

Properties of Soils Developed from Ultramafic Rocks and their Land Suitability for Cocoa in East Kolaka Regency, Indonesia

Edi Yatno[1*], Sudarsono[2], Budi Mulyanto[2], Iskandar[2]

1.Study Program of Soil Science, Graduate School, Bogor Agricultural University, Bogor 16680, Indonesia

2.Department of Soil Science and Land Resources, Bogor Agricultural University, Bogor 16680, Indonesia

Abstract

Soils developed from ultramafic rocks are widely distributed in East Kolaka Regency, Southeast Sulawesi Province, Indonesia. However, the soil characteristics and their land suitability for cocoa crop have not been known. Three soil profiles developed from ultramafic rocks in East Kolaka were described, sampled, and analyzed to characterize their mineralogical, physical, and chemical properties. Results indicated that sand mineral composition was dominated by opaque, quartz, and garnet minerals, while clay minerals were composed of kaolinite, goetite and hematite. All the soils were characterized by clay textures, low bulk density (0.89-1.04 g/cm^3), medium to very high available water (11-22%), and rapid permeability (13-25 cm/hour). The soil reaction was acid (pH 4.64-5.03). The soil organic carbon was medium in A horizon (2.02-2.95%) and very low in B horizons (0.35-0.87%). The N total values were medium to high in A horizon (0.37-0.51%) and low to very low in B horizons (0.07-0.18%). The available P and potential K_2O contents were very low, while the potential P_2O_5 content was low to medium (18-35 mg/100g).The exchangeable Ca content was low to very low (0.23-2.94 $cmol_c/kg$), while the exchangeable Mg content was low to high (0.22-2.59 $cmol_c/kg$). The soil CEC was low to very low (3-12 $cmol_c/kg$), while clay CEC was very low (< 6 $cmol_c/kg$). The base saturation was low to medium (19-51%), while Al saturation was very low (<3%). At family level, all the soils were classified as fine, kaolinitic, isohyperthermic, Rhodic Hapludox, All soils were marginally suitable (S3 class) for cocoa crop with limiting factors of acid soil reaction and very low potential K_2O. Liming and NPK fertilization should be applied to increase the soil productivity for cocoa development.

Keywords : soil properties, ultramafic rocks, land suitability, cocoa, East Kolaka

1. Introduction

Cocoa (*Theobroma cacao* L.) is one of the main plantation commodities that plays an important role in Indonesian economy, mainly as job field supply, farmer and national income. Furthermore, it also contributes to support regional and agroindustrial development (Goenadi *et al*. 2005).

East Kolaka is one of the central areas of cocoa production in Southeast Sulawesi. In 2013, cocoa production in this area is 32,023 ton. However, the mean cocoa productivity is stil low (753 kg/ha/year) (Diperhutbun of East Kolaka 2014). This is because the land used for cocoa plantation developments is not planted and evaluated based on their soil characteristics and land suitability resulting low cocoa production.

In Indonesia, beside climate and topography, soil parent material is the most dominant soil forming factors affecting to soil properties and their potency for agricultural development (Buol *et al*. 1980). The variability of soil parent materials may contribute to the variability of soil propeties formed, and this also affects to the land quality that influences to land suitability level and production of agricultural crops (Sys 1978).

Land evaluation is a prediction process of land use potency based on their land characteristics (Rossiter 1996). The land suitability evaluation is required for land use planning so that the land can be used optimally, productive and sustainable (Zhang *et al*. 2004). Land use potency and limiting factors can be accurately identified as soon as posibble so that land management can be effectively conducted to be suited for developed commodities (FAO 1976).

Ultramafic rock is part of igneous rocks that naturally composed of low quartz mineral but high in the dark-coloured ferromagnesian minerals (hornblende, micas, pyroxene) (White 1987; Munir 1996; Brady & Weil 2000). Soils developed from this rock generally had low sand content. The soil colour was usually red due to high in free iron oxides. The exchangeable Al was low. Clay minerals found in the soils were kaolinite, goethite, and hematite (Hidayat 2002; Prasetyo & Suharta 2004).

In Indonesia, studies on soils properties formed from ultramafic rocks and their land suitability for cocoa development are still lacking so that the information of the soils related to their properties and management is limited. Buurman & Soepraptohardjo (1980), Anda *et al*. (2000), Yatno & Prasetyo (2010) reported that Oxisols developed on ultramafic rocks in Southeast Sulawesi and South Kalimantan had high clay content, low bulk density, acid soil reaction, medium organic C in the upper horizons, very low exchangeable bases and low base saturation, low cation exchange capacity and exchangeable Al. The mineralogical composition of sand fraction was dominated by opaque, while their clay fraction was mainly composed of kaolinite with minor gibbsite and quartz.

