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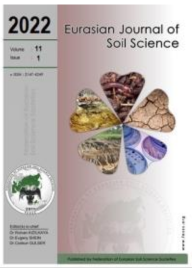

Properties, geochemical composition, and fertility of highly weathered soils in Central Philippines

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Abstract

Highly weathered soils are widepsread in the humid tropics. These soils are deep, clayey, and reddish and contain scant amounts of nutrients like Si due to excessive leaching, heavy desilication-aluminization, and erosion owing to their slope gradient and position. However, few investigations have been published in terms of their nature, characteristics, and nutrient status, especially for the geologically young Philippine islands. This study assessed the properties, geochemical composition, and fertility of deep and highly weathered soils developed from various parent materials in Central Philippines (Leyte and Samar). Sampling covered the entire soil profiles, including the lower portions, that are usually neglected in common soil characterization studies. Among the soil profiles, only profiles 3 and 8 have developed from non-uniform or heterogeneous parent materials. Findings likewise revealed heavy losses of K_2O, CaO, MgO, and Na_2O from the highly soil profiles evaluated. The amount and profile distribution of K_2O and CaO is below 0.5% in the entire profile of most soils. On the other hand, there is apparent enrichment of Al_2O_3, Fe_2O_3, and to a lesser extent SiO_2 in the highly weathered soil profiles, thus supporting the residua hypothesis. In terms of morpho-physical characteristics, the soils have deep solum, reddish color, subangular structure, friable moist consistence, and sticky and plastic wet consistence which are all related to the highly weathered nature of the soils. They also generally have low bulk density and higher porosity due to the iron oxides aggregation effect. The strong acidity (pH <5) and negative delta pH values revealed that the soil colloids possess a negative net charge. Nutrient status also showed low contents of organic matter, total N, available P, and exchangeable bases. Majority of the deep and highly weathered soils evaluated have possibly developed from homogenous parent materials. The soils are classified as Hapludox, Hapludult, and Paleudult.

Keywords: Geochemical composition, highly weathered soils, nutrient status.

Introduction

Weathering is the disintegration of rocks on the earth's surface as a result of physical, chemical, and biological processes. According to Strakhov (1967), although weathering is a fundamental characteristic of humid regions, the degree of its development differs depending on the combination of temperature and moisture, the introduction of organic material, and the relief of the region, the latter being greatly influenced by tectonic uplift. He further explained that the maximum intensity of weathering is attained in the moist tropics resulting in the thickest weathered residue with a characteristic geochemical composition (Strakhov, 1967). As first demonstrated by V.V. Dokuchaev, the products from rock weathering are subjected to various factors such as climate, parent rock, organisms, topography, and time all of which determine the nature of the soil that develops (Jenny, 1941; Barshad, 1964; Kyuma, 2021).

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Highly weathered soils are prevalent in the wet tropics, often derived from Precambrian rocks, developed from pre-weathered parent materials (Stoops, 2003), and have undergone prolonged and intense weathering under the net leaching environment, specifically humid tropics (Mohr et al., 1972; Sanchez, 1976).

Humid tropics are estimated to be covered by 70% of strongly weathered soils (Dudal, 2003). These soils are deep, clayey, and reddish and mostly contain low amounts of nutrients like Si due to excessive leaching, heavy desilication-aluminization, and erosion due to their slope gradient and position. Strongly weathered soils with low contents of weatherable minerals and with clays consist mainly of kaolinite and oxides of iron and aluminum.

Chesworth (1973a) hypothesized that there is a tendency to simplify weathering products with time towards what he calls a “residua system” composed of SiO_2, Al_2O_3, Fe_2O_3, and H_2O. This implies that highly weathered soils would have comparable geochemistry even if derived from different parent materials. The typical minerals in weathering residue are quartz, a hydrous form of silica (opal and chalcedony), gibbsite, boehmite, goethite, hematite, kaolinite, and halloysite.

On the other hand, accumulation of Titanium (Ti) and Zircon (Zr) minerals are higher in tropical regions than in temperate with high anion and cation adsorption and pH-dependent charged as observed in titaniferous Oxisols from Malaysia (Fitzpatrick and Chittleborough, 2002).

Recent studies on highly weathered soils in Central Philippines determined the properties, geochemical composition, and fertility in the lower portions of the deep soil properties (Asio, 1996; Navarrete et al., 2007; Piamonte et al., 2014). Evaluating these parameters will contribute to a better understanding of the genesis of the soil, especially from the Philippines. Thus, this study was conducted to assess the properties, geochemical composition, and fertility of deep and highly weathered soils developed from various parent materials in Central Philippines (Leyte and Samar) of the entire soil profile, including the lower portions, which are usually ignored in common soil characterization studies.

Material and Methods

Site Selection and Characteristics

Eight soil profiles at various elevations and physiographic positions were selected from several parts of Central Philippines. Specifically, places include Leyte (Baybay and Silago) and Samar (Salcedo, Hernani, and Hinabangan) (Figure 1). The climate is classified as Af (tropical wet climate) in the Köppen climatic classification and as Type II and Type IV in the Coronas climatic classification of the Philippines (Coronas, 1920). Rainfall is evenly distributed throughout the year, with an average annual rainfall of∼2800mm. Diverse plant species dominated the areas. The soil moisture regime is udic, which implies that the water is available year-round. In addition, the soil temperature regime is hyperthermic, with an annual average temperature of above 22˚C, and it does not fluctuate above 5˚C (Soil Survey Staff, 1999). Table 1 presents the detailed characteristics of the sampling sites.

Soil Profile Description and Sampling

Preference was set to recent road cuts to get samples from deeper soil layers. Soil profile descriptions were done following the standard procedure of FAO Guidelines for Soil Description (Jahn et al., 2006). Soil samples were taken from each horizon of every soil profile quantitatively by taking three (3) continuous and even slices from the uppermost horizon down to the lowest and were mixed thoroughly (Schlichting et al., 1995). Wider soil slices were collected in thin horizons to ensure that the sample volume is approximately equal to those from the thicker horizons. For the purpose of comparison, sampling was done using a uniform measurement of (0-20 cm, 20-40 cm, 40-70 cm, 700-100 cm, 100-130 cm, 130-160 cm, 160-190 cm 190-210 cm, 210-240 cm, 240-270 cm, 270-300 cm, 300-330 cm, 330-360 cm and 360-400 cm). All soil samples were placed in a properly labeled plastic and brought to the Department of Soil Science Visayas State University for processing. Samples were unfettered from rocks and leaves, air dried, pulverized, and sieved in different wire mesh sizes to determine physical and chemical properties.

Laboratory Analyses

The total elemental composition was analyzed by X-ray fluorescence analytical microscope (HORIBA XGT-7200). Bulk density (g/cm^{-3}) was determined using the paraffin-clod method (Blake and Hartge, 1986) and percent (%) porosity was computed from the bulk density value and an assumed particle density value of 2.65 g/cm^3 (ISRIC, 1995). Particle size distribution was determined using a pipette after pretreatment with H_2O_2 to oxidize organic matter (ISRIC, 1995). Water holding capacity (WHC) and field capacity (FC) were determined using the gravimetric method (Klute, 1986). Soil pH (1:25 H_2O) and 0.01 M KCl were measured using pH meter, and total nitrogen (N) was determined following the Micro-Kjeldahl method (ISRIC, 1995). Percent (%) organic matter (OM) was measured by the modified Walkley-Black method (Nelson and Sommers, 1996). Available P was obtained following the Bray P2 (ISRIC, 1995). The exchangeable bases (cmolc kg^{-1}) were quantified following the ammonium acetate method (Jones, 2001), and quantified using Agilent 4200 (microwave plasma-atomic emission spectrometry).

