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Soils Derived from Ophiolitic Rocks in Northeastern Leyte: Morphological, Physical, and Chemical Properties

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ABSTRACT

Soils that developed from ophiolitic rocks in Leyte, Philippines are relatively unknown. Seven soil profiles were studied at various slope positions in Basper watershed underlain by ophiolitic rock to evaluate the soil morphological, physical-hydrological, and chemical properties. Results show that the soils range from poorly to moderately developed and from shallow to deep soils. The soil profile development appears to be related to the slope positions. Those on the footslope and summit positions had thinner solum while those in the lower backslope developed into deep soils. In addition, the soils are generally clay loam to sandy clay loam in the upper horizon. They tend to be sandy in the lower section of the profile due to the saprolite coming from the ophiolitic parent rock. Physical-hydrological properties such as bulk density values increase with depth which is accompanied by a decrease in total porosity while saturated hydraulic conductivity of surface soils are higher than that in the subsurface soils. In terms of chemical properties, soil pH values vary from 5.9 to 7.10 indicating near neutral soil reaction. Available P, soil organic carbon, total N, as well as the exhangeable K and Na are generally low. Effective CEC measures of the soils range from 10.61 to 25.81 $cmol_c\,kg^{-1}$.

Keywords: Ophiolite, Ultramafic Soils, Soil formation, Soil Characteristics

INTRODUCTION

Ophiolites are pieces of oceanic lithospheric plates that have been thrusted onto the edge of continental plates. They are a distinctive assemblage of mafic to ultramafic rocks (Dilek, 2003). In a completely developed ophiolite, the rock types occur in the following sequence from bottom to top: ultramafic complex, gabbro complex, mafic sheeted dike complex, mafic volcanic complex, and associated rock types (e.g. cherts, shale, limestone) (Dilek, 2003; Huang, 1962). According to Dimalanta *et al.,* (2006) ophiolites occur in several locations in Central Philippines such as Antique, Bohol, Cebu, Leyte, and Samar. The Tacloban Ophiolite Complex in Northeastern Leyte is composed of harzburgite (an ultrabasic rock dominated by olivine and pyroxene), gabbro, sheeted diabase, basalt dike complex, and pillowed and massive basaltic flows. It originated during the Early Cretaceous period with an age of 145.1 ±3.2 Ma (Dimalanta *et al.,* 2006). Due to the heterogeneity of the rock materials within the ophiolite complex, different soils can develop from these materials.

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Baillie *et al.,* (2000), in their study in Palawan, observed that although the ophiolitic crystalline rocks are lithologically heterogeneous, the soils derived from these materials had similar morphologies but considerably different chemical characteristics. D'Amico (2009) noted that among the ophiolitic soils, those that developed from ultramafic rocks have long attracted the interest of soil scientists and ecologists because of their unique vegetation and chemical characteristics particularly their high nickel content.

Primarily due to their mineralogical composition which is characterized by high olivine (Mg, Fe) SiO content, ultramafic rocks are easily weathered especially under the humid tropical environment which in turn affects the rate of soil development (Wyllie, 1969). Moreover, the geochemical composition of these rocks may also influence the properties of the soils derived from them. Until at present, only a few studies have been conducted on the soil chemistry and fertility of ultramafic soils in the Philippines and these were mostly done in Palawan and Sibuyan Islands (Proctor, 2003). The objective of the study was to evaluate the morphological, physical, and chemical properties of soils derived from ophiolitic rocks in Tacloban, Northeastern Leyte.

MATERIALS AND METHODS

A. *Study site*

The study site is located in Basper, Tacloban City, Northeastern Leyte, Philippines. Based on the FAO Guidelines for Soil Description (Jahn *et al.,* 2006), the area can be described as a medium gradient hill. Its vegetation cover is dominated by *Imperata cylindrica* (cogon grass) at its upper slope; a grass-shrub transition at the middle slope; and largely shrubs with some planted *Acacia mangium* trees at the lower slope. This was the study site of the ACIAR Hydrology Project led by Prof. Dr. L.A. Bruijnzeel who came from the Free University, Amsterdam, The Netherlands.

The dominance of cogon grass indicates that the watershed is degraded. This grass persists as a response to periodic burning which was last practiced years before the conduct of this study. This practice and other farming activities were mainly done at the lower slopes of the landscape. In terms of geology, the area belongs to the Tacloban Ophiolite Complex (Dimalanta *et al.*, 2006) (Fig.1). The warmest month is experienced in April with an average temperature of 28.1°C while pronounced wetness occurs in the months of November, December, and January with rainfall of 279.0 mm, 305.3 mm, and 281.17 mm, respectively. The soil moisture regime based on climatic data is udic which implies that soil moisture is available year round while the soil temperature regime is isohyperthermic implying that the annual average temperature is above 22 °C and it does not fluctuate above 5 °C (Soil Survey Staff, 1996). Although there was slight erosion and acceptable drainage from where each profile was located, the steep areas especially those close to soil profiles 3, 4, and 6 experienced periodic landslides particularly during heavy rainfall events consequently eroding the topsoil and subsoil. As constantly observed, minor landslides were common that have further exposed some of the partly weathered parent rocks.

B. *Field Soil Description and Sampling*

Field soil description and sampling were mostly done from September to December 2013. We selected seven soil profiles along the east-facing slope of the ophiolite hill, with at least one soil profile representing the following slope positions: summit, shoulder, upper and lower backslope, and footslope (Fig. 1; Table 1). To examine and sample the profiles, a soil pit with a surface area of 1x1 m and having a depth of at least 1 m was dug manually. Soil profile description followed the international standard FAO Guidelines for Soil Description (Jahn *et al.,* 2006). About one-half kilogram of composite soil sample was obtained from three subsamples collected from every horizon of each soil profile

(Schlichting et al., 1995). Samples were air-dried, ground using a wooden hammer, sieved to pass a 2-mm and 0.425-mm wire mesh, and stored in properly labeled plastic bags.