The objective of this study is to characterize soil mineralogical, physical, and chemical properties, and to determine the soil suitability for cocoa development in East Kolaka Regency, Southeast Sulawesi Province, Indonesia.

2. Materials and Methods

2.1 Description of the Study Area

The study area was located in southern part of East Kolaka Regency, Southeast Sulawesi Province, Indonesia. It is situated in the central areas of cocoa production with low input management. Three representative soil profiles (MF 1, MF 2, and MF 3) formed from serpentinite ultramafic rocks (Simandjuntak *et al*. 1993) were selected for this study. All the profiles are located in the volcanic intrusion landform with rolling topography (slope of 12 %), and elevation between 49 and 78 m above sea level (asl). Location and description of the studied profiles are presented in Table 1 and Figure 1.

Table 1. Location and description of the studied soils

Profiles	Location	Coordinate	Elevation	Landform	Relieve	Slope
			m asl			(%)
MF 1	Iwoikondo, Loea	04°05’16.6”S 121°56’00.7” E	49	Volcanic intrution	Rolling	12
MF 2	Iwoikondo, Loea	04°05’16.8” S 121°55’59.9” E	68	Volcanic intrution	Rolling	12
MF 3	Iwoikondo, Loea	04°05’16.3” S 121°55’59.4” E	78	Volcanic intrution	Rolling	12

The mean annual rainfall of the study area is 1,901 mm. The wet period starts from March to July, with the wettest and driest months reaching 306 mm and 81 mm, respectively. The mean monthly air temperature is 27.9 °C, while the mean monthly air humidity is 75.6%. According to Schmidt & Ferguson (1951), the study area can be classified as humid tropical type and B rainfall type. This is indicated by the presence of 10 wet month (rainfall > 100 mm/month) and no dry month (rainfall < 60 mm/month). The study area has a udic soil moisture regime because there is no drought for as long as 90 cumulative days in normal years.