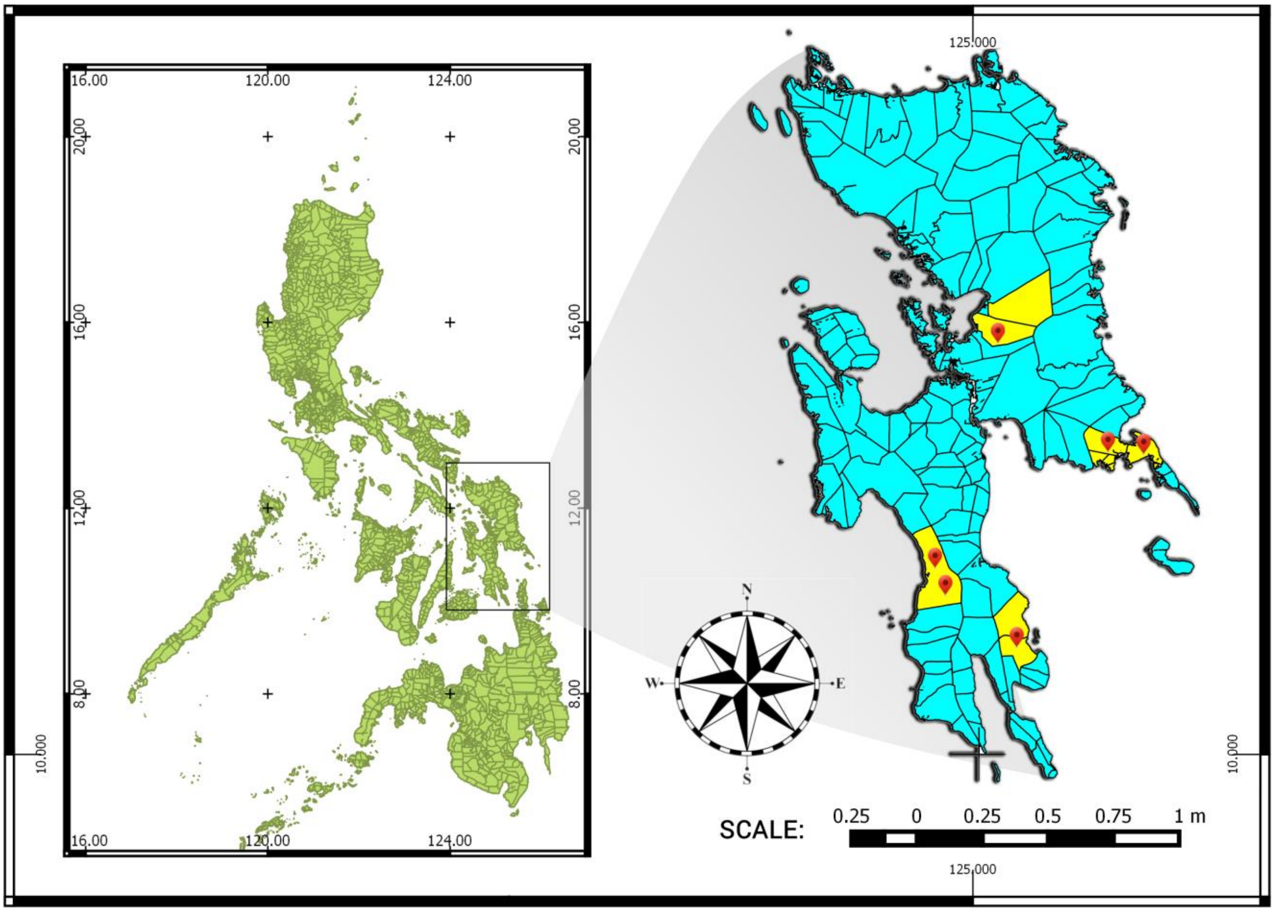

Figure 1. Study sites in Leyte and Samar, Philippines

Table 1. Site characteristics of the sampling sites of deep and highly weathered soils in Leyte and Samar

Site Characteristics	PROFILE NO.							
	1	2	3	4	5	6	7	8
Location	Naparaan, Salcedo E. Samar	Naparaan, Salcedo E. Samar	Hernani, Samar	Bagacay, Hinabangan Samar	Mt. Pangasugan Baybay Leyte	Tubod, Silago, So. Leyte	Imelda, Silago So. Leyte	Makinhas, Baybay Leyte
Coordinates	N10°08'941" E125°39'313"	N11°09'676" E125°037'452"	N11°16'895" E125°33'588"	N11°49'675" E125°12'415"	N10°44'901" E124°48'206"	N10°32.323' E125°8.777"	N10°33'734" E125°05'48.3"	N10°38'890" E124°51'621"
Elevation	65 m asl	100 m asl	26 m asl	251 m asl	129 m asl	156 m asl	369 m asl	82 m asl
Slope Formation	Backslope	Upper Backslope	Shoulder	Backslope	Upper backslope	Upper backslope	Summit	Summit
Slope Gradient	Sloping	Sloping	Sloping	Sloping	Sloping	Sloping	Nearly level	Gently sloping
Parent Material	Serpentinized Ultrabasic Rock	Serpentinized Ultrabasic Rock	Ophiolite	Slate	Andesite-Basalt	Basaltic-andesitic volcanics	Basaltic-andesitic volcanics	Andesite
Soil Moisture Regime	Udic	Udic	Udic	Udic	Udic	Udic	Udic	Udic
Soil Temperature	Isohyperthermic	Isohyperthermic	Isohyperthermic	Isohyperthermic	Isohyperthermic	Isohyperthermic	Isohyperthermic	Isohyperthermic
Erosion	Slight Water Erosion	Slight Water Erosion	Moderate	Slight Water Erosion	Slight Water Erosion	No evidence	No evidence	No evidence
Rock outcrops	Few	Few	Common	Few	Few	Very few	Very few	Very few
Drainage	Well-drained	Well-drained	Well-drained	Well-drained	Well-drained	Poorly drained	Well-drained	Well-drained
Land-use	Dipterocarp forest	Dipterocarp forest	Degraded land	Forest	Secondary forest	Agricultural	Secondary Forest	Secondary Forest
Vegetation	Deciduous woods	Deciduous woods	*Pteridium aquilinum*	Deciduous woods	Dipterocarps, Grasses	Ferns, cogon	Ferns, cogon, taro, goatweed	Coconut, grass, ferns

Results

Uniformity of Parent Material

The depth function of TiO_2 and ZrO_2 defined the characteristic of parent materials (Figure 2). Soil profiles (3, 5, 6, and 8) showed considerable variations of TiO_2 and ZrO_2 with depth, indicating possible heterogeneity of the parent materials. Conversely, for the depth function of ZrO_2, only profiles 3 and 8 show considerable variations with depth. From these two findings, it is most likely that profiles 3 and 8 have developed from non-uniform or heterogeneous parent materials.