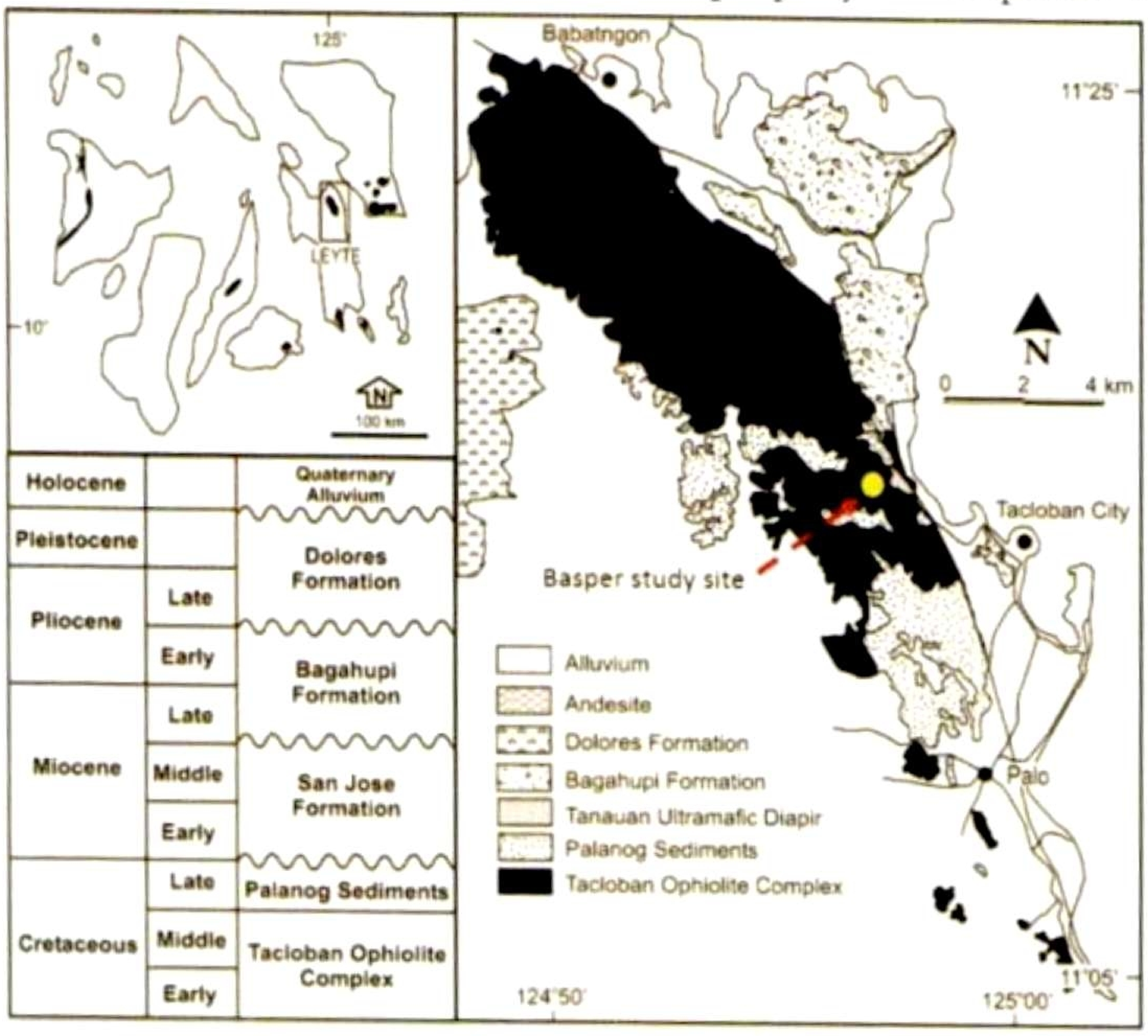

Figure 1. Geologic map showing the age formation of the Tacloban Ophiolite Complex in Northeastern, Leyte (Dimalanta *et al.*, 2006). The Basper study site is indicated by yellow circle.

C. *Laboratory Analysis*

Particle size distribution was analyzed by the Pipette method (Schlichting *et al.*, 1995) after pre-treatment of the soil samples with sodium hypochlorite (NaOCl) to remove organic matter and mechanical dispersion followed by using a Hielscher ultrasonic sonicator. Bulk density was determined by taking three soil cores from each horizon. The same soil cores were used for the total porosity determination according to the method of Schlichting *et al.*, (1995) and the hydraulic conductivity (Ksat) by the Amoozemeter (Amoozegar, 1989). The Amoozemeter (also called Compact Constant Head Permeameter) is a permeameter that can help field scientists run measurements of saturated hydraulic conductivity (Ksat) of soils and fill material at sites that previously proved to be a challenge to measure. It is composed of a set of four constant-head tubes, a 5-liter water reservoir, a flow-measuring reservoir, a water-dissipating unit, and a base housing a three-way valve that connects the two reservoirs and the water-dissipating unit together. The Amoozemeter uses the constant head tubes to keep a constant head in the bore hole and then the water drop from the reservoirs is measured over time. Apart from the field measurements, core samples were collected from each soil profile to determine the Ksat in the laboratory with the use of a Permeameter (Eijkelkamp, 2013).

For the chemical properties, soil pH was determined potentiometrically using distilled water and 0.01 mol/L $CaCl_2$ at a soil-solution ratio of 1:2.5 (ISRIC, 1995); soil organic Carbon (C) by the modified Walkley-Black method (Nelson and Sommers, 1982); total Nitrogen (N) by the micro-Kjeldahl method (ISRIC, 1995); available Phosphorus (P) by the Bray No. 2 method (USDA-NRCS, 1996). Exchangeable Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na) were extracted using 1 N Ammonium acetate (NH_4OA_c) adjusted to pH 7.0 according to the Metson method (Metson, 1956) as described in ISRIC (1995) and quantified by atomic absorption spectrophotometry (Varian Spectra 220 FS). Exchangeable acidity Aluminum and Hydrogen (Al and H) was extracted using 1N Potassium chloride KCl (Thomas, 1982) and followed by titration. Effective Cation

Table 1. Site characteristics of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte.

Site Characteristics	Soil Profile						
	1	2	3	4	5	6	7
Location	Basper watershed, Tacloban, Northeastern Leyte						
Coordinates	N 11° 15' 25.9" E 124° 57' 23.6"	N 11° 15' 25.4" E 124° 57' 23.4"	N 11° 15' 25.5" E 124° 57' 20.8"	N 11° 15' 26.6" E 124° 57' 18.9"	N 11° 15' 30.5" E 124° 57' 19.1"	N 11° 15' 29.6" E 124° 57' 21.9"	N 11° 15' 26.6" E 124° 57' 23.6"
Elevation	64 m asl	71 m asl	91 m asl	118 m asl	141 m asl	122 m asl	76 m asl
Landform	Medium-gradient mountain						
Slope position	Foot slope	Lower backslope	Upper backslope	Shoulder	Summit	Upper backslope	Lower backslope
Slope gradient	Moderately steep			Sloping	Slightly sloping	Moderately steep	
Parent material	Ultramafic rock / Mafic						
Soil moisture regime	Udic						
Soil temperature	Isohyperthermic						
Erosion	Slight	Slight	Slight	Slight	Slight	Slight	Slight
Rock outcrops	Common	Common	None	None	None	None	None
Drainage	Weakly drained	Well drained	Well drained	Well drained	Well drained	Well drained	Moderately drained
Land use	Grassland fallow	Grassland fallow	Grassland fallow	Grassland fallow	Grassland fallow	Grassland fallow	Grassland fallow
Vegetation	Grasses, shrubs, ferns	Grasses, shrubs, broad leaves, ferns	Grasses, shrubs, Herbs, ferns, sedges	Grasses	Grasses, Coconut trees	Grasses, shrubs	Grasses, shrubs, *A. mangium*

Exchange Capacity (Eff. CEC) was calculated by simply adding the values of exchangeable K, Na, Ca, and Mg along with exchangeable acidity (Al and H). The levels of nutrients were described according to the criteria by Landon (1991).

RESULTS AND DISCUSSION

Soil Morphological Properties

Table 2 presents the horizons, color, texture, structure, consistency, presence of roots and rock fragments of the soil profiles investigated. The soils have horizonation varying from Ap-C-R in the footslope position to Ap-Bw-BC-C in the upper backslope, shoulder and summit positions, to Ap-Bt-BC-C in the lower backslope. The A horizons of the soils range in thickness from 12 cm in the shoulder position to 25 cm in the footslope position suggesting the influence of soil erosion on the top soil thickness. Except the soil on the shoulder position which has a hue (dominant spectral color) of 2.5Y (yellow), all the other soils have a hue of 10YR (yellow-red). In terms of soil texture, most of the soil profiles are clay loam on the surface to sandy clay loam in the subsurface. A clearly different soil texture can be observed in the footslope soil which is sandy clay loam on the surface to loamy sand in the subsurface. Most of the soils have subangular blocky structure and leave firm moist consistence. Because of the grass vegetation, most top soils have common fine roots. The presence of many fine roots is restricted to the first three horizons from the surface, this may suggest that the access of nutrients and water is limited to these horizons.

