belt in islands of Sumatra, Java, Bali, Nusa Tenggara, Celebes, and Halmahera. The investigation of the volcanic soils in Indonesia was initiated by some researchers, such as Van Schuylenborgh (1957), Dudal and Soepraptohardjo (1960), and Tan (1965). Some studies of the volcanic soils in last decade have been reported, especially from Sumatra (Fiantis and Van Ranst 1997; Alkasuma and Badayos 2003), Java (Arifin and Hardjowigeno 1997; Van Ranst *et al*. 2002; Fauzi and Stoops 2004; Yatno and Zauyah 2008), North Sulawesi (Hikmatullah 2008), and Dompu Sumbawa (Sukarman *et al*. 1993).

Soils that are developed on volcanic parent materials of Quarternary age have important role, due to unique morphological, physical, chemical and mineralogical properties and high potential for agricultural development to produce many kinds of agricultural commodities. The volcanic soils, in most cases are classified into Andisols order but not all volcanic soils are Andisols, depend on the weathering stage and soil forming processes (Shoji *et al*. 1993). Many studies of the volcanic soils have been reported from certain countries, such as from Japan (Shoji and Ono 1978), United States (Wada *et al*. 1986; Shoji *et al*. 1988), Mexico (Prado *et al*. 2007), Ecuador (Zehetner *et al*. 2003; Buytaert *et al*. 2007), Costa

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Rica (Nieuwenhuyse *et al*. 1993), New Zealands (Parfitt *et al*. 1983), Portugal (Madeira *et al*. 1994), Greece (Moustakas and Georgoulias 2005) and Rwanda Africa (Nizeyimana 1997).

Soil resources of the Flores Island with a total area of 1.4 M ha had been documented in reconnaissance level. About 0.45 Mha of the soil resources was developed from volcanic parent materials, and dominantly grouped into Andisols, Mollisols and Inceptisols orders (CSAR 1997). The composition of sand mineral fraction of the volcanic materials consists of plagioclase, andesine, pyroxene, hypersthene, augite and olivine (Suwarna *et al*. 1990; Kusumadinata *et al*. 1981).

The main characteristics of the soils developed from volcanic materials, such as Andisols, have unique characteristics, such as dark color in the topsoils, high content of organic materials, low bulk density, high porosity, high P retention, high content of acid ammonium oxalate extractable Al, Fe and Si (Al_o, Fe_o, Si_o), and high weatherable minerals reserve (Shoji *et al*. 1993; Nanzyo 2002). In general, the Andisols order are found in high plain (>700 m asl.), but it also found in low plain, such as in North and West Sumatra, as reported by Tan (1998). Andisols should meet the requirements for andic soil properties. The andic soil properties are based on soil physical, chemical, and mineralogical properties, consisting of sand content, bulk density, P retention, content of (Al_o+0,5Fe_o) extractable ammonium oxalate, and volcanic glasses (Soil Survey Staff 2006).

The objective of the study was to characterize the andic properties of the soils which were originated from the parent materials of five volcanoes with different climatic conditions in Flores Island, Indonesia. The characterization were executed according to the methods and criteria of the Soil Taxonomy (Soil Survey Staff 2006).

MATERIALS AND METHODS

Study Area

There are five soils profile from five different locations that had been observed their characteristics (Table 1). The soils were taken from Flores Islands, eastern part of Java and Bali islands. Flores island, Indonesia, with a total area of 1.4 millions ha, is located at coordinate of 08°10'- 09°05' South Latitude, and 119°45'-123°10' East Longitude, with elevation of 0-2,350 m above sea level. The location of soil profiles is presented in Figure 1.