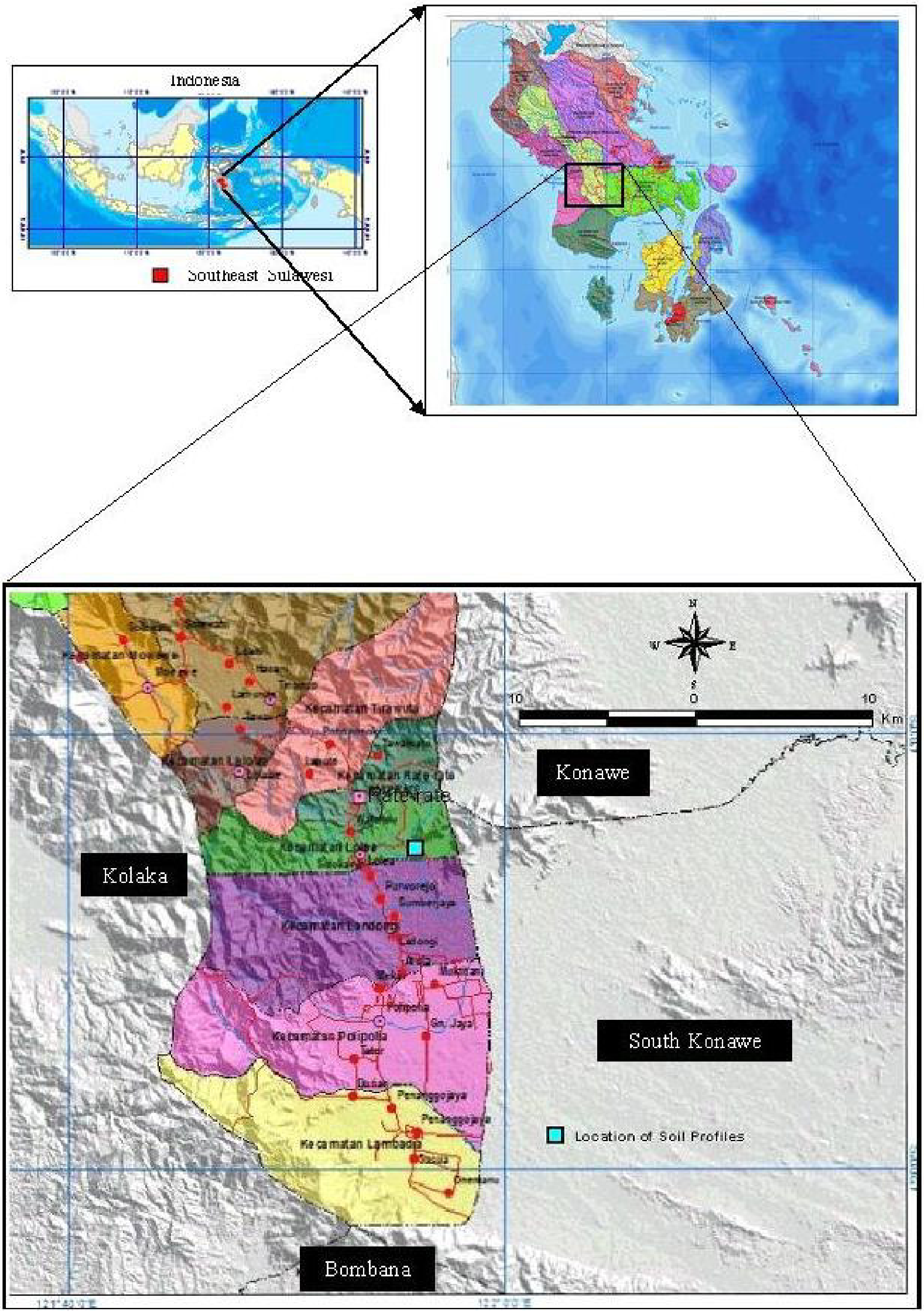


Figure 1. Location of the representative soil profiles in the studied areas

2.2 Methods

The morphological characteristics of the soil profiles were described in the field following the Soil Survey Manual (Soil Survey Division Staff 1993). All the soils were classified at family level according to Keys to Soil Taxonomy (Soil Survey Staff 2014).

Laboratory analysis consists of soil physical, chemical, and mineralogical properties. All laboratory determinations, except for bulk density, water retention and permeability, were made on air-dried materials passing a 2-mm sieve. Particle size distribution was determined by a pipette method after dispersion. Bulk density was measured on undisturbed soil samples. Soil water content at 33 kPa and 1,500 kPa was determined by using pressure membrane method, while soil permeability was determined by constant water head method.

Soil pH was measured with a glass electrode in water using a soil : solution ratio of 1 : 5. Organic carbon was determined by the Walkley-Black wet combustion method, while total N was determined by Kjeldahl method. Available P_2O_5 was determined by the Bray 1 extraction method, while potential P_2O_5 dan K_2O contents were determined by the HCl 25% extraction method. Exchangeable bases were extracted with 1M NH4OAc at pH 7.0 and determined by atomic absorption spectrometry (AAS). Cation exchange capacity (CEC) was determined by saturation with 1 M NH4OAc at pH 7.0. Exchangeable Al was determined using the KCl extraction method.

The mineralogy of total fine sand fraction (50-500 µm) was identified on a glass slide using a petrographic microscope, and the minerals were then counted according to the line counting method (Buurman 1990). Clay mineralogy was determined by X-ray diffraction analysis using the oriented clay specimens (<2 um) after the treatments with Mg^{2+} saturated, Mg^{2+} saturated and glycerol solvated, and K^+ saturated heated at 550 °C (van Reeuwijk 1993).

Land suitability evaluation was conducted by matching method between land characteristics and crop growth requirements. Criteria of crop growth requirements used in this study follow the Technical Guideline of Land Evaluation for Agricultural Commodities (ICALRRD 2011).

3. Results and Discussion

3.1 Soil Morphological Properties

All the soils show deep solum (Table 2). The soil colors were reddish dark brown (2.5YR 3/3) in A horizons and reddish dark brown to dark red (2.5YR 3/4-3/6) in B horizons. The color of A horizons is darker than that of B horizons due to higher organic matter content in A horizons (Table 5), while the reddish color is due to the presence of iron oxide minerals. The presence of reddish color and chroma of more than 3 indicates that all profiles have good soil drainage.

These soils have clay texture, granular to subangular blocky structure, very friable consistency, and diffuse smooth horizon boundary. The good soil drainage and very friable consistency may support easiness for soil tillage.

3.2 Soil Mineralogical Properties

The mineralogy of sand fraction was dominated by opaque minerals, followed by garnet, and quartz. The other minerals such as limonite, sanidine (feldspar group), and enstatite (pyroksen group) were only found in low amount (Table 3). The presence of opaque, garnet, and enstatite indicated that the soils were developed from ultramafic volcanic rocks. The low amount of weatherable minerals and the high amount of opaque, quartz, and garnet indicated that the soils studied have a high weathering stage and low fertility status due to low amount of nutrient reserves.

Mineral composition of clay fraction of the studied profiles showed that the soils were dominated by kaolinite, goethite, and hematite minerals (Figure 2). The presence of kaolinite was indicated by XRD peaks with d spacing of 0.729 nm (order 1) and 0.350 nm (order 2) after treatment of Mg^{2+}, and further the peaks collapsed after treatments of K^+ plus heating at 550 °C. Goethite and hematite have d spacing of 0.421 nm and 0.270 nm, respectively after Mg^{2+} treatment. The presence of goethite, kaolinite and hematite indicated that these soils have advanced weathering stages.