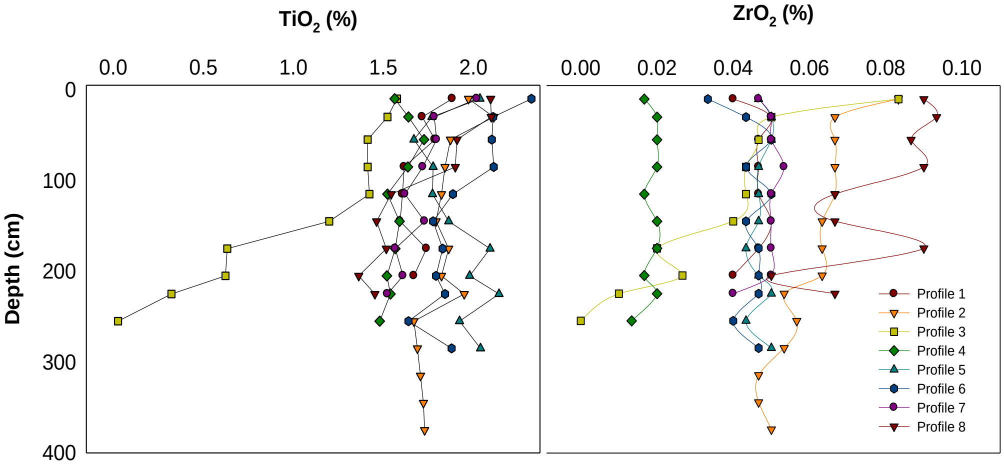

Figure 2. Depth functions of TiO2 and ZrO2 in deep and highly weathered soils in Leyte and Samar

Composition of the Weathered Residue

The depth function of SiO_2, Al_2O_3, and Fe_2O_3 demonstrated the composition of the weathered residue (Figure 3). Most of the soils except profiles 1 and 3 have close to 40% SiO_2 in their profiles which generally appeared uniform with soil depth. This implies that weathering of these soils has been intensive down to a few meters' depths. For Al_2O_3, most soils have a uniform distribution with depth and contain considerable amounts (between 15 and 35%) because of the intensive weathering process. However, Fe_2O_3 findings reveal high amounts ranging from 30 to 50%.

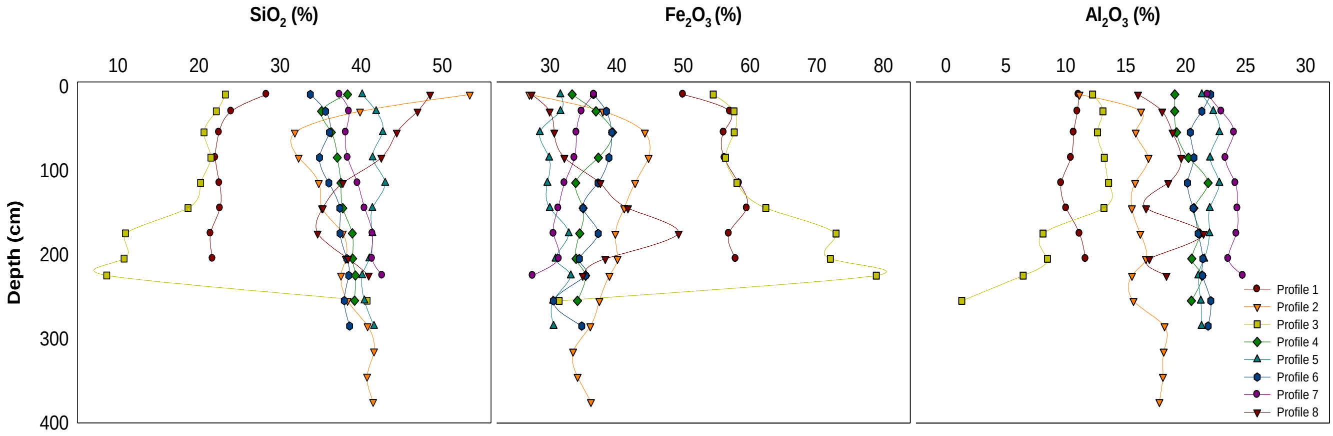

Figure 3. Depth functions of SiO_2, Al_2O_3, and Fe_2O_3 in deep and highly weathered soils in Leyte and Samar

Amounts of Basic Elements (K_2O, CaO, MgO, and Na_2O)

Findings revealed generally heavy losses of K_2O, CaO, MgO, and Na_2O from the highly soil profiles evaluated (Figure 4). The amount and profile distribution of K_2O and CaO is below 0.5% in the entire profile of most soils. Profiles 1, 2, and 8 show a slight tendency for K_2O to increase with soil depth, suggesting the possible contribution of deep rock weathering. On the other hand, MgO and Na_2O are much higher in all the soils than CaO and K_2O. This suggests that CaO and K_2O are more mobile in the weathering environment compared to MgO and Na_2O.

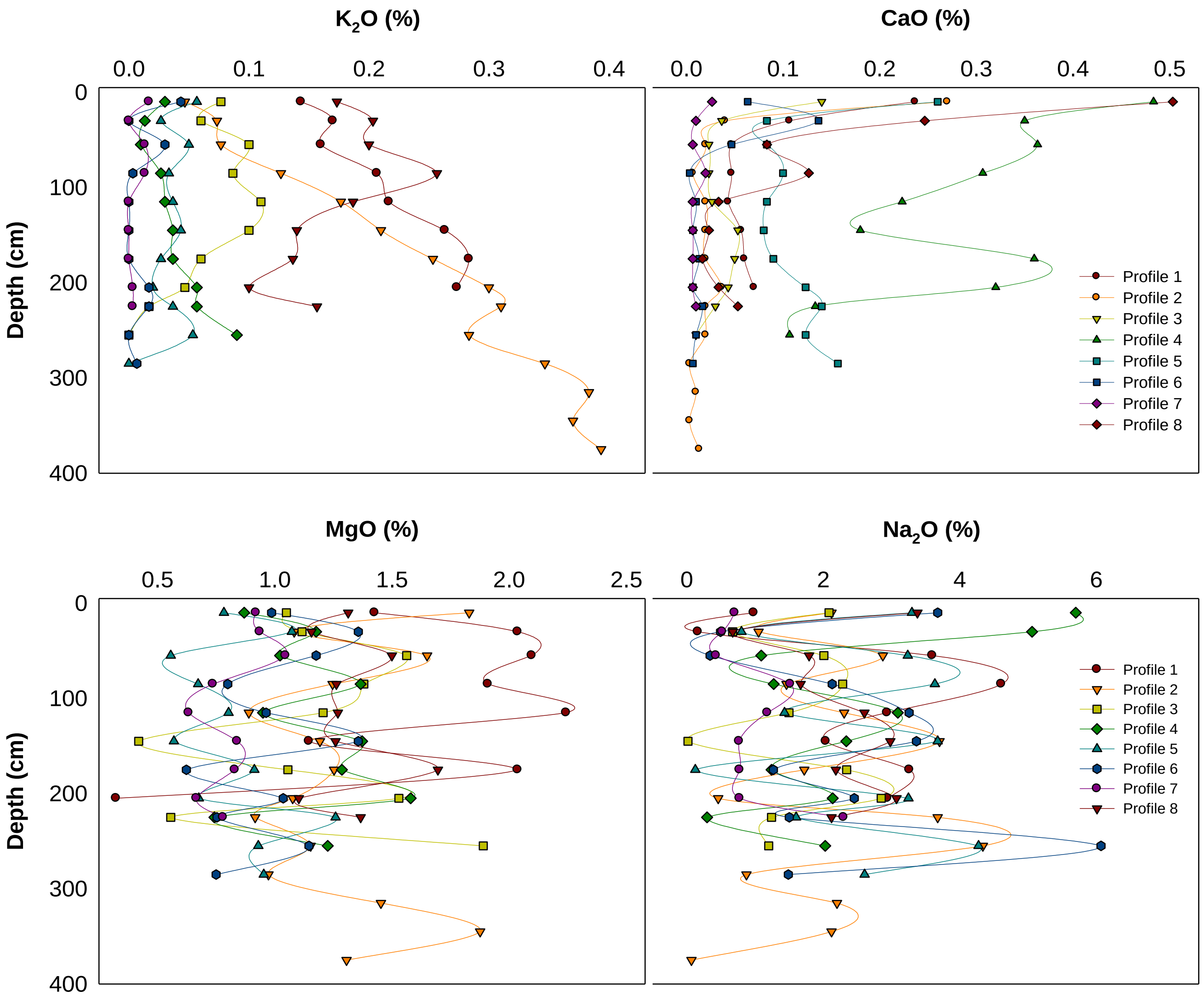

Figure 4. Depth functions of basic elements K_2O, CaO, MgO, and Na_2O in deep and highly weathered soils in Leyte and Samar

Other Elements (CuO, ZnO, PbO, NiO, CrO, and SO_2)

The amounts of CuO, ZnO, PbO, NiO, CrO, and SO_2 in the soil profiles were very small except for profiles 1 and 3, revealing considerable amounts of CrO. Also, profile 3 had more NiO compared to other soil profiles (Figure 5).