The above-mentioned horizon sequence and texture of the footslope soil confirm its poor development. In contrast, the good development of the lower backslope soil is shown by the horizonation and the soil texture. This is unexpected since the soil is located on erosional surface where run-off is a common occurrence during and after heavy rainfall events. On the other hand, the relatively poor development of the summit soil suggests that the surface was affected by past soil erosion.

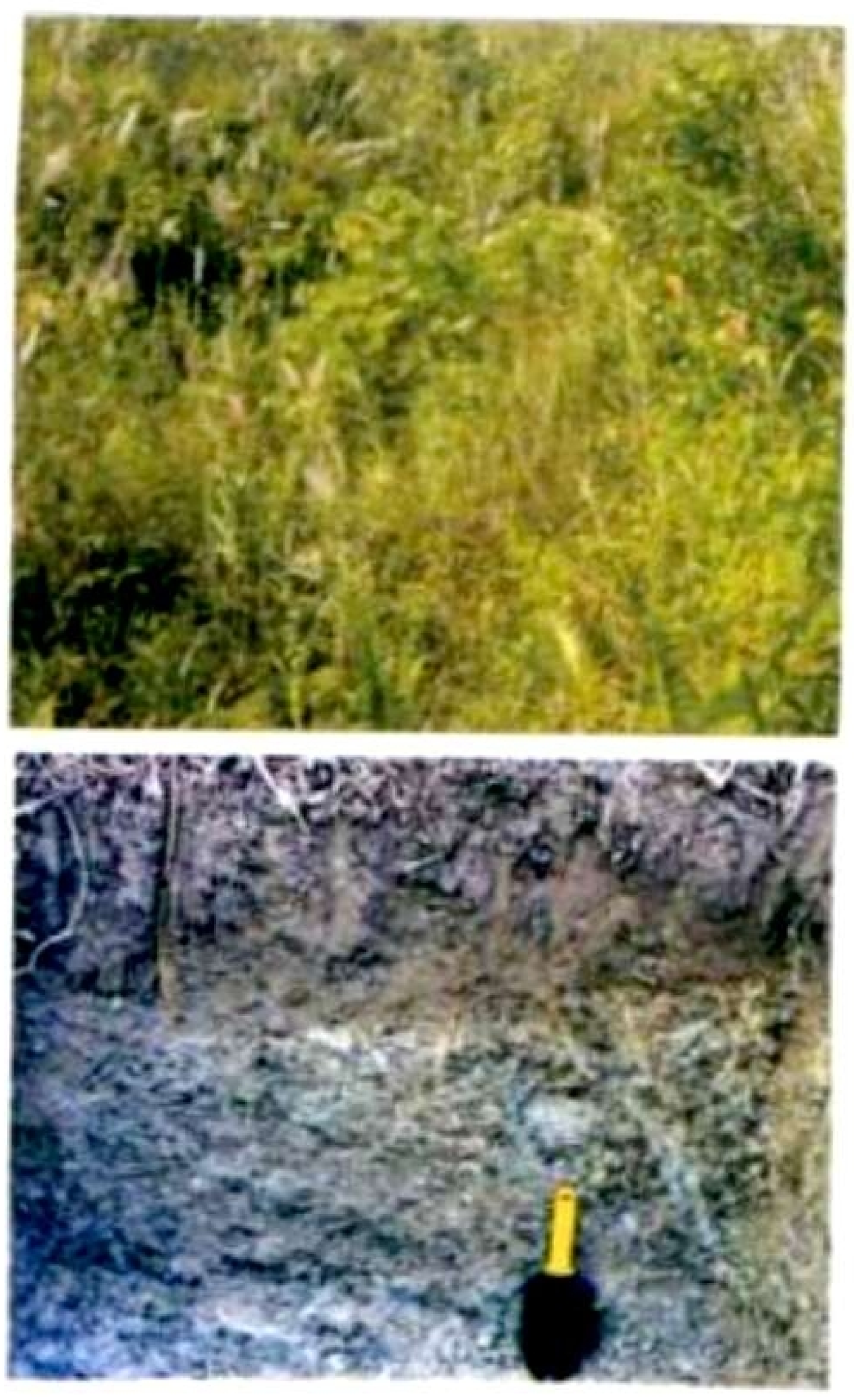

Figure 2a. Soil profile 1 in the footslope position showing a thin solum overlying the greenish colored ophiolitic rock.

Figure 2b. The moderately deep soil profile 2 showing a massive and clayey solum.

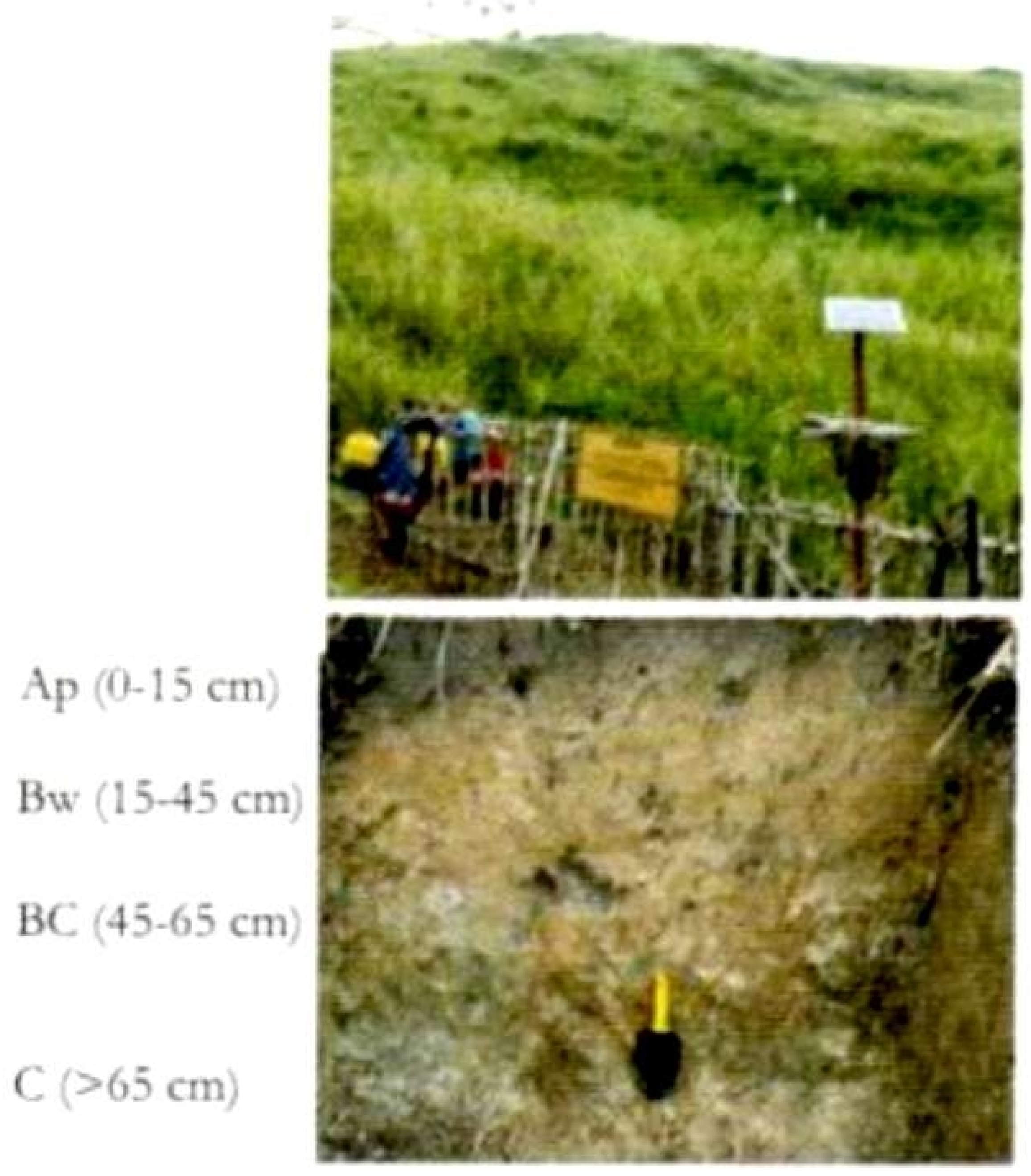

Figure 2c. The moderately deep soil profile 3 in the upper backslope position.