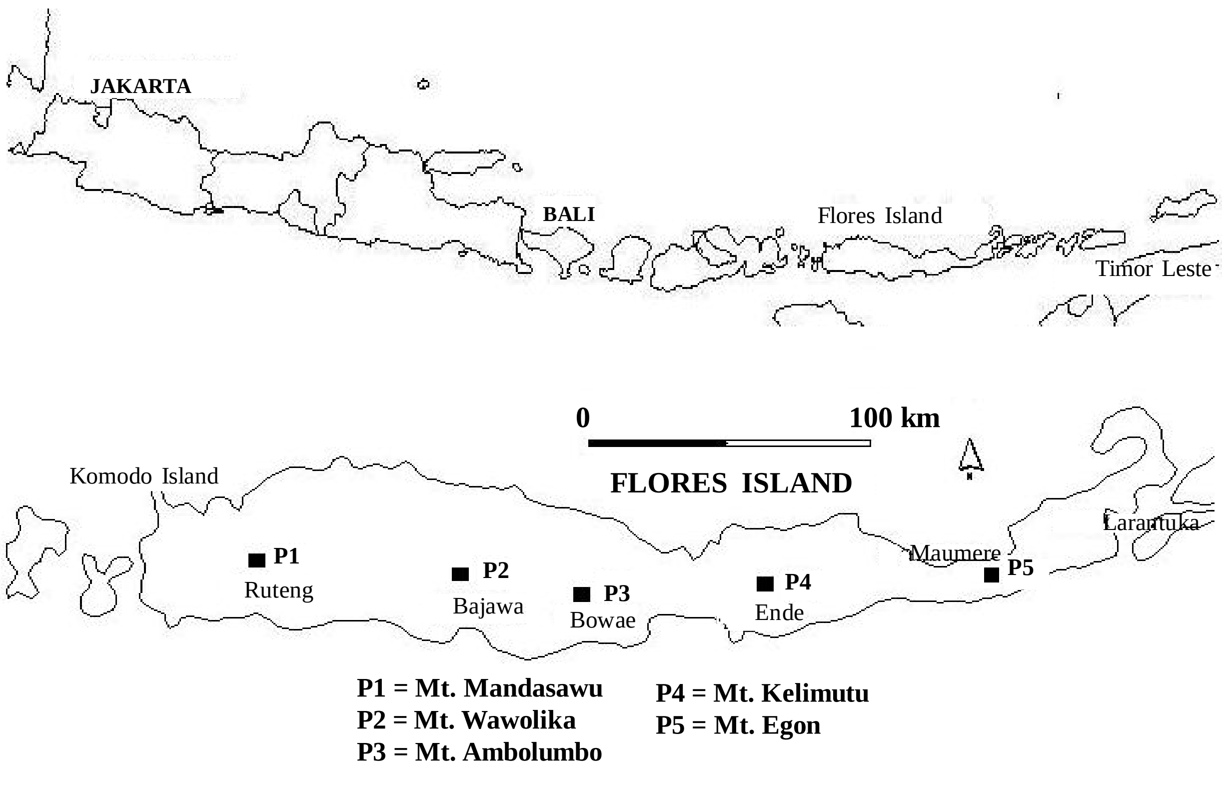

Figure 1. Location of soil profiles in Flores Island.

Table 1. Location, slope, parent material, land use and elevation of the profiles studied.

Profile	Location	Volcano	% Slope	Parent material	Landuse	Elevation (m, asl.)
P1	Ruteng	Mt. Mandasawu	45	Andesitic ash	Forest	1,500
P2	Bajawa	Mt. Wawolika	32	Andesitic ash	Pine forest	1,300
P3	Boawae	Mt. Ambolumbo	30	Andesitic tuffs	Shrub, bush	1,100
P4	Ende	Mt. Kelimutu	40	Andesitic tuffs	Vegetables, shrub	1,400
P5	Maumere	Mt. Egon	32	Andesitic tuffs	Shrub	750

The climate of the island is generally humid tropical region. Rainfall data from five stations (Table 2) showed an increasing amount of rainfall from east to west area of the island; with average annual rainfall vary from 1,206 mm in Maumere, to 3,070 mm in Ruteng. Rain season is occurring in November to March. The average temperature varies between 26.6-29.3^{o}C in Maumere, and 18.5-20.8^{o}C in Ruteng. Flores Island belongs to Afa climate type in western part with B rainfall type, and Awa type in eastern part with D rainfall type (Schmidt and Ferguson 1951). Calculated water balance using Newhall Simulation Model (Wambeke *et al*. 1986) showed udic soil moisture regime in the western part and ustic soil moisture regime in the eastern part. The soil temperature regime belongs to isohyphertermic for the area less than 1,000 m and isothermic for area more than 1,000 m above sea level.

Methodology

In generally, the soil profiles were compared, following the differences in their lithological characteristics (parent material) including their occurrences. The studied profiles were examined according to their climatic condition (annual rainfall).

Samples were air-dried, crushed and sieved to pass a 2 mm sieve. In the fine earth fraction, the sand fraction was determined by wet sieving, and the silt and clay fraction using the pipette method. Bulk density (BD) was determined in 33 kPa and 1,500 kPa water retention. Organic matter was determined by dry combustion using the method of Walkley and Black. Soil pH was measured in a suspension of soil in water (1:1) and in 0.01 *M* KCl (1:10). Exchangeable cations (Ca, Mg, K dan Na) and cation exchange capacity (CEC) of soils were determined in ammonium acetate extraction pH 7.0. All the above procedures of soil sample analyses were outlined in Soil Survey Laboratory Method Manual (Burt 2004).