Soil Morpho-Physical Properties

Table 2 presents the morphological properties of the highly weathered soils evaluated. Soil profile 1 has a clay texture and a reddish brown surface horizon which turns to red in the subsurface. Soil profile 2 is a silty clay and very deep soil with a color ranging from brown to orange in the subsoil. Soil profile 3 is a sandy clay soil varying in color from yellowish brown to brown. All three profiles showed no rock fragments in their profile. They have subangular blocky structure, friable moist consistence but sticky and plastic wet consistence. Soil profiles 4 and 5 are clayey deep soils ranging in color from bright reddishbrown to red. They have subangular blocky structure, friable moist consistence and sticky and plastic wet consistence. Soil profiles 6, 7, and 8 have closely similar soil morphology especially in terms of color, structure, and consistence. Results also revealed that the bulk density values of the soils are below 1.0 g/cm^3, porosity values range from 60 to 80%, and water holding capacity is high 75-95% (Figure 7). Also, the soil profiles 1, 2, and 5 had the highest clay contents (Figure 8).

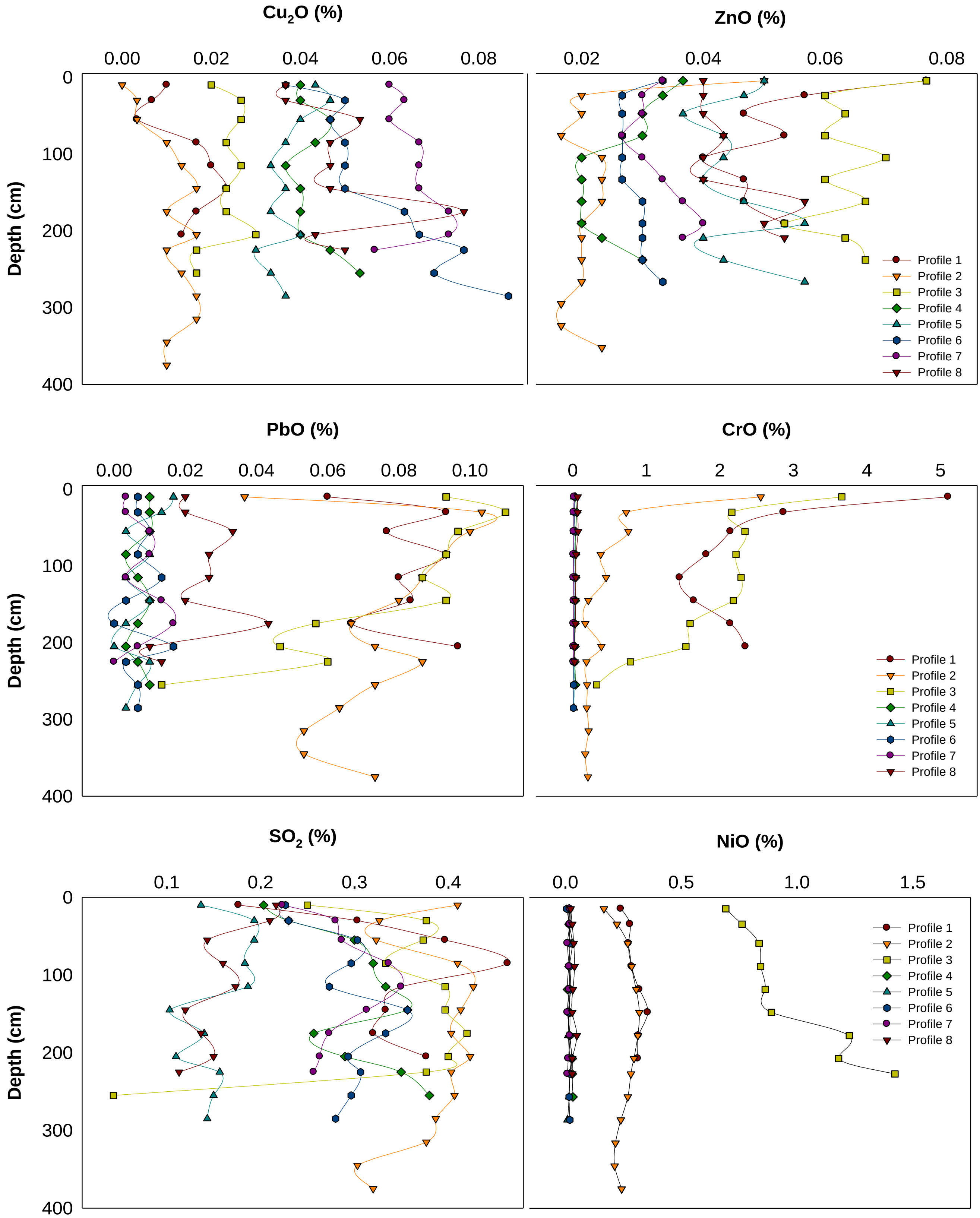

Figure 5. Depth functions of CuO, ZnO, PbO, NiO, CrO, and SO_2 in deep and highly weathered soils in Leyte and Samar

Soil Chemical Properties

Most of the highly weathered soils evaluated are strongly acidic. Moreover, they have a higher pH in H_2O than pH in KCl (Figure 9). They also have low organic matter contents and P availability (Figure 10). Except for the surface horizons of soil profiles 4 and 6, all other soil profiles have lower than 3% organic matter content, which decreased to below 1% in the lower portions. All soil profiles also revealed low exchangeable base contents (Supplementary Table 1).

Table 2. Morphological characteristics of deep and highly weathered soils in Central Philippines