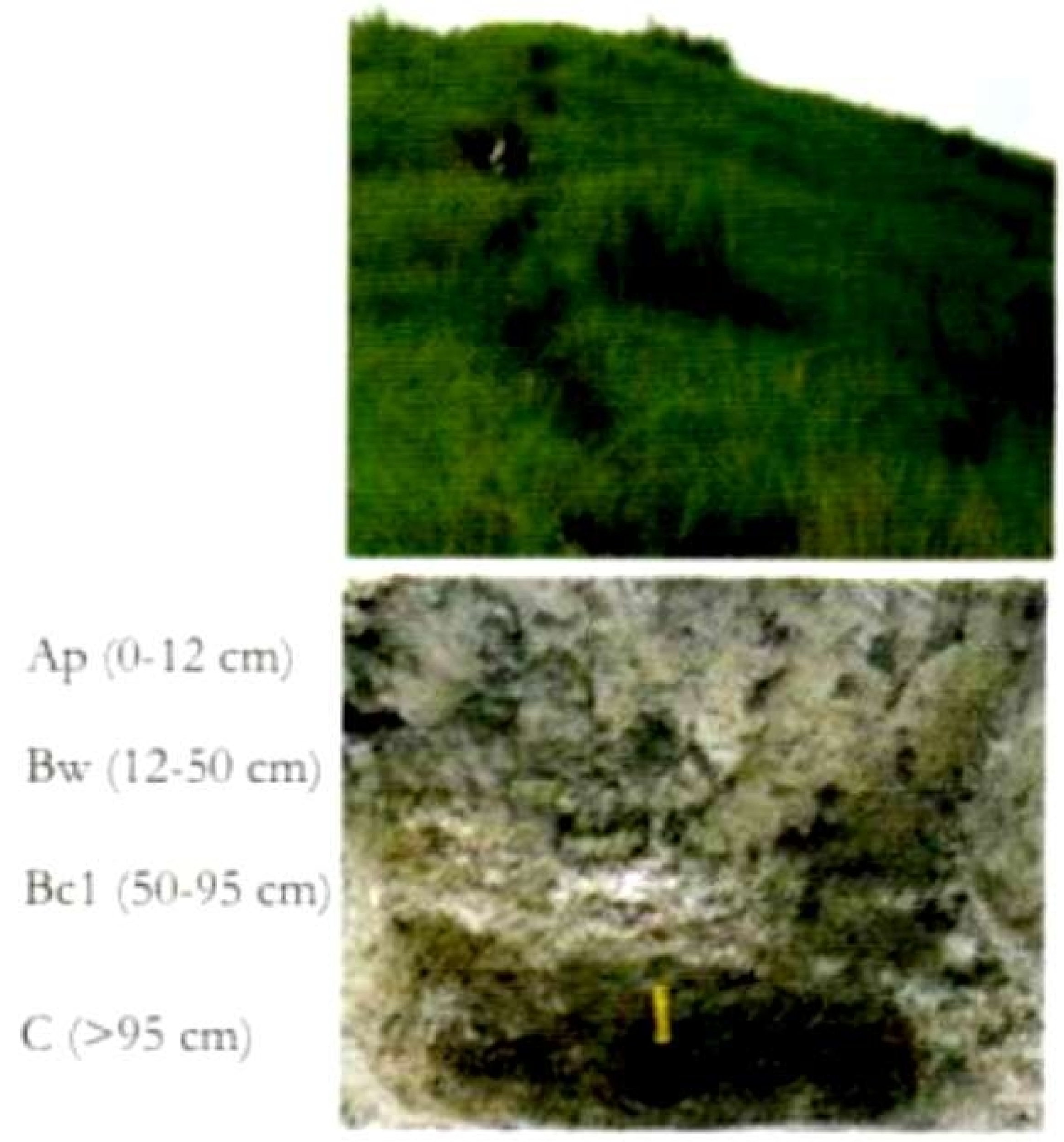

Figure 2d. Soil profile 4 located on the shoulder position.