Table 2. Morphological properties of the studied soils

Horizon	Depth (cm)	Colour	Texture	Structure	Consistency	Horizon Boundary
Profile MF 1						
AB	0-16	2.5YR 3/3	C	gr-sb	vf; s, p	d, s
Bo1	16-50	2.5YR 3/4	C	gr-sb	vf; s, p	d, s
Bo2	50-92	2.5YR 3/6	C	gr-sb	vf; s, p	d, s
Bo3	92-125	2.5YR 3/4	C	gr-sb	vf; s, p	d, s
Profile MF 2						
AB	0-14	2.5YR 3/3	C	gr-sb	vf; s, p	d, s
Bo1	14-47	2.5YR 3/4	C	gr-sb	vf; s, p	d, s
Bo2	47-90	2.5YR 3/6	C	gr-sb	vf; s, p	d, s
Bo3	90-120	2.5YR 3/4	C	gr-sb	vf; s, p	d, s
Profile MF 3						
AB	0-15	2.5YR 3/3	C	gr-sb	vf; s, p	d, s
Bo1	15-45	2.5YR 3/4	C	gr-sb	vf; s, p	d, s
Bo2	45-89	2.5YR 3/6	C	gr-sb	vf; s, p	d, s
Bo3	89-120	2.5YR 3/4	C	gr-sb	vf; s, p	d, s

Notes : Texture : C=clay; Structure: gr=granular, sb=subangular blocky; Consistency: vf=very friable, s=sticky, p= plastic; Horizon Boundary: d=diffuse, s=smooth

Table 3. Mineral composition of sand fraction of the studied soils

Profile	Horizon	Depth (cm)	Kinds of Sand Fraction Minerals (%)							
			Op	Qz	Ln	Wm	Rf	Sn	Gr	En
MF 3	AB	0-15	66	8	1	2	1	-	19	3
	Bo1	15-45	67	12	tr	1	1	Tr	15	4
	Bo2	45-89	58	15	tr	3	3	-	15	6
	Bo3	89-120	63	7	tr	1	2	-	19	8

Notes: Op=opaque, Qz=quartz, Ln=limonite, Wm=Weathered mineral, Rf=Rock fragment, Sn=Sanidine, Gr=Garnet, En=enstatite, tr=trace (<1%)

3.3 Soil Physical Properties

Particle-size distribution of all the soils is dominated by clay fraction (53-58%) (Table 4). The high clay contents may indicate that the soils have high degree of weathering. Although the soils have high clay content, the bulk density of all the soils is low (0.89-1.04 g/cm^3). The low bulk density may cause the high total porosity (58-65%). The low bulk density and the high total porosity are good condition for plant root development. The low bulk density and high total pore space may affected by soil texture and the presence of moderate amount of organic matter. This is true because the solid particles of the fine-textured soils tend to be organized in porous granules. In theses aggregated soils, pores exist both between and within the granules. This condition assures high total pore space and a low bulk density (Brady & Weil 2000).

Water retention at field capacity (33kPa) ranges from 35 to 45%. The water retention at wilting coefficient (1,500 kPa) is moderate which ranges from 20 to 27%. Plant-available water is the amount of water held at potentials between those of field capacity (33 kPa) and wilting point (1,500 kPa). All of the studied soils have high moisture content both at field capacity and wilting point. However, the plant-available water of all the soils is moderate to high (11-22%). The soil permeability is high (21-25 cm/hour) in A horizons and moderate (13-18 cm/hour) in B horizons. The high water retention at 1,500 kPa and permeability are positively affected by the presence of organic C (R^2=0.55 and R^2=0.63, respectively) (Figure 3A dan 3B).