Horizon[A]	Depth (cm)	Boundary[B]	Color (Moist)	Texture [C]	Rock fragments [D]	Structure[E]	Consistence[F]		Roots[G]
							Wet	Moist	
				Profile 1					
Ah	0-20	cs	2.5YR 4/6 reddish brown	SiC	n	3fg	fr	spl&st	vff
Bo1	20-40	cs	2.5YR 4/6 reddish brown	C	n	3abk	fr	spl&sst	fm
Bo2	40-70	cs	2.5 YR 4/6 reddish brown	C	n	3sbk	vfr	pl&st	fm
Bo3	70-100	cs	2.5 YR 3/6 brown	C	n	3sbk	vfr	pl&st	cf
Bo4	100-130	cs	10YR 4/6 reddish brown	C	n	3sbk	vfr	pl&st	-
Bo5	130-160	ds	10R 4/6 red	C	n	3sbk	vfr	pl&st	-
Bo6	160-190	ds	10R 4/8 red	C	n	3sbk	vfr	pl&st	-
Bo7	190 below	ds	10R 4/6 red	C	n	3sbk	vfr	pl&st	-
				Profile 2					
Ah	0-20	ds	10YR 4/6 brown	SiC	n	3fg	l	sst&spl	fm
AB	20-40	ds	7.5 YR 5/6 bright brown	SiC	n	3fg	fr	st&pl	ff
Bo1	40-70	ds	7.5 YR 5/6 bright brown	SiC	n	3sbk	fr	sst&spl	ff
Bo2	70-100	ds	7.5 YR 6/8 orange	SiC	n	3sbk	fr	st&pl	fm
Bo3	100-130	ds	7.5 YR 5/6 bright brown	SiC	n	3sbk	fr	st&pl	fm
Bo4	130-160	ds	7.5 YR 5/6 bright brown	SiC	n	3sbk	fr	st&pl	fm
Bo5	160-190	ds	7.5 YR 4/6 orange	SiC	n	3sbk	fr	st&pl	fm
Bo6	190-210	ds	7.5 YR 5/6 bright brown	SiC	n	3sbk	fr	st&pl	fm
Bo7	210-240	ds	7.5 YR 6/8 orange	SiC	n	3sbk	fr	sst&spl	fm
Bo8	240-270	ds	7.5 YR 6/8 orange	SiC	n	3sbk	fr	sst&spl	fm
Bo9	270-300	ds	7.5 YR 6/8 orange	SiC	n	3sbk	fr	sst&spl	fm
Bo10	300-330	ds	7.5 YR 6/8 orange	SiC	n	3sbk	fr	st&spl	fm
Bo11	330-360	ds	7.5 YR 6/8 orange	SiC	n	3sbk	fr	st&spl	fm
Bo12	360 below	ds	7.5 YR 6/8 orange	SiC	n	3sbk	fr	st&spl	fm
				Profile 3					
Ah	0-20	ds	10YR 5/6 yellowish brown	SC	n	2fg	fr	st&spl	cm
Bo1	20-40	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
Bo2	40-70	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
Bo3	70-100	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
Bo4	100-130	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
Bo5	130-160	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
Bo6	160-190	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
BC1	190-210	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
BC2	210-240	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
BC3	240 below	ds	10YR 4/6 brown	SC	n	2fsbk	fr	st&spl	ff&vfm
				Profile 4					
Ah	0-20	cs	5YR 5/6 bright reddish brown	SiCl	n	3fg	fi	st&spl	cf
BA	20-40	cs	2.5YR 5/6 bright brown	SiCl	n	3sbk	fi	sst&spl	ff
Bt1	40-70	cs	2.5 YR 6/8 bright reddish brown	HC	n	3sbk	vf	vst&vpl	vf
Bt2	70-100	d	10R 4/6 red	HC	n	3sbk	vf	vst&vpl	vf
Bt3	100-130	d	10YR 4/8 brown	HC	n	3sbk	vf	vst&vpl	vf
Bt4	130-160	d	10YR 4/8 brown	HC	n	3sbk	vf	vst&vpl	vf
Bt5	160-190	d	10R 4/6 red	HC	n	3sbk	vf	vst&vpl	vf
Bt6	190-210	d	10R 4/8 red	HC	n	3sbk	vf	vst&vpl	vf
Bt7	210-240	d	10R 4/6 red	HC	n	3sbk	vf	vst&vpl	vf
Bt8	240 below	d	10R 4/6 red	HC	n	3sbk	vf	vst&vpl	vf
				Profile 5					
Ah	0-20	cs	7.5YR 3/4 bright brown	C	n	1fsbk	fr	st, pl	cf
Bw1	20-40	cs	5YR 5/8 bright reddish	C	f	3sbk	fr	st, pl	cff&ff
Bw2	40-70	cs	5YR 5/8 bright reddish	C	f	3sbk	fr	st, pl	cff&ff
Bt1	70-100	d	7.5YR 4/6 brown	C	f	3sbk	fr	st, pl	cff&ff
Bt2	100-130	cb	5YR 4/6 reddish brown	C	f	3sbk	fr	st, pl	cff&ff
Bt3	130-160	cb	5YR 4/6 bright reddish brown	C	f	3sbk	fr	st, pl	cff&ff
BC	160-190	d	5YR 4/6 bright reddish brown	C	f	3sbk	fr	st, pl	cff&ff
CB1	190-210	cb	2.5 Y 5/6 bright brown	C	f	3sbk	fr	st, pl	cff&ff
CB2	210-240	cb	2.5 Y 5/6 bright brown	C	f	3sbk	fr	st, pl	cff&ff
CB3	240-270	cb	2.5 Y 5/6 bright brown	C	f	3sbk	fr	st, pl	cff&ff
Cw	270 below	Dominated by saprolite, appears massive but can be easily broken by shovel							

Table 2 (continue)

Horizon[A]	Depth (cm)	Boundary[B]	Color (Moist)	Texture[C]	Rock fragments[D]	Structure[E]	Consistence[F]		Roots[G]
							Wet	Moist	
Profile 6									
Ah	0-20	as	10YR 3/4 (dark yellowish brown)	CL	n	1fsbk	fr	st & pl	fm
Bw	20-40	as	10YR 5/8 (yellowish brown)	C	n	1fsbk	fi	st & pl	cf
Bt1	40-70	gs	5YR 5/8 (yellowish red)	C	n	2fsbk	vfi	vst & vpl	cf
Bt2	70-100	gs	5YR 5/8 (yellowish red)	C	n	2fsbk	vfi	vst & vpl	vff
Bt3	100-130	gs	5YR 5/8 (yellowish red)	C	n	2fsbk	vfi	vst & vpl	-
Bt4	130-160	gs	5YR 5/8 (yellowish red)	C	n	2fsbk	vfi	vst & vpl	-
BC1	160-190	gs	5YR 5/8 (yellowish red)	C	c	2fsbk	vfi	vst & vpl	-
BC2	190-210	gs	5YR 5/8 (yellowish red)	C	c	2fsbk	vfi	vst & vpl	-
BC3	210-240	gs	5YR 5/8 (yellowish red)	C	c	2fsbk	vfi	vst & vpl	-
BC4	240-270	gs	5YR 5/8 (yellowish red)	C	c	2fsbk	vfi	vst & vpl	-
BC5	270 below	gs	5YR 5/8 (yellowish red)	C	c	2fsbk	vfi	vst & vpl	-
Profile 7									
Ah	0-20	cs	5YR 4/6 (yellowish red)	CL	n	1fsbk	fr	sst & spl	cf
Bw	20-40	gs	5YR 4/6 (yellowish red)	CL	n	1fsbk	fr	sst & spl	cf
Bt1	40-70	gw	5YR 4/6 (yellowish red)	C	n	2msbk	fi	st & pl	cf
Bt2	70-100	gw	5YR 5/6 (yellowish red)	C	n	1fsbk	fr	vst & vpl	vff
Bt3	100-130	gw	5YR 4/6 (yellowish red)	C	n	1fsbk	fr	vst & vpl	vff
BC1	130-160	cs	5YR 4/6 (yellowish red)	C	c	1fsbk	fr	vst & vpl	vff
BC2	160-190	cs	5YR 4/6 (yellowish red)	C	c	1fsbk	fr	vst & vpl	vff
BC3	190-210	cs	5YR 4/6 (yellowish red)	C	c	1fsbk	fr	vst & vpl	vff
BC4	210 below	cs	5YR 4/6 (yellowish red)	C	c	1fsbk	fr	vst & vpl	vff
Profile 8									
Ah	0-20	dw	5YR 4/4 reddish brown	SiC	f	3fsbk	fr	Sst&spl	cm
Bt1	20-40	dw	5YR 5/6 yellowish red	C	f	3fsbk	fr	Vst& pl	cm
Bt2	40-70	dw	5YR 5/6 yellowish red	SL	f	2fsbk	fr	St&pl	cm
Bt3	70-100	dw	5YR 5/8 yellowish red	SL	f	2fsbk	fr	Vst&pl	ff
Bt4	100-130	ds	5YR 5/8 yellowish red	L	f	3msbk	fr	Sstk&spl	ff
BC1	130-160	ds	2.5YR 4/8 red	L	c	3msbk	fr	Sstk&spl	ff
BC2	160-190	ds	2.5YR 4/8 red	SiC	c	3msbk	fr	Sstk&spl	-
BC3	190-210	dw	2.5YR 4/8 red	SiC	c	1fsbk	fr	Sstk&spl	-
BC4	210 below	dw	2.5YR 4/8 red	SiC	c	1fsbk	fr	Sstk&spl	vfm