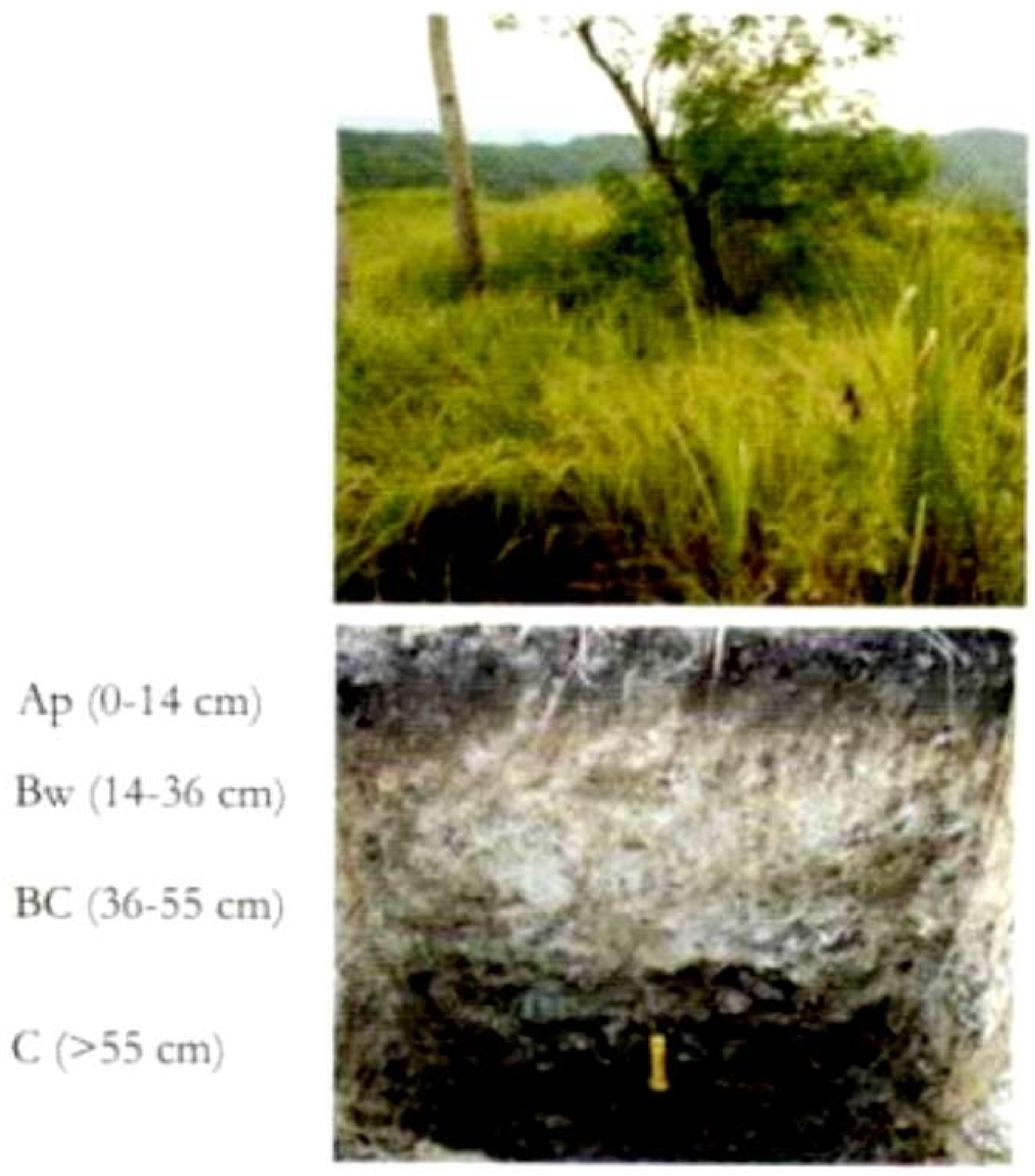

Figure 2e. The moderately deep soil profile 5 in the summit position.

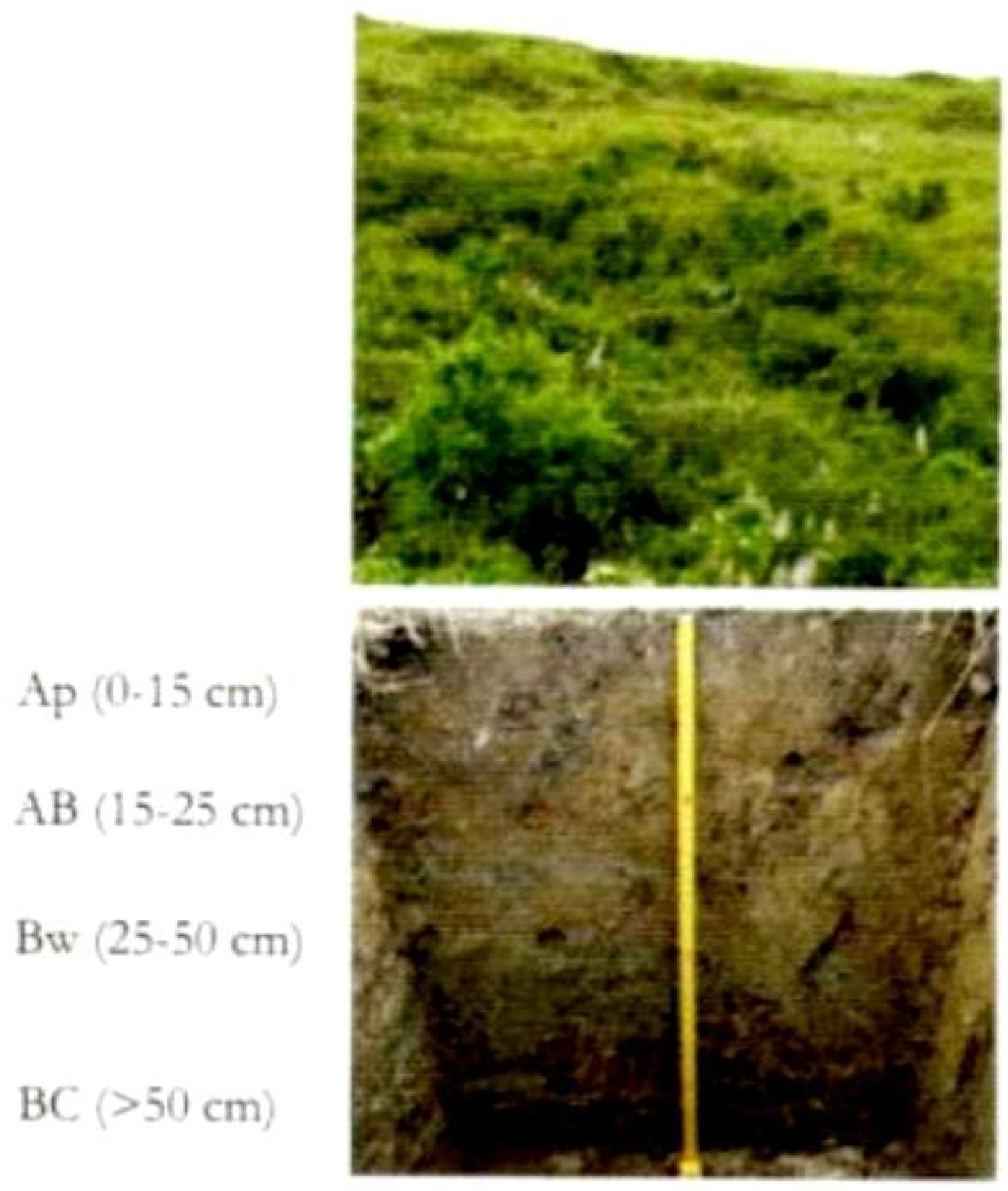

Figure 2f. The moderately developed soil profile 6 in the upper backslope position.