To test amorphous materials and andic soil properties, soil pH in 1*M* NaF was measured at 1:50 after exactly 60 minutes. Phosphate retention was determined using the method of Blakemore *et al*. (1987). Dissolution analyses were conducted for acid ammonium oxalate extractable Al, Fe and Si (Al_o, Fe_o, Si_o), and ammonium pyrophosphate extractable Al and Fe (Al_p, Fe_p) using the method of Blakemore *et al*. (1987).

Mineral composition of sand fraction was determined by line counting method, using polarization microscope (Buurman 1990). The clay fraction analyses used X-Ray Diffraction (XRD) with standard treatment of Mg^{2+} saturation. Soil classification was determined using the Keys to Soil Taxonomy (Soil Survey Staff 2006) at subgroup level.

For the purposes of the study, five selected profiles from the above volcanoes were described in the field, and soil samples were taken by horizons for physical, chemical and mineralogical analyses in the laboratory. The distribution of the profiles and

Table 2. Average monthly rainfall in the Flores Island.

Station	Elev.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	m, asl.	mm												
Ruteng	1,200	500	360	439	323	166	102	86	105	146	203	314	326	3,070
Bajawa	1,175	332	315	218	217	79	65	45	36	44	34	211	276	1,872
Boawae	800	331	253	250	109	31	24	15	5	8	73	119	275	1,493
Ende	10	144	206	173	58	125	38	60	46	60	142	262	195	1,509
Maumere	25	216	220	162	77	70	46	46	4	23	21	131	190	1,206

Table 3. Morphological and physical properties of the profile studied.

Horizon	Depth	Matrix color	Texture [1)] class	sand	silt	clay	Structure[2)]	Bulk density (BD)	Total pore space	pF 2.54	pF 4.2	Available water
	cm	moist		-----% -------				g cm^{-3}	-----------% vol.----------			
P1: Mt. Mandasawu, Ruteng (1,500 m asl.).												
A	0-25	10 YR 3/2	SiL	23	50	27	2.f.g	0.43	83.9	37.2	18.6	18.6
Bw1	25-44	10 YR 3/3	SiL	14	74	12	1.m.g	0.37	86.1	53.7	15.0	38.7
2Bw1	44-69	10 YR 3/3	SiL	12	75	13	1.m.sb	0.37	86.2	58.1	11.6	46.5
2Bw2	69-108	10 YR 3/6	SiL	14	73	13	1.m.sb					
2Bw3	108-143	10 YR 3/4	SiCL	19	51	30	2.c.sb					
2Bw4	143-173	10 YR 3/6	SiL	18	64	18	1.c.sb					
P2: Mt. Wawolika, Bajawa (1,300 m asl.).												
A1	0-15	10 YR 3/1	SiL	28	61	11	2.m.g	0.75	71.8	36.5	21.8	14.7
A2	15-29	10 YR 2/1	SiL	38	53	9	2.f.g					
Bw1	29-53	10 YR 2/1	SiL	32	55	13	1.f.sb	0.63	76.2	42.0	19.9	22.1
Bw2	53-75	10 YR 2/1	SiL	37	52	11	1.f.sb					
Bw3	75-94	10 YR 2/1	SiL	29	52	19	1.f.sb					
BC	94-110	10 YR 2/1	L	39	47	14	1.f.sb					
C	110-135	10 YR 4/3	SL	59	31	10	1.f.sb					
P3: Mt. Ambolumbo, Boawae (1,100 m asl.).												
A1	0-14	10 YR 3/2	SL	72	24	4	2.f.g	0.74	57.1	24.7	14.3	10.4
A2	14-32	10 YR 3/4	SL	68	29	3	2.f.g					
Bw1	32-62	10 YR 4/4	SL	63	28	9	1.f.g	0.85	55.3	27.1	20.3	6.8
Bw3	62-100	10 YR 4/6	SL	66	26	8	1.vf.sb					
BC	100-130	10 YR 5/4	SCL	62	10	28	1.vf.sb					
P4: Mt. Kelimutu, Ende (1.400 m asl.).												
Ah	0-16	10 YR 4/2	SL	64	25	11	2.f.g	0.68	74.4	27.8	17.8	10.0
Bw1	16-57	10 YR 5/4	SL	64	27	9	1.f.sb	0.91	62.1	33.0	13.9	19.1
Bw2	57-90	10 YR 3/2	SL	63	30	7	1.f.sb					
2Ah	90-126	10 YR 4/3	SL	73	24	3	1.f.sb					
2Bw	126-190	10 YR 5/3	L	72	26	2	1.f.sb					
P5: Mt. Egon, Maumere (750 m asl.).												
A	0-15	10 YR 3/3	L	34	47	19	1.f.g	0.80	68.8	28.6	16.6	12.0
Bw1	15-43	10 YR 4/3	LS	79	17	4	1.m.g	0.73	72.4	26.6	18.7	7.9
Bw2	43-70	10 YR 4/4	LS	80	16	4	1.m.sb					
2Bw1	70-96	10 YR 4/6	SL	62	30	8	1.m.sb					
2Bw2	96-150	10 YR 4/6	SL	75	17	8	1.c.sb					