A -Based on IUSS Working Group WRB (2015)
B -ds, diffuse smooth; dw, diffuse wavy; cw, clear and wavy; cs, clear and smooth
C -SC, Sandy clay; SL, sandy loam; SCL, Sandy clay loam; C, clay; L, loam
D -1, weak; 2, moderate; 3, strong; vf, very fine; f, fine; m, medium; sbk, sub-angular blocky; abk, angular blocky; g, granular
E -n, no rock fragments; f, few; c, common
F -fi, firm; vfr, very friable; fr, friable; nst, non-sticky; sst, slightly sticky; st, sticky; vst, very sticky; npl, non-plastic; spl, slightly plastic; pl, plastic; pvp, plastic to very plastic; vpl, very plastic
G -vff, very few fine; ff, few fine; cf, common fine; fm, few medium; vfm, very few medium; cm, common medium; fm, fine medium

Discussion

Uniformity of Parent Material

Blume (1963) and Barshad (1964) explained that the first task in the evaluation of soil profile development is the establishment of the uniformity of the parent material from which the soil has developed. Stahr (1979) and Alaily (1984) reported that indications of heterogeneity of parent material are inferred from depth functions and distribution of morphological, physical, chemical, and mineralogical properties which cannot be explained by pedogenesis. Barshad (1964) recommended the use of stable minerals or elements such as TiO_2 and ZrO_2 although he emphasized that it is not necessary that all stable elements should have a uniform distribution in the soil profile. Asio (1996) found that Al_2O_3, TiO_2 and ZrO_2 were the most suitable for establishing parent material uniformity of soils developed from volcanic rocks in Leyte, Philippines. In this present study, the depth function of ZrO_2 showed that only two of the eight highly weathered soil profiles have developed from non-uniform parent materials and thus it is contrary to the widespread notion that highly weathered tropical soils are polygenetic and developed from heterogenous pre-weathered parent materials (Stolbovoy, 1992; Mohr et al., 1972; Birkeland, 1984).

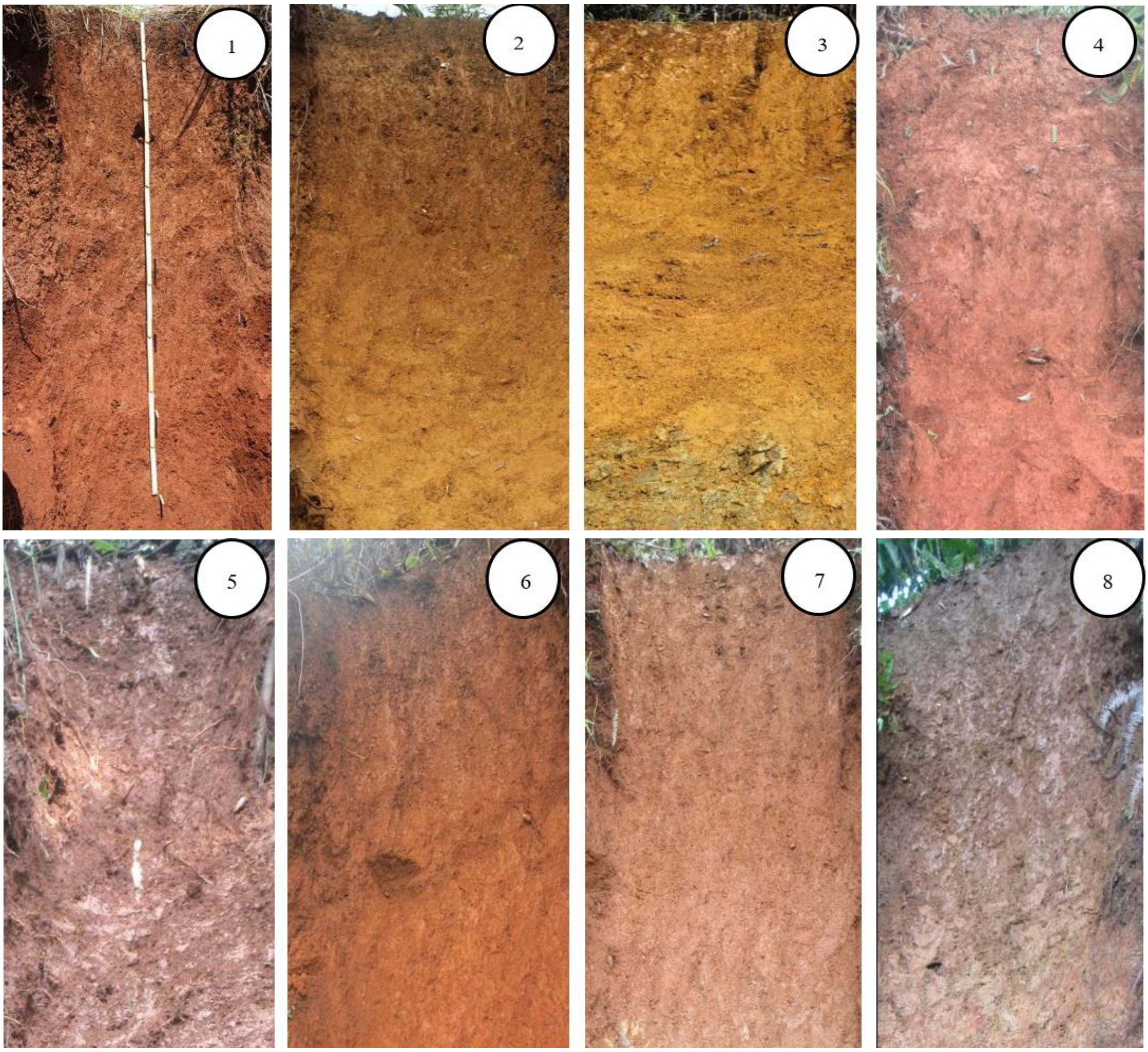

Figure 6. Eight soil profiles showing deep and highly weathered soils in Salcedo, Hernani and Bagacay Samar (Soil profile1-4), Baybay and Silago Southern Leyte (Soil profile 4-8)

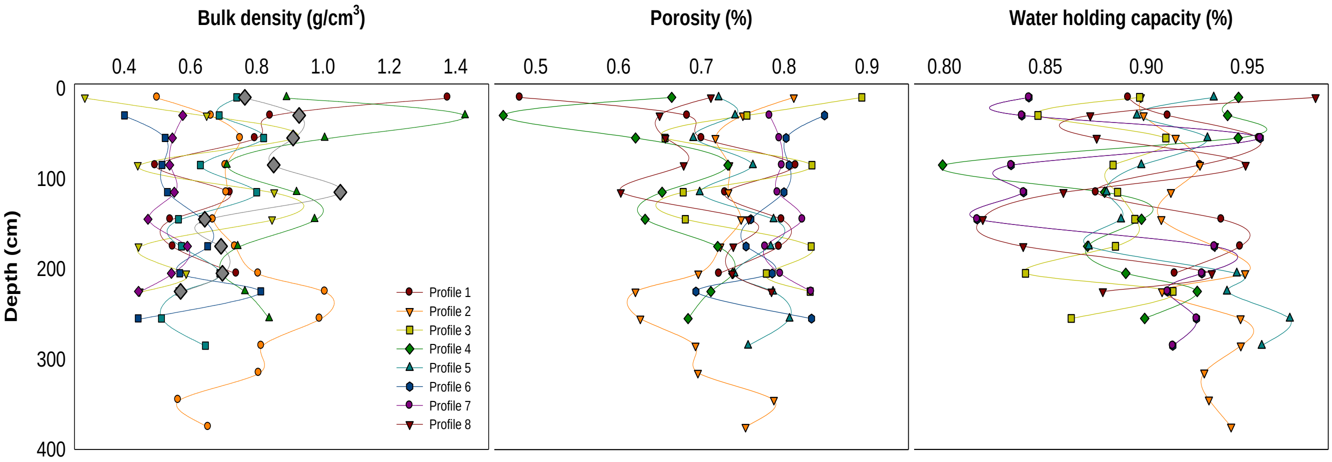

Figure 7. Depth function of bulk density, percent (%) porosity and water holding capacity in deep and highly weathered soils in Leyte and Samar