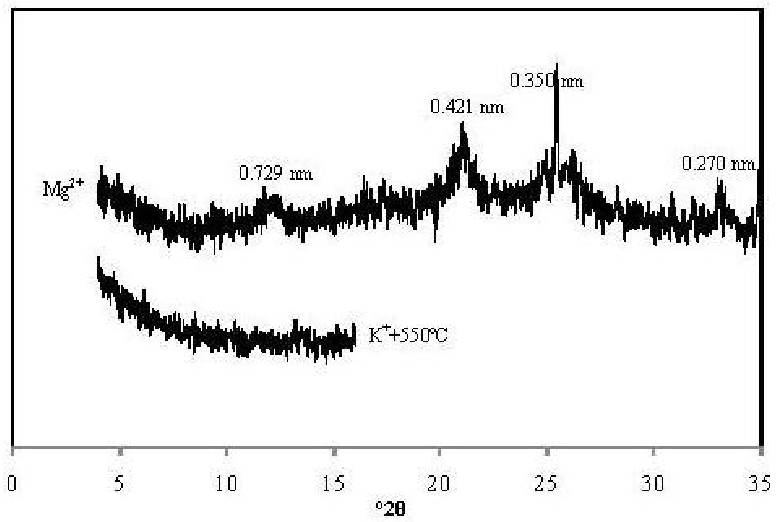
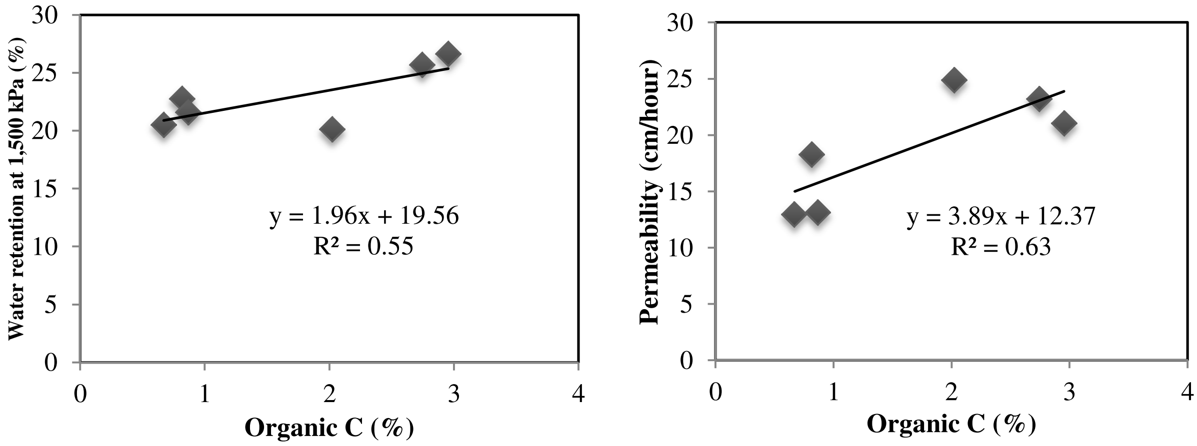


Figure 2. X-ray diffractogram in horizon Bo1 of profile MF 3 with $Mg^{2+}$and K^{+}+heating 550°C treatments.

Table 4. Physical properties of the studied soils

Horizon	**Depth**	**Texture**			**Bulk Density**	**Total Pores**	**Water Retention**		**Available Water**	**Permeability**
		Sand	**Silt**	**Clay**			**33 kPa**	**1,500 kPa**		
	cm	%			g/cm^3	------ % volume ------				cm/jam
Profile MF 1										
AB	0-16	10	37	53	0.89	64.0	41.6	20.1	21.5	24.89
Bo1	16-50	6	38	56	0.91	58.3	35.0	20.5	14.8	12.94
Bo2	50-92	7	39	54						
Bo3	92-125	10	38	52						
Profile MF 2										
AB	0-14	6	39	55	1.04	58.6	42.1	25.7	16.4	23.20
Bo1	14-47	8	34	58	0.97	62.8	36.2	22.7	13.1	18.28
Bo2	47-90	7	36	57						
Bo3	90-120	6	39	55						
Profile MF 3										
AB	0-15	7	37	56	0.94	59.2	37.4	26.6	10.8	21.05
Bo1	15-45	6	36	58	0.90	65.0	43.2	21.6	21.6	13.12
Bo2	45-89	7	38	55						
Bo3	89-120	11	36	53						



(A) (B)

Figure 3. Relationship between Organic C and Water Retention at 1,500 kPa (A), Organic C and Permeability (B) of the studied soils

3.4 Soil Chemical Properties

All of the soils have acid soil reaction (pH_{H2O}4.64-5.03) (Table 5). Acid soil reaction of the studied soils may indicate that there is a limited amount of exchangeable cations, mainly Ca, K, Mg and Na in the exchange complexes. The exchangeable Mg is low to high (0.55-2.59 $cmol_c$/kg) in A horizon and low to very low (0.24-0.88 $cmol_c$/kg) in B horizon. The value of pH_{H2O} is positively related to the presence of exchangeable Ca (Figure 4A). The sum of exchangeable cations is mostly low (less than 5 $cmol_c$/kg) indicating that only a few amounts of nutrients retained to support crop growth. Materials such as agricultural lime containing calcium carbonate ($CaCO_3$) and dolomite can be used to increase the amounts of exchangeable cations in soils, and thus increasing soil reaction.

The organic carbon values are medium (2.02-2.95%) in A horizon and very low (0.35-0.87%) in B horizon, while total N is medium to high in A horizon and low in B horizon. The higher organic C in A horizon compared with B horizon is due to a higher addition of organic matter from plant residues in A horizon than that of B horizon.