[1)]Texture class: L =loam; SL = sandy loam; SCL = sandy clay loam: SiL = silt loam; SiCl = silty clay loam; LS = loamy sand,
[2)] Structure development grade: 1 = weak; 2 = moderate; size vf = very fine; f = fine; m = medium; c = coarse; shape: g = granular; sb = subangular blocky.

their environments are presented in Table 1 and Figure 1.

RESULTS AND DISCUSSION

Morphological Properties

All the soil profiles had deep solum (>100 cm) with variation of A horizon from 15 to 32 cm, and B horizon more than 75 cm (Table 3). The A horizon of profile P4 and P5 is thinner than the others which is probably affected by agriculture use. The color of A horizon is very dark brown (10YR2/1-3/3) to dark grayish brown (10YR4/2). While the B horizon have lighter color to dark brown (10YR3/4) to brown (10YR4/6), except for profile P2 has very dark brown (10YR2/1).

The darker color in A horizon than in B horizon is related to higher content of organic materials in A horizon. The horizon sequences of all the profiles were characterized by A umbric epipedon, Bw cambic diagnostic horizons, and C horizons, as A-Bw-C. The horizon sequence indicated that the soils have moderate profile development (Van Ranst *et al*. 2002).

The A and B horizons of the profiles show weak structural development, indicated by subangular blocky breaking to fine if pressed by hand, and have very friable to friable consistency in moist condition. The friable properties have benefits in agricultural use, because of it easy to tillage and better roots development. The smeary or thixotropic properties, as an indication of high content of amorphous materials are significant in profile P1 and P2, but not clear in other profiles. This may be affected by high sand content indicating the parent materials have not yet much weathered. The profiles showed little different morphological properties, where the soil profiles from the western region (profile P1 and P2) are more developed than the eastern region.

Physical Properties

The soil profiles showed variation in silt and sand content. The soil texture varies from silt loam, loam, sandy loam and loamy sand that classified as medium to slightly coarse classes (Soil Survey Division Staff 1993). The sand distribution varies from 23 to 72% in A horizon, and from 12 to 80% in B horizon. On the contrary, the clay content is low, varies from 4 to 27% in A horizon, and from 9 to 30% in B horizon. It is clear that the soil texture of the soil profiles from eastern Flores Island has high sand content (sandy loam to loamy sand), while in the western it is high silt content (silt loam). The high sand content indicated that the soil has lower weathering stage as showed in structural development features. Niuwenhuys *et al*. (1993) reported that in wet tropical climate in Costa Rica, the formation of Andisols from sandy volcanic materials need of time as long as 2000 years. But Wada (1985) mentioned that the formation of Andisols with full horizons of A-Bw-C in wet climate in Japan need a time at least 1000 years. The soils from volcanic materials with high sand content were similar to the volcanic materials found in Mt. Soputan, North Sulawesi (Hikmatullah 2008) and Mt. Kimangbuleng in Flores Island (Sukarman *et al*. 1999).

The bulk density (BD) has variation from 0.37 to 0.91 g cm^{-3}, both in A and B horizons. The low BD values meet one of the requirements of andic soil materials for the first group in Soil Taxonomy (Soil Survey Staff 2006). The amorphous material, i.e. allophone is one of the most important non-crystalline materials contributing to the low bulk density of the soils through the development of porous soil structure (Nanzyo *et al*. 1993). The high total pore spaces for all the soils profiles were also contribute to low bulk density. The content of available water percentages was higher in the subsoils than topsoils, that it may be related to large amount of organic matter and allophone content.

Chemical Properties

The organic carbon content of the soil profiles is generally high in A horizons and decrease to B horizons (Table 4). In A horizon the organic carbon content varied from 2.67 to 9.24% as classified as high. But in B horizons the organic carbon content varied from 0.31 to 7.37% as classified as low to high.

In general, the value of soil- pH_{H2O} varied from 5.1 to 6.6 in A horizons, and from 5.3 to 6.6 in B horizons, as classified as relatively high, except for soil profiles P1 and P4 is more acid. The relatively high soil pH is benefit for crop growth, because of available soil nutrient and favorable for the growth. The relatively high pH in profiles P2, P3, and P5 may be caused by the nature of parent materials that not much yet weathered, and lower amount of rainfall that leaching bases are not intensively occurred.