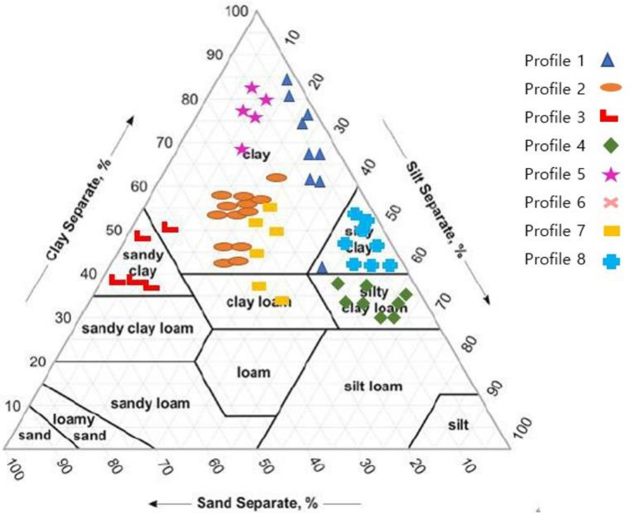

Figure 8. Particle Size Distribution of deep and highly weathered soils in Leyte and Samar

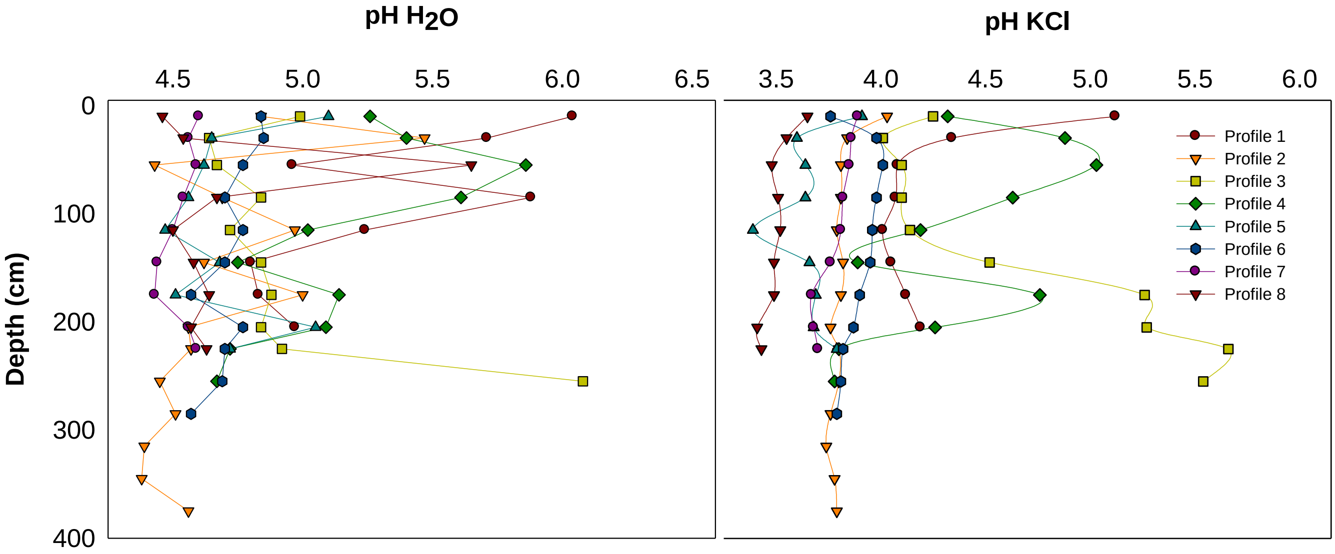

Figure 9. Depth functions of pH values (H_2O and KCl) in deep and highly weathered soils in Leyte and Samar

Composition of the Weathered Residue

Chesworth (1973a) proposed the residua system hypothesis to explain the weathering of silicate rocks. He specified that the weathered products (residua system) would move towards SiO_2 – Al_2O_3 – Fe_2O_3-H_2O system. This hypothesis helps explain the findings of this study for the apparent enrichment of Al_2O_3, Fe_2O_3, and to a lesser extent SiO_2 in the highly weathered soil profiles evaluated. Mohr et al. (1972) reported several profiles of highly weathered soils from Indonesia that showed generally comparable levels of SiO_2, Al_2O_3, and Fe_2O_3 with the soils that we have investigated. Tsozue and Yongue-Fouateu (2017) observed the accumulation of aluminum and iron oxides during the weathering of micaschist in the rainforest of Cameroon. Asio and Jahn (2007) likewise reported SiO_2, Al_2O_3, and Fe_2O_3 enrichment in highly weathered soils from basalt in Leyte, Philippines.

According to Chesworth (1973b), the chemical imprint left upon soil by its parent material diminishes with time. This means that the effect of parent material on derived soil is an inverse function of time. This suggests that weathering of different rocks under identical humid tropical conditions could produce soils of closely similar geochemical compositions.

This explains the findings of the present study in which different parent materials produced closely related soils classified as Oxisols and Ultisols. Mohr et al. (1972) showed examples of highly weathered humid tropical soils having similar mineralogical composition in the clay fraction although they were derived from different parent materials.