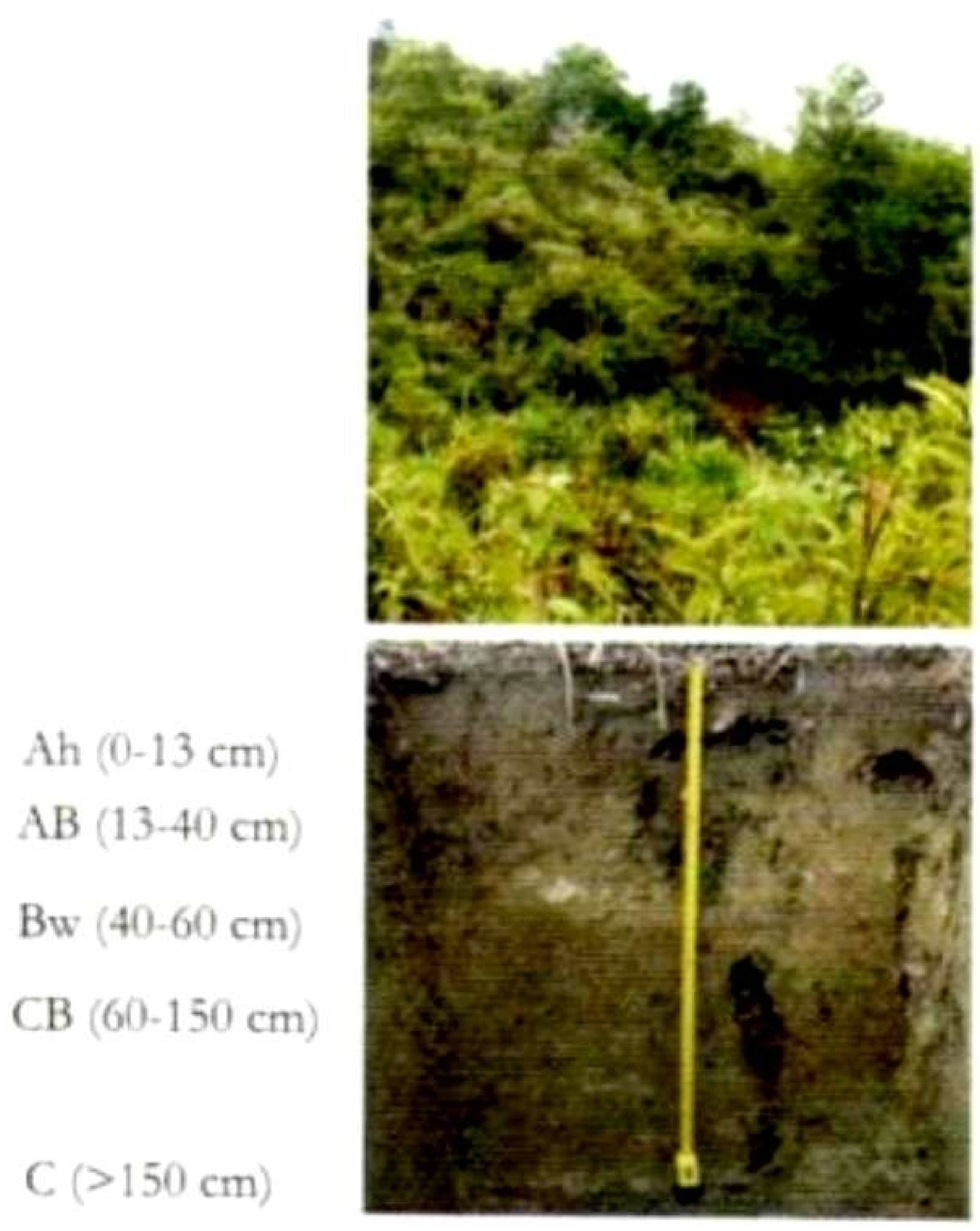

Figure 2g. The deep soil profile 7 in the lower backslope position under shrub and *A. mangium* vegetation cover.

Table 2. Morphological characteristics of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte.

Soil Profile	Soil Horizon	Depth (cm)	Soil Color (Munsell notation)	Texture	Structure	Consistence		Roots	Boundary	Rock fragments
						Moist	Wet			
1	Ap	0 - 25	10YR 2/2 (very dark brown)	SCL	1msbk	fi	st & pl	cvf, cf, cm	cs	n
	C	25 - 56	10YR 5/1 (gray)					vfvf	cs	c
	R	> 56	10YR 6/2 (olive gray)					n		c
2	Ap	0 - 12	10YR 3/2 (brown black)	SiC	1csbk	fi	st & pl	cf, fm, fc	cs	n
	Bt	12 - 52	10YR 6/2 (light brownish gray)	C	2csbk	vfi	st & pl	cf, fm, fc	cw	n
	BC	52 - 90	2.5YR 5/4 (yellowish brown)	SC	1csbk	vfi	sst & spl	ff, fm	gw	
	C_1	90 - 100	10YR 6/2 (olive gray)	SC	1csbk	fi	sst & spl	n		
	C_2	100 - 120	10YR 6/3 (pale brown)	SC		fi				
	C_3	120 - 140	10YR 5/2 (grayish brown)	CL		fr-fi				
	C_4	140 - 160	10YR 4/4 (dark yellowish brown)	SiL		fi				
3	Ap	0-15	10YR 3/1 (very dark gray)	SiC	1csbk	vfi	sst & spl	cvf, cf, fm	cw	n
	Bw	15 - 45	10YR 5/2 (grayish brown)	SC	1csbk	vfi	st & pl	fvf	gw	n
	BC	45 - 65	10YR 6/1 (gray)	SC	1csbk	vfi	st & pl	vff	gw	n
	C1	65 - 90	5Y 6/4 (olive yellow)	SC	1msbk	fi	st & pl	n		
	C2	90 - 110	10YR 6/2 (light brownish gray)	CL		fi	sst & spl			
3	C_3	110 - 130	10YR 7/3 (very pale brown)	C		vfi	vst & vpl			
3	C_4	130 - 150	10YR 6/3 (pale brown)	SiC		vfi	st & pl			
4	Ap	0 - 12	2.5Y 3/1 (brownish black)	SiC	1csbk	fi	sst & spl	cvf, cf, cm	gw	n
	Bw	12 - 50	2.5Y 5/3 (yellowish brown)	C	2csbk	vfi	st & pl	ff	cs	n
	BC1	50 - 70	2.5Y 5/3 (yellowish brown)	SC	1msbk	fi	sst & spl	vf	cw	n
	BC2	70 - 95	2.5Y 5/3 (yellowish brown)	SC	1msbk	fi	sst & spl	n		

Table 2. Continuation.

Soil Profile	Soil Horizon	Depth (cm)	Soil Color (Munsell notation)	Texture	Structure	Consistence		Roots	Boundary	Rock fragments
						Moist	Wet			
4	CB1	95 - 115	10YR 4/6 (light brownish gray)	SC		fi	st & pl			
	CB2	115 - 135	10YR 7/3 (very pale brown)	LS		fi	sst & spl			
	CB3	135 - 155	10YR 6/2 (light brownish gray)	SiCL		fi	sst & spl			
	CB4	155 - 175	10YR 4/1 (dark gray)	SC		fi	sst & spl			
5	Ap	0 - 14	10YR 3/1 (brownish black)	SiC	1msbk	fi	st & pl	cvf, cf, cm	cs	n
	Bw	14 - 36	10YR 4/4 (dark yellowish brown)	SiC	1msbk	fi	st & pl	fvf, ff	gw	n
	BC	36 - 55	10YR 5/6 (yellowish brown)	SC	1msbk	fi	st & pl	vff	cw	n
	C1	55 - 90	2.5Y 5/3 (yellowish brown)	LS	1msbk	fi	st & pl	n		c
	C_2	90 - 110	10YR 4/3 (dark brown)	LS		fi	sst & spl			c
6	Ap	0 - 15	10YR 3/3 (dark brown)	SiC	1fsbk	fi	st & pl	cvf, fm	cs	n
	AB	15 - 25	10YR 3/6 (dark yellowish brown)	SiC	2msbk	fi	vst & vpl	ff	cw	f
	Bw	25 - 50	10YR 6/2 (light brownish)	SC	1msbk	vfi	vst & vpl	vf	cw	c
	BC_1	50 - 80	10YR 5/6 (yellowish brown)	SC	1msbk	vfi	st & pl	vf	cw	m
	BC_2	80 - 120	10YR 5/8 (yellowish brown)	SC	1fsbk	vfi	st & pl			m
	BC_3	120 - 140	10YR 5/6 (yellowish brown)	LS		fi	sst & spl			
	BC_4	140 - 160	10YR 4/4 (dark yellowish brown)	SC		fi	sst & spl			
7	Ah	0 - 13	10YR 2/1 (black)	CL	1msbk	fi	sst & spl	cvf, cf	cw	n
	AB	13 - 40	10YR 5/6 (yellowish brown)	C	2csbk	fi	st & pl	ff, fc	cw	n
	Bw	40 - 60	2.5Y 4/6 (olive brown)	SiCL	2csbk	fi	sst & spl	ff	gw	n
	CB_1	60 - 110	2.5Y 4/6 (olive brown)	SL	2csbk	vfi	sst & spl	ff		
	CB_2	110 - 130	10YR 4/6 (dark yellowish brown)	SiC		fi	sst & spl	n		

Table 2. Continuation.