The exchangeable bases (Ca, Mg, K, and Na) were generally dominated by high content of Ca and Mg that classified as low to medium. The content of bases reflected that the soils contain of nutrient bases that caused of higher pH (> 6.0). The base saturation varied from low to high (28-78%), except for profile P1 is very low (4-10%) indicating intensive leaching due to highest rainfall in western Flores Island.

The soil cation exchange capacity (CEC) is vary from low (<16 $cmol_c$ kg^{-1}) to high (>24 $cmol_c$ kg^{-1}) both in A and B horizons. The low soil CEC is probably caused by low content of clay and high of sand, especially in profile P3, P4 and P5.

Andic Properties and Soil Classification

The requirements for andic soil properties according to Soil Taxonomy (Soil Survey Staff 2006) can be grouped into 2 groups. The soils have to be classified as andic soils if meet one of the following groups. The first group is having: (a) Organic C content < 25%, (b) BD $\leq$ 0.90 g cm^{-3} at retention 33 kPa, (c) P retention $\geq$ 85%, and (d) (Al_o + 0.5 Fe_o) content $\geq$2,0%. The second group is having: (a) Organic C content < 25%, (b) sand fraction content $\geq$ 30%, (c) P retention $\geq$ 25%, (d) (Al_o + 0.5 Fe_o) content $\geq$ 0,4%; (e) volcanic glass content $\geq$ 5%, and (f) index

Table 4. Chemical properties of the profile studied.

Profile	Depth	pH-$_{H2O}$	Org. C	Exchangeable cations Ca^{2+}	Mg^{2+}	K^+	Na^+	Total	soil-CEC	Base sat.	1*N* KCl Al^{3+}
	cm		%	---------- cmol (+) kg^{-1}					----------	%	cmol (+) kg^{-1}
P1: Mt. Mandasawu, Ruteng (1,500 m asl.)											
A	0-25	5.1	9.24	1.71	0.40	0.13	0.18	2.42	40	6	0.00
Bw1	25-44	5.5	7.37	1.21	0.28	0.07	0.22	1.78	40	4	0.00
2Bw1	44-69	5.9	5.23	2.77	0.24	0.05	0.06	3.12	32	10	0.00
2Bw2	69-108	5.7	3.70	0.91	0.20	0.05	0.07	1.23	33	4	0.00
2Bw3	108-143	5.9	2.70	0.92	0.17	0.04	0.05	1.18	31	4	
2Bw4	143-173	5.7	2.28	0.60	0.20	0.02	0.03	0.85	30	3	
P2: Mt. Wawolika, Bajawa (1,300 m asl.)											
A1	0-15	6.3	7.04	21.65	2.14	0.18	0.20	24.17	32	75	0.01
A2	15-29	6.4	6.34	11.28	0.93	0.08	0.19	12.48	27	46	0.00
Bw1	29-53	6.2	4.99	7.90	0.80	0.07	0.18	8.95	28	32	0.00
Bw2	53-75	6.2	4.84	8.81	0.86	0.07	0.18	9.92	30	33	0.00
Bw3	75-94	6.3	4.35	9.78	0.89	0.06	0.21	10.94	29	38	
BC	94-110	6.3	2.43	6.41	0.67	0.02	0.14	7.24	21	35	
C	110-135	6.4	0.57	4.95	0.56	0.02	0.10	5.63	17	33	
P3: Mt. Ambolumbo, Boawae (1,100 m asl.)											
A1	0-14	6.1	6.55	14.05	2.89	0.32	0.06	17.32	23	75	0.01
A2	14-32	5.6	4.52	6.17	0.85	0.16	0.09	7.27	14	51	0.00
Bw1	32-62	6.1	3.90	6.05	0.51	0.08	0.06	16.70	24	28	0.00
Bw3	62-100	6.3	1.97	9.66	0.32	0.04	0.06	20.08	18	56	0.00
BC	100-130	6.3	1.15	1.56	0.14	0.02	0.25	11.97	10	19	
P4: Mt. Kelimutu, Ende (1,400 m asl.).											
Ah	0-16	5.3	4.06	7.01	0.82	10.6	0.05	18.48	12	66	0.23
Bw1	16-57	5.6	1.80	3.73	0.43	0.08	0.09	4.33	5	81	0.00
Bw2	57-90	5.4	0.95	1.39	0.14	0.02	0.09	1.64	4	44	0.08
2Ah	90-126	5.3	2.18	2.11	0.26	0.02	0.22	2.61	7	39	0.04
2Bw	126-190	5.4	0.81	0.88	0.10	0.02	0.23	1.23	4	34	0.04
P5: Mt. Egon, Maumere (750 m asl.)											
A	0-15	6.6	2.67	6.97	1.72	0.49	0.06	9.24	12	78	0.00
Bw1	15-43	6.6	0.98	2.94	0.91	0.45	0.05	4.35	9	50	0.06
Bw2	43-70	6.6	0.46	2.50	0.68	0.29	0.06	3.53	7	48	0.01
2Bw1	70-96	6.4	0.46	3.66	1.02	0.40	0.11	5.19	12	44	0.00
2Bw2	96-150	6.3	0.31	3.26	1.02	0.25	0.12	4.65	11	43	0.00