Available P and potential K_2O contents are very low (Table 5), while potential $P_2O_5$is low to medium (19-35 mg/100g). The very low available P is related to the presence of Fe oxides and hydroxides. Some P in soil solution may be retained by Fe oxides. P fixation by Fe seems to play more important role, than that by Al. The very low available P suggests that P deficiency is the major problem for crop production. Therefore, application of P fertilizer is strongly required to support plant nutrient.

Cation exchange capacity (CEC) of soil could provide a figure of soil capability to retain and release cation nutrients from the exchange complex. All of the soils have low CEC-soil (8-11 $cmol_c$/kg) in A horizon and very low (3-5 $cmol_c$/kg) in B horizon. This indicates that soils have a low capacity to retain cations. Organic matter in term of organic carbon content tend to influence the CEC of soil. The CEC increase with soil organic carbon (Figure 4B). Similar results were reported by Becquer *et al*. (2001), Prasetyo & Suharta (2004), Yatno & Prasetyo (2010). Management of CEC should receive more attention in order to be able to reduce cation leaching that might occur during rainy season. Attemps to apply materials that increase soil CEC, such as farm manure (chicken or cattle), green manure, P fertilizer, and lime applications could be made to increase soil productivity.

Base saturation is low to medium (19-51%), while Al saturation of all the soils is very low (0-2%). The low value of Al saturation is due to the soils derived from ultramafic rocks. These types of rocks contain mainly ferromagnesian minerals that upon weathering only release a small amount of Al ion into the soil. On the contrary, Fe and Mg ions may be released in a higher amount. Base saturation tends to increase with increasing exchangeable Ca.

Table 5. Chemical properties of studied soils

Horizon	Depth	pH	C	Total	Bray 1	HCl 25 %		NH$_4$OAc 1 M, pH 7						BS	Al
		H$_2$O	Org	N	P$_2$O$_5$	P$_2$O$_5$	K$_2$O	K	Ca	Mg	Na	CECs	CECc		Sat
	cm		%		mg/kg	mg/100 g		cmol$_c$/kg						%	
Profile MF 1															
AB	0-16	5.02	2.02	0.37	0	19	0	0.07	1.50	0.55	0.02	8.19	0.17	26	2
Bo1	16-50	4.64	0.67	0.18	0	24	0	0.03	0.45	0.24	0.02	3.84	2.05	19	0
Bo2	50-92	4.69	0.46	0.07	1	27	0	0.02	0.64	0.33	0.00	3.30	2.69	30	0
Bo3	92-125	4.79	0.54	0.09	0	19	0	0.02	0.23	0.55	0.00	3.66	2.88	22	0
Profile MF 2															
AB	0-14	4.99	2.75	0.38	1	18	1	0.07	2.33	1.68	0.07	11.04	0.10	38	1
Bo1	14-47	4.98	0.82	0.15	1	23	0	0.03	1.08	0.22	0.02	4.34	1.85	31	2
Bo2	47-90	4.77	0.53	0.09	0	29	0	0.02	1.00	0.26	0.01	3.84	3.03	34	0
Bo3	90-120	4.8	0.39	0.13	0	27	0	0.03	1.00	0.28	0.03	3.66	3.77	36	2
Profile MF 3															
AB	0-15	5.03	2.95	0.51	1	21	1	0.07	2.94	2.59	0.04	12.03	0.38	47	0
Bo1	15-45	5.03	0.87	0.17	1	24	0	0.03	2.25	0.44	0.00	6.43	5.11	42	0
Bo2	45-89	4.81	0.44	0.17	1	35	0	0.02	1.23	0.32	0.02	4.54	5.07	35	0
Bo3	89-120	4.83	0.35	0.07	1	27	0	0.02	1.35	0.88	0.00	4.44	5.74	51	0

Notes: CECs=Cation Exchange Capacity-soil, CECc=Cation Exchange Capacity-clay, BS=Base Saturation, Al Sat.=Al Saturation