Soil Profile	Soil Horizon	Depth (cm)	Soil Color (Munsell notation)	Texture	Structure	Consistence		Roots	Boundary	Rock fragments
						Moist	Wet			
7	CB_3	130 - 150	10YR 4/6 (dark yellowish brown)	SiC		fi	sst & spl			
	C	150 - 170	10YR 6/3 (pale brown)	CL		fi	sst & spl			

Abbreviations

Texture:

SC- Sandy Clay
SCL- Sandy Clay Loam
SiCL- Silty Clay Loam
SiL- Silt Loam
SiC- Silty Clay
C- Clay
CL- Clay loam
SC- Sandy clay
LS- Loamy sand

Structure:

1msbk- weak medium subangular blocky
2msbk- moderate medium subangular blocky
1csbk- weak coarse subangular blocky
2csbk- moderate coarse subangular blocky
1fsbk- weak fine subangular blocky

Consistence:

Moist

fi- firm
vfi- very firm
fr- friable

Wet

nst- non sticky
st- sticky
sst- slightly sticky
vst- very sticky
npl- non plastic
pl- plastic
spl- slightly plastic
vpl- very plastic

Roots:

Size

n- none
vfvf- very few very fine
fvf- few very fine
vff- very few fine
ff- few fine

Abundance

fc- few coarse
fm- few medium
cf- common fine
cvf- common very fine
cm- common medium

Boundary:

as- abrupt smooth
cs- clear smooth
ds- diffuse smooth
cw- clear wavy
dw- diffuse wavy

Rock fragments:

n- none
f- few
c- common
m- many

C. Soil physical and hydrological properties

1. *Soil texture*

Soil texture, the relative proportion of sand, silt and clay particles, influences the fertility, water relations, mechanical resistance, and erodibility of the soil. Except for the footslope soil (Soil Profile 1) and the shoulder soil (Soil Profile 4) which have high sand and clay contents, respectively, in the A horizon, all the other soils examined have generally equal distribution of sand, silt and clay in the A horizon and thus have clay loam texture (Table 3 and Fig 3). The lower backslope soil (Soil Profile 2) has a considerable clay increase in the B horizon and qualifies as an argillic (Bt) horizon. Except Soil Profile 2, all the soils are weakly developed suggesting the possible role of soil erosion in impeding soil development.

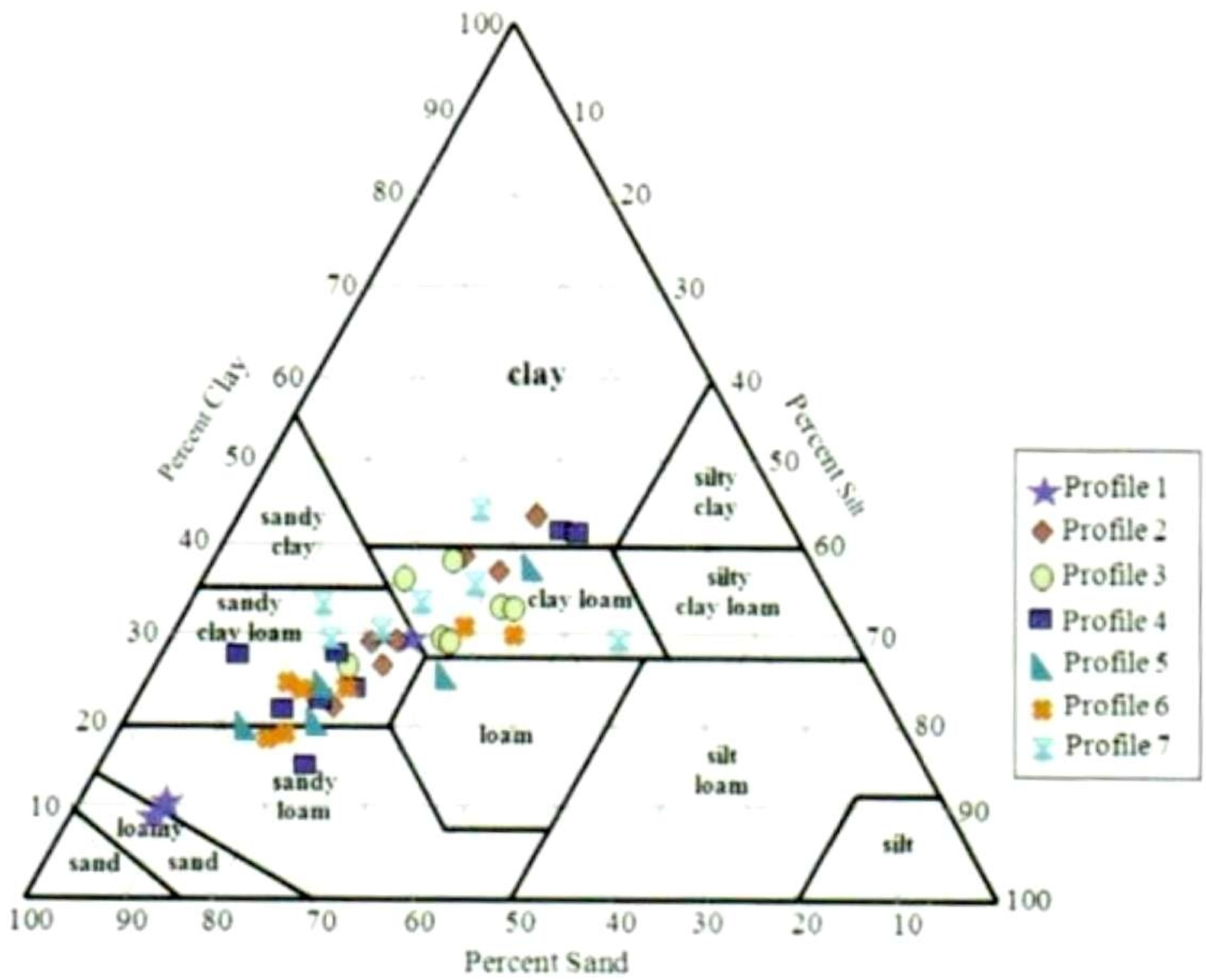

Figure 3. Particle size distribution and textural classes of horizons from the studied soil profiles derived from ophiolitic rock in Basper, Tacloban, Northeastern Leyte

Table 3. Particle size distribution of the soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte.

Soil Profile	Soil Horizon	Depth (cm)	Particle Size Distribution (%) Sand	Silt	Clay	Textural Class
1	Ap	0 - 25	45.5	25.7	28.8	Sandy clay loam
	C	25 - 56	78.0	9.5	12.5	Sandy loam
	R	> 56	-	-	-	-
2	Ap	0 - 12	33.0	30.8	36.2	Clay loam
	Bt	12 - 52	27.0	30.0	43.0	Clay
	BC	52 - 90	38.5	25.00	36.5	Clay loam
	C_1	90 - 100	58.0	20.5	21.5	Sandy clay loam
	C_2	100 - 120	50.7	21.5	27.8	Sandy clay loam
	C_3	120 - 140	50.5	24.2	25.3	Sandy clay loam
	C_4	140 - 160	46.7	24.00	29.3	Sandy clay loam
3	Ap	0-15	34.7	31.8	33.5	Clay loam

Table 3. Continuation.