value of $[(Al_o + 0.5\ Fe_o) \times 15.625] + [\%\ \text{volcanic glass}] \geq 36.25$.

All the profiles have P retention > 85%, that meet the requirements of the second group, except for profile P5. The high P retention is close related to capability of soils to fix phosphate in adsorption complex; therefore the P nutrient may not be available to plant.

The content of Al_o is very high for profile P1 and P2, with variation from 25.99 to 53.84%, and from 0.76 to 4.85% for profile P3, P4 and P5. While the content of Fe_o is lower than the Al_o with variation from 4.68 to 9.43% for profile P1, P2 and P3, and from 0.43 to 0.87% for profile P4 and P5. The content of (Al_o + 0.5 Fe_o) varied from 7.4 to 57.8% for profile P1, P2 and P3, and from 1.2 to 3.1% for profile P4 and P5, that fulfill one of the requirements for andic soils both in first and second groups. The high content of Al_o and Fe_o reflected the high content of amorphous materials (Table 5).

It should be noted although the pH_{NaF} is not to be one of the requirements for andic soil properties; it can be used as indicator for soils that contain of amorphous materials. Data on Table 3 shows that pH_{NaF} of all the profiles are high (pH_{NaF} 11.2-11.9) indicating that the soils contain high amorphous materials. There were clearly observed that the volcanic ash materials had more silica content than the soils derived from volcanic tuff.

Table 5. Andic soil properties of the profile studied.

Profile	Depth	pH NaF	P Ret.	Ammonium oxalate extr.				Pyrophosphate		Volcanic glass
				Fe	Al	Si	(Al+0.5Fe)	Fe	Al	
	cm			---------------------------------- % ----------------------------------						
P1: Mt. Mandasawu, Ruteng (1,500 m asl.)										
A	0-25	11.8	99	8.11	40.15	26.54	44.21	1.07	5.93	22
Bw1	25-44	11.9	100	8.01	53.84	35.67	57.85	1.83	6.25	7
2Bw1	44-69	11.8	100	8.28	52.75	34.95	56.89	2.17	5.65	2
P2: Mt. Wawolika, Bajawa (1,300 m asl.)										
A1	0-15	11.2	99	4.85	25.99	17.09	28.42	1.08	4.91	11
A2	15-29	11.5	89	4.68	29.25	19.26	31.59	1.18	5.06	15
Bw1	29-53	11.5	62	5.91	46.99	31.10	49.95	0.60	3.76	7
Bw2	53-75	11.5	64	5.91	46.37	30.69	49.33	0.48	2.98	10
P3: Mt. Ambolumbo, Boawae (1,100 m asl.)										
A1	0-14	11.3	86	8.86	2.93	1.70	7.36	1.15	3.13	9
A2	14-32	11.5	91	9.43	3.36	1.99	8.08	1.26	3.57	13
Bw1	32-62	11.6	100	9.32	4.85	2.98	9.51	0.79	3.27	9
P4: Mt. Kelimutu, Ende (1,400 m asl.)										
Ah	0-16	10.7	68	0.81	0.76	0.25	1.17	0.65	0.41	25
Bw	16-57	11.2	80	0.87	1.12	0.49	1.56	0.40	0.31	25
2Ah	57-90	11.3	78	0.43	1.63	0.83	1.85	0.05	0.23	28
P5: Mt. Egon, Maumere (750 m asl.)										
A	0-15	11.2	31	0.66	1.47	0.72	1.80	0.13	0.40	4
Bw1	15-43	11.4	31	0.56	2.59	1.47	2.87	0.04	0.30	5
Bw2	43-70	11.3	28	0.43	2.88	1.67	3.10	0.03	0.22	3

Based on the above requirements for andic soil properties, it is concluded that all the profiles are fulfill the requirements for andic soil properties of the second group. Thus the soils can be classified as Andisols order with subgroup of Thaptic Hapludands (profile P1 and P2), Typic Hapludands (profile P4), and Dystric Haplustands (profile P3 and P5).