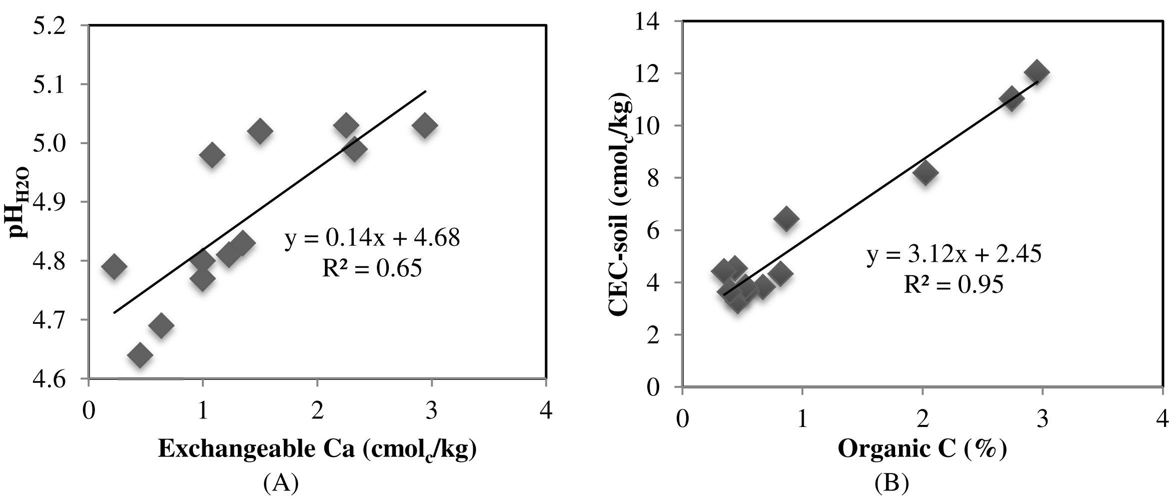


Figure 4. Relationship between Exchangeable Ca and pH$_{H2O}$ (A), Organic C and Cation Exchange Capacity (CEC)-soil (B) of the studied soils

In the studied area, parent material seems to play a significant role in soil formation. Other important factors that govern soil formation, is probably climate and time of soil formation. High annual rainfall, around 2,000 mm with isohyperthermic soil temperature regime, had caused the formation of soils with advanced stage of weathering. Intensive chemical weathering has depleted primary minerals and bases as source of plant nutrient. Time of soil formation seems also had important effect. Deep soils, fine textured, low activity clay and rich in iron oxide are signs that soils had passes through a very long time in soil formation (Yatno & Prasetyo 2010).

3.5 Soil Classification

Based on field observation and soil analysis data, all the studied soils are classified as Oxisols. This is because the soils have low clay cation exchange capacity (less than 16 $cmol_c$/kg clay) and high clay content (more than 40%) without clay illuviation.

At family level, these soils are classified as fine, kaolinitic, isohyperthermic Rhodic Hapludox, because they have udic soil moisture regime or not dry in any part for as long as 90 cumulative days in normal years, hue 2.5YR with value (moist) of 3 or less, high clay content (52-58%), large amount of kaolinite, and the mean annual soil termperature of 22°C or higher.

3.6 Land Suitability Evaluation for Cocoa

Land suitability evaluation is meant to know or to predict whether a land/soil is suitable or not suitable for growing and production of a particular crop. It is expected that land suitability could serve as a guideline to select and cultivate a certain crop or particular commodity that has a sustained yield, without damaging land/soil and or minimizing of soil degradation.

The result of land evaluation shows that all studied soils are marginally suitable (S3 class) for cocoa production (Table 6). The soils exhibit low nutrient retention (low CEC-clay and acid soil reaction) and low nutrient availability (very low potential K_2O extracted by HCl 25%) as the main constraints. This land suitability class of marginally suitable (S3) means that the soils have severe limitation to use, mainly for cocoa development.

Table 6. Land suitability class for cocoa of the studied soils

Profiles	Land Suitability Class (ICALRRD, 2011)	Limiting Factors
MF 1	S3nr, na	Acid soil reaction (pH <5.5), do not have potential K_2O
MF 2	S3nr, na	Acid soil reaction (pH <5.5), do not have potential K_2O
MF 3	S3nr, na	Acid soil reaction (pH <5.5), do not have potential K_2O

Notes : S3 = marginally suitable, nr =nutrient retention, na=nutrient availability

Addition of organic matter, liming, and K fertilization should be applied to improve the soil productivity. Cation exchange capacity may increase with increasing organic C, while soil acidity may decrease with liming. Addition of high K fertilizer may increase availability K in soil solution. K nutrient is highly required for cocoa growth and development.

5. Conclusion

Sand mineral composition of soils developed from serpentinite ultramafic rocks in East Kolaka was dominated by opaque, quartz, and garnet, while clay minerals were composed of kaolinite, goetite, and hematite.

These soils were characterized by deep solum, clay textures, low bulk density, medium to very high available water and rapid permeability, acid soil reaction, medium organic C in A horizons and very low in B horizons, very low available P and potential K_2O contents, very low exchangeable cations (Ca, K, Na), low to very low soil CEC, very low clay CEC and Al saturation, and low to medium base saturation.

At family level, all the soils were classified as fine, kaolinitic, isohyperthermic, Rhodic Hapludox. These soils were marginally suitable (S3 class) for cocoa crop with limiting factors of acid soil reaction and very low potential K_2O. Liming and K fertilization should be applied to increase the soil productivity for cocoa development.