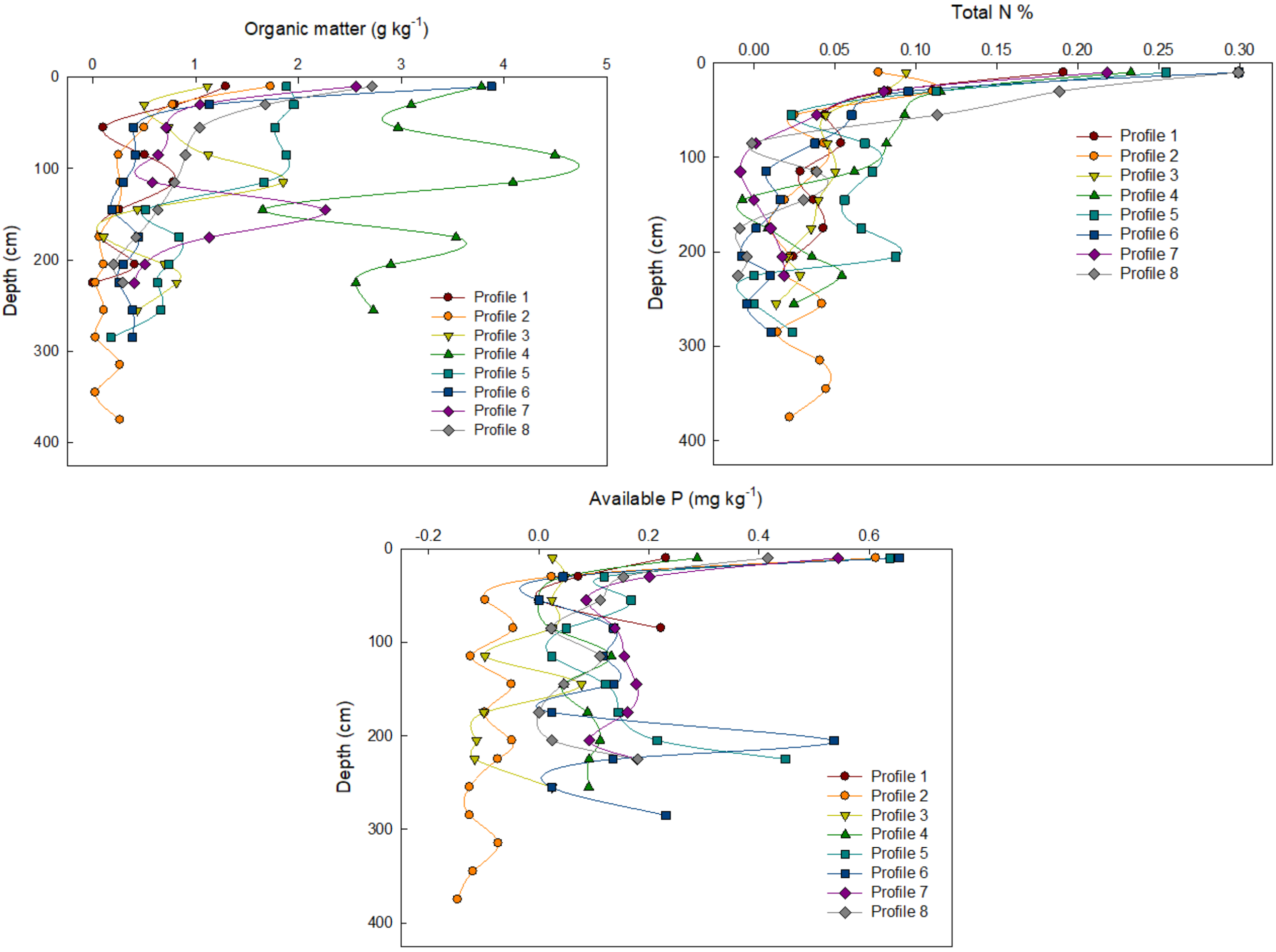

Figure 10. Depth functions of organic matter, total nitrogen (%) and available P of deep and highly weathered soils in Leyte and Samar.

Amounts of Basic Elements (K_2O, CaO, MgO and Na_2O)

Mohr et al. (1972) reported extensive data from various parts of the humid tropics showing heavy losses of K, Ca, Mg, and Na during intense weathering. Asio (1996) and Asio and Jahn (2007) observed that intensive chemical weathering resulted in substantial loss of elements, particularly Ca, Mg, K and Na, during basalt weathering into the deep, clayey, and acidic soil in the study site (Leyte, Philippines). Such heavy losses are due to the high mobility of these basic cations in the weathering environment. According to the Polynov's ion mobility series (Polynov, 1937), Ca is the most mobile followed by Na, then by Mg and K. Studies have shown that the sequence slightly varies depending on environmental conditions. Middelburg et al. (1988) suggested that the Polynov's ion mobility series is applicable only on a global scale but not on smaller scales where the mineralogy of the rock is the predominant factor controlling the mobility of major elements.

Soil Morpho-Physical Properties

The morpho-physical properties of the soils particularly in terms of type of horizons, soil depth, color, texture, structure, and consistence are typical of highly weathered tropical soils (e.g. Juo and Franzluebbers, 2003). The deep solum, reddish color, subangular structure, friable moist consistence, and sticky and plastic wet consistence are all related to the highly weathered nature of the soils (Mohr et al., 1972; Sanchez, 1976; Jahn and Asio, 2006). As was elucidated by Strakhov (1967), the high temperature and high rainfall in the humid tropics enhance the intense weathering resulting in deep soils. The brown and reddish color of highly weathered tropical soils is due to the considerable amounts of iron oxides produced by the intense weathering. The friable consistence is attributed to the excellent aggregation brought about by iron oxides while the sticky and plastic consistence can be explained by the high clay content and the kaolinitic clay mineralogy of the soils (Asio, 1996). The excellent soil aggregation also explains the low bulk density and high porosity of the highly weathered soils evaluated.

Soil Chemical Properties

Highly weathered soils in the humid tropics are generally strongly acidic since they have been subjected to intensive leaching resulting in the excessive loss of bases and nutrients (Sanchez, 1976; Juo and

Franzluebbers, 2003). Highly weathered soils also generally possess variable charge colloids due to the abundance of oxide clays. Mekaru and Uehara (1972) introduced a simple method to determine the net charge of soil colloids and that is the use of pH in H_2O and pH in KCl. When pH in KCl is lower than pH in H_2O, it indicates that the soil colloids net charge is negative. Findings of the study revealed that the soils have a net negative charge which implies that the soils can hold and retain positively charged nutrients. The low organic matter contents of the highly weathered soils suggests a low capacity to sequester carbon which can be ascribed to their clay mineralogy that is dominated by iron oxides and kaolinite clays. In terms of P availability, Jahn and Asio (2006) highlighted that P is the most limiting nutrient in tropical soils. This is due to the soils acidic nature, which results in P fixation by iron and aluminum oxides. It could also be due to the low P stock in the soil from intense weathering that occurred. The low exchangeable bases of all soil profiles indicated that the bases have already been lost by prolonged leaching (please see previous discussion). Previous pedological studies in central Philippines (Asio, 1996; Asio and Jahn, 2006; Navarrete et al., 2007) support the findings of the present study.

Soil Classification

The highly weathered soils studied belong to Ultisols and Oxisols in Soil Taxonomy (Soil Survey Staff, 1999). Ultisols are acidleached soils of warm and humid climates that have a B horizon enriched in clay usually 1:1 and oxide clays. Oxisols are highly weathered soils of warm and humid climates that are infertile and dominated by oxide and low activity clays (Schaetzl and Anderson, 2005). Both soils have low fertility and pose problems for crop production in humid tropical areas especially because they are generally widespread in this part of the world. Soil profiles 1, 2, and 3 have ochric epipedon and oxic endopedon and are classified as Hapludox. Soil profiles 4 and 5 have ochric epipedon and argillic endopedon and are classified as Paleudult. Lastly, soil profiles 6, 7, and 8 have ochric epipedon and argillic endopedon and belong to Hapludult. Paleudults generally have more developed profiles than Hapludults. Soil profiles 4 and 5 are located stable surfaces under rainforests vegetation that have been subject to less human disturbance. This probably explains for their betterdeveloped solum than soil profiles 6, 7, and 8.

Conclusion

Among the soil profiles, only profiles 3 and 8 have developed from non-uniform or heterogeneous parent materials. Findings also revealed generally heavy losses of K_2O, CaO, MgO, and Na_2O from the highly soil profiles evaluated. The amount and profile distribution of K_2O and CaO is below 0.5% in the entire profile of most soils. On the other hand, there is apparent enrichment of Al_2O_3, Fe_2O_3, and to a lesser extent SiO_2 in the highly weathered soil profiles thus supporting the residua hypothesis. In terms of morpho-physical characteristics, the soils have deep solum, reddish color, subangular structure, friable moist consistence, and sticky and plastic wet consistence which are all related to the highly weathered nature of the soils. They also generally have low bulk density and higher porosity due to iron oxides aggregation effect. The strong acidity (pH <5) and negative delta pH values revealed that the soil colloids possess a negative net charge. Nutrient status also showed low contents of organic matter, total N, available P, and exchangeable bases. Majority of the deep and highly weathered soils evaluated have possibly developed from homogenous parent materials. The soils are classified as Hapludox, Hapludult, and Paleudult.

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