Mineral Composition of the Sand and Clay Fraction

The composition of light minerals of sand fraction for all the profiles is dominated by high hypersthene and augite (pyroxene), green hornblende, and andesine (intermediary plagioclase), and volcanic glass, and rock fragments, with few weathered mineral fragments (Table 6). The composition of heavy minerals of sand fraction is also similar as light minerals, which is dominated by hypersthene, augite and green hornblende. The content of opaque and quartz as resistant minerals are low for all the profiles. This indicates that the weathering process in initial stage. The present of high hypersthene, augite and andesine indicates that the parent materials are classified as intermediary or andesitic volcanic character of the eruption products. This is in agreement with the original geologic description of Suwarna *et al*. (1990) and Kusumadinata *et al*. (1990). The amount of weatherable mineral reserve, including volcanic glasses, is very high (48-81%). Therefore the soil nutrient reserve is considered high, and in long terms it is expected to supply the nutrient need from the weathered minerals for crop growth.

The results of semi-quantitative determination of the clay mineral composition of the profiles are presented in Table 7. The composition of clay mineral fraction showed that all the soil profiles have differences of clay mineral. The conditions indicated that the soil had different parent materials containing weathered minerals indicated in the Table 6. The soils were generally composed dominantly of disordered kaolinite, and small amount of hydrated halloysite in the soils derived from volcanic ash. The soils derived from volcanic tuff had less disordered kaolinitic clay. There is no difference in the composition of clay minerals between the topsoil and subsoil. The soils characteristics of each location had similar chemical properties and mineralogical compositions were reported by Sukarman and Subardja (1997) for Maumere volcanic soils.

Table 6. Mineral composition of sand fraction of the profile studied.

Profile	Light minerals													Heavy minerals					
Depth	Op	Qt	Qg	Fc	Ze	Wm	Rf	Vg	Ad	Sn	Hg	Au	Hy	Op	Hg	Hc	Au	Hy	Ol
cm	-- % ----------------------------------													--------------- % --------------					
P1: Mt. Mandasawu, Ruteng (1,500 m asl.)																			
0-25	3	1	-	1	-	6	16	22	24	-	6	3	18	4	21	-	24	55	-
25-44	7	1	-	1	1	7	5	7	12	-	13	10	36	10	25	-	20	55	-
44-69	1	1	1	1	2	14	2	2	6	1	21	7	41	3	25	1	13	61	-
69-108	6	1	2	1	-	12	1	1	3	3	22	1	47	12	34	-	2	64	-
108-143	25	1	-	1	-	11	1	-	1	1	8	1	50	37	13	-	3	84	-
143-173	6	3	4	-	1	33	3	-	-	-	16	1	33	10	37	2	3	58	-
173-210	10	6	5	-	1	29	3	-	-	-	13	1	32	24	23	-	1	76	-
P2: Mt. Wawolika, Bajawa (1,300 m asl.)																			
0-15	5	-	-	1	-	1	16	11	37	-	4	5	20	10	5	-	24	71	-
15-29	3	-	-	-	-	3	17	15	37	-	1	5	19	8	8	-	19	73	-
29-53	3	-	-	1	-	2	15	7	32	-	4	10	26	4	20	-	27	53	-
53-75	2	-	-	1	-	1	19	10	32	-	-	8	27	6	1	-	31	68	-
75-94	1	-	-	1	-	1	18	6	34	-	1	9	29	5	2	-	26	72	-
94-110	5	-	-	1	-	2	29	3	28	-	-	8	24	5	2	-	30	67	1
110-135	4	-	-	1	-	2	26	4	25	-	-	8	30	7	3	-	35	61	1
P3: Mt. Ambolumbo, Boawae (1,100 m asl.)																			
0-14	6	-	1	-	-	3	28	9	21	-	2	10	20	nd					
14-32	3	-	-	-	-	5	29	13	27	-	-	7	16						
32-62	4	-	-	-	-	5	18	9	27	-	1	7	29						
62-100	6	-	1	-	-	3	19	12	27	-	5	9	18						
100-130	4	-	1	-	-	6	21	6	33	-	5	7	17						
P4: Mt. Kelimutu, Ende (1,400 m asl.)																			
0-16	3	-	-	-	1	5	31	25	17	-	-	6	12	nd					
16-57	1	-	-	-	-	2	35	25	21	-	-	6	10						
57-90	sp	-	-	-	-	1	45	28	15	-	-	5	6						
90-126	1	-	-	-	-	2	40	23	20	-	-	6	8						
126-190	1	-	-	-	-	1	32	26	20	-	-	6	14						
P5: Mt. Egon, Maumere (750 m asl.)																			
0-15	4	1	-	-	1	6	21	5	24	-	8	11	19	9	29	1	29	41	-
15-43	7	1	-	1	-	7	15	5	28	-	10	9	17	13	33	-	26	41	-
43-70	11	1	-		-	5	14	3	35	-	17	4	10	32	54	-	16	30	-
70-96	9	1	-	1	-	4	8	2	24	-	5	14	32	16	11	-	35	54	-
96-150	10	-	-	-	-	5	9	2	27	-	4	14	29	12	7	-	33	59	1