Acknowledgments

This study was carried out as part of a doctoral fellowship awarded to Edi Yatno by the Indonesian Agency for Agricultural Research and Development. The authors thank Mr. Imran, researcher staff at BPTP of Southeast Sulawesi Province, for his collaboration and help in soil sampling.

References

Anda, M., Suharta, N. & Ritung, S. (2000). "Development of soils derived from weathered sedimentary, granitic,and ultrabasic rocks on South Kalimantan Province: I. Mineralogical composition and chemical properties", *Indonesian Soil and Climate Journal* **18**, 1-10.

Becquer, T., Petard, J., Duwig, C., Bourdon, E., Moreau, R. & Herbillon, A.J. (2001). "Mineralogical, chemical and charge properties of Geric Ferralsols from New Caledonia". *Geoderma* **103**, 291-306.

Brady, N.C. & Weil, R.R. (2000). "Elements of Nature and Properties of Soils". Prentice-Hall, Inc. New Jersey. 559p.

Buol, S.W., Hole, F.D. & McCraken, R.J. (1980). "Soil Genesis and Classification". The Iowa State University Press.

Buurman, P. & Soepraptohardjo, M. (1980). "Oxisols and associated soils on ultramafic and felsic volcanic rocks in Indonesia". p 79-92. *In* P. Buurman (Ed.). Red soils in Indonesia. Agric. Res. Rep. Bulletin No, 5. Soil Research Institute. Bogor.

Buurman, P. (1990). "Chemical, physical, and mineralogical characteristics for the soil data base". Tech. Report No.7, Version 2.1. LREPP Part 2, Soil Data Base Management. CSAR. Bogor.

Diperhutbun (Agricultural, Forestry, and Plantation Office) of East Kolaka Regency. (2014). "Recapitulation of land area, productivity, and farmer amount of civil plantation in East Kolaka Regency during period of 2013". Agricultural, Forestry, and Plantation Office of East Kolaka Regency.

FAO (Food and Agriculture Organization). (1976). "A Framework for Land Evaluation". FAO Soil Bull. No. 32. Rome.

Goenadi, D.H.,Baon, J.B. & Herman, P.A. (2005). "Prospect of Cocoa Agribussines Development in Indonesia". Indonesian Agency for Agricultural Research and Development. Jakarta.

Hardjowigeno, S. (2003). "Soil Classification and Pedogenesis". Akademika Pressindo, Jakarta.

Hidayat, A. (2002). "Clay mineral and Classification of Oxisols at family level in Pelaihari, South Kalimantan". *Indonesian Soil and Water Journal* **1**, 10-20.

ICALRRD (Indonesian Centre for Agricultural Land Resource Research and Development). (2011)."Technical Guideline of Land Evaluation for Agricultural Commodities". Revision Edition. Indonesian Centre for Agricultural Land Resource Research and Development. Bogor.

Munir, M. (1996). "Geology and Soil Mineralogy". PT. Dunia Pustaka Jaya. Jakarta.

Prasetyo, B.H. & Suharta, N. (2004). "Properties of low activity clay soils from South Kalimantan". *Indonesian Soil and Climate Journal* **22,** 26-30.

Rossiter, D.G. (1996). "A theoretical framework for land evaluation. Discussion Paper". *Geoderma* **72,** 165-190.

Schmidt, F.H. & Ferguson, J.H.A. (1951). "Rainfall types based on wet and dry period ratios for Indonesia and Western New Guinea". Verh. 42. Jaw. Meteo. and Geophysic, Jakarta.

Simandjuntak, T.O., Surono & Sukido. (1993). "Geological Map of the Kolaka Sheet, Sulawesi". Geological Research and Development Centre, Bandung.

Soil Survey Division Staff. (1993). "Soil Survey Manual". USDA Handbook No.18. United States Department of Agriculture, Washington DC.

Soil Survey Staff. (2014). "Keys to Soil Taxonomy". 12^{th}ed. Natural Resources Conservation Service. USDA. Washington DC.

Sys, C. (1978). "Evaluation of land limitations in the humid tropics". *Pedologie* **28** (3), 307-335.

van Reeuwijk, L.P. (1993). "Procedures for Soil Analysis". Fourth Edition. ISRIC, Wageningen. Netherlands.

White, R.E. (1987). "Introduction to the Principles and Practice of Soil Science". Second Edition. Blackwell Scientific Publications. Osney Mead, Oxford. p 244.

Yatno, E. & Prasetyo, B.H. (2010). "Soil developed on serpentinite in Panyipatan District, South Kalimantan : characteristics and their suitability for maize". *Indonesian Soil and Climate Journal* **32**, 1-11.

Zhang, B., Zhang, Y., Chen, D., White, R.E. & Li, Y. (2004). "A quantitative evaluation system of soil productivity for intensive agriculture in China". *Geoderma* **123**, 319-331