Soil Profile	Soil Horizon	Depth (cm)	Particle Size Distribution (%) Sand	Silt	Clay	Textural Class
	Bw	15 - 45	35.0	26.00	39.0	Clay loam
	BC	45 - 65	44.5	19.5	36.0	Clay loam
	C_1	65 - 90	54.5	20.5	25.0	Sandy clay loam
	C_2	90 - 110	43.5	27.2	29.3	Clay loam
	C_3	110 - 130	44.0	29.00	27.0	Clay loam
	C_4	130 - 150	32.8	33.5	33.8	Clay loam
4	Ap	0 - 12	22.5	34.00	43.5	Clay
	Bw	12 - 50	23.2	36.00	40.8	Clay
	BC_1	50 - 70	53.7	19.00	27.3	Sandy clay loam
	BC_2	70 - 95	63.0	16.00	21.0	Sandy clay loam
	CB_1	95 - 115	58.2	20.3	21.5	Sandy clay loam
	CB_2	115 - 135	65.7	7.3	27.0	Sandy clay loam
	CB_3	135 - 155	54.5	22.00	23.5	Sandy clay loam
	CB_4	155 - 175	65.0	21.3	13.7	Sandy loam
5	Ap	0 - 14	30.5	33.2	36.3	Clay loam
	Bw	14 - 36	44.5	29.00	26.5	Loam
	BC	36 - 55	57.2	18.8	24.0	Sandy clay loam
	C_1	55 - 90	68.2	13.3	18.5	Sandy loam
	C_2	90 - 110	60.7	19.3	20.0	Sandy loam
6	Ap	0 - 15	36.0	33.5	30.5	Clay loam
	AB	15 - 25	39.0	29.5	31.5	Clay loam
	Bw	25 - 50	60.7	17.3	22.0	Sandy clay loam
	BC1	50 - 80	55.5	21.7	22.8	Sandy clay loam
	BC2	80 - 120	66.5	14.00	19.5	Sandy loam
	BC3	120 - 140	65.7	16.3	18.0	Sandy loam
	BC4	140 - 160	60.5	16.5	23.0	Sandy clay loam
7	Ah	0 - 13	35.7	27.3	37.0	Clay loam
	AB	13 - 40	25.7	48.00	26.3	Clay loam
	Bw	40 - 60	43.2	23.8	33.0	Clay loam
	CB1	60 - 110	54.5	16.7	28.8	Sandy clay loam
	CB2	110 - 130	31.2	26.3	42.5	Clay
	CB3	130 - 150	52.7	13.8	33.5	Sandy clay loam
	C	150 - 170	47.2	22.00	30.8	Sandy clay loam

2. *Bulk Density*

Soil bulk density refers to the dry weight of soil per unit soil volume. Results reveal that surface horizons have generally lower bulk density values than the subsurface horizons (Fig. 4). This has favored the growth of shallow rooted vegetation, mostly grasses, at the upper solum of the profile. Moreover, it also suggests the role of organic matter and biological activity in improving soil aggregation resulting in lower bulk density values. The intermediate (>1.40 g/cm) bulk density values of the subsoils indicate that they are generally compact thus, restricting root penetration and water movement at deeper depth.

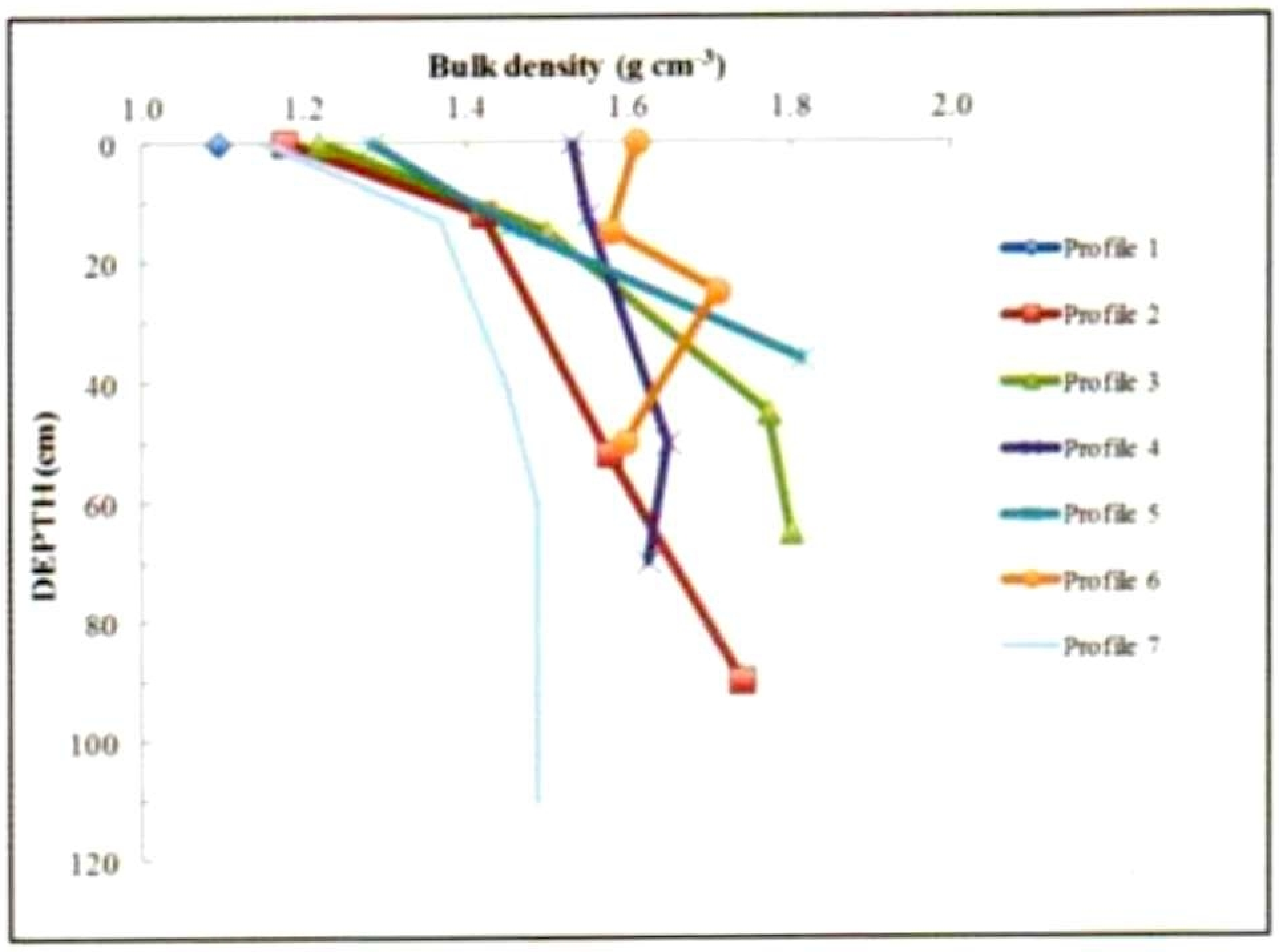

Figure 4. Depth function of bulk density (g cm^{-3}) of soils developed from ultramafic rock in Basper, Tacloban, Northeastern Leyte (n=49)

3. *Total Porosity*

Total porosity is an estimate that is useful in quantifying the amount of soil pores including their size distribution (Landon, 1991). Total air space, on one hand, is equivalent to the volume percentage water content of soil at maximum saturation whereby, the volume of water approximates the amount of pore space and is used to estimate total porosity (Foth, 1990). Most of the soils investigated reveal decreasing total porosity with soil depth confirming its contrasting trend with bulk density values (Fig. 5). These results pose problematic root penetration as well as impeded air and water movement in the subsoils.