Note: Op = opaque; Qt = turbid quartz; Qg = transp. quartz; Ze = zeolite; Hi = hydragilite; Wm = weathered minerals; Rf = rock fragment; Vg = volcanic glass; An =andesine; Sn = sanidine; Hg = green hornblende; Hc = brown hornblende; Au = augite; Hy = hyperstine; nd=not determined.

Land Management Implication for Agricultural Use

The volcanic soils that were developed in the Flores Island, indicated the conditions influence the characteristics of the soils. At the first places, the parent material of the soils from the volcanic ash, have more fertile with higher cation exchange capacity, and bases. The clay mineralogical of soils derived from volcanic ash tended having more kaolinitic clays than the soils derived from volcanic tuff (Mt. Ambolumbo, Mt. Kelimutu, and Mt. Egon).

The volcanic soils of the island are considered to have good characteristics. It is reflected by thick solum, medium soil texture with friable consistency,

Table 7. Mineral composition of clay fraction of the profile studied.

Depth (cm)	Soil Subgroups	Disordered kaolinite	Hydrated halloysite
P1: Mt. Mandasawu, Ruteng (1,500 m asl.)			
0-25	Thaptic Hapludands	++++	-
44-69		++++	
108-143		++++	
P2: Mt. Wawolika, Bajawa (1,300 m asl.)			
0-15	Thaptic Hapludands		
29-53		++++	-
75-94		++++	
P3: Mt. Ambolumbo, Boawae (1,100 m asl.)			
0-14	Dystric Haplustands	++	++
32-62		++	++
P4: Mt. Kelimutu, Ende (1,400 m asl.)			
0-16	Typic Hapludands	-	-
57-90			
P5: Mt. Egon, Maumere (750 m asl.)			
0-15	Dystric Haplustands	+++	+
43-70		+++	+
96-150		+++	+

Note: ++++ = predominant; +++ = dominant; ++ = moderate; + = minor; - = not detected.

fertile, and easy to tillage and root crop growth. The organic materials are high especially in top soils, soil pH is slightly acid to acid, and moderate to low content bases, which are to be favorable condition for nutrient availability to crop growth. Beside that, the amount of weather-able mineral reserve is considered very high which could support to nutrient supply for long terms. The climatic conditions were clearly shown in their amount of weathered minerals. The western part of the island has more rain.

The main problem of the volcanic soils for agricultural use is slope steepness. It has potential to erosion and landslide, especially for the soils planted with annual crops if it is often to tillage periodically, and the surface soils becomes open without vegetation. To solve the problem, it is recommended to apply soil conservation technique properly, such as terracing, raised bed terrace, and contour planting. Suganda *et al*. (1999) mentioned that contour planting was the best method for controlling runoff and soil loss in highland vegetable cultivation. The other problem is the high P retention, which can reduce the availability of soil P to crops, so that it is need a higher dosage of P fertilizer. Increasing organic materials is very suggested to maintenance high status of soil organic materials such as using crop residue after harvesting.

CONCLUSIONS

The soils developed from volcanic ash parent materials in Flores Island showed different properties compared to the soils derived from volcanic tuff, even though they were developed from the same intermediary volcanic materials. The silica contents, clay mineralogy and sand fractions, were shown as the differences. The different in climatic conditions developed similar properties such as deep solum, dark color, medium texture, and very friable soil consistency. The soils have high organic materials, slightly acid to acid, low to medium CEC. The soils in western region have higher clay content and showing more developed than of the eastern region. All the profiles meet the requirements for andic soil properties, and classified as Andisols order.

The mineral composition of sand fraction was dominated by andesine-hornblende-augite-hypersthene association, except soil profile from Mt. Kelimutu was dominated by volcanic glasses-andesine-augite-hypersthene association. The mineral composition of clay fraction was dominated by disordered kaolinite and disordered halloysite. The high mineral reserve could supply the nutrient need for crop growth for long terms.

The volcanic soils have good soil characteristics which can support increasing agricultural production both annual and perennial crops. The land management for the land should be focused on the increasing organic materials and P nutrient, and soil conservation to control soil erosion and land slide.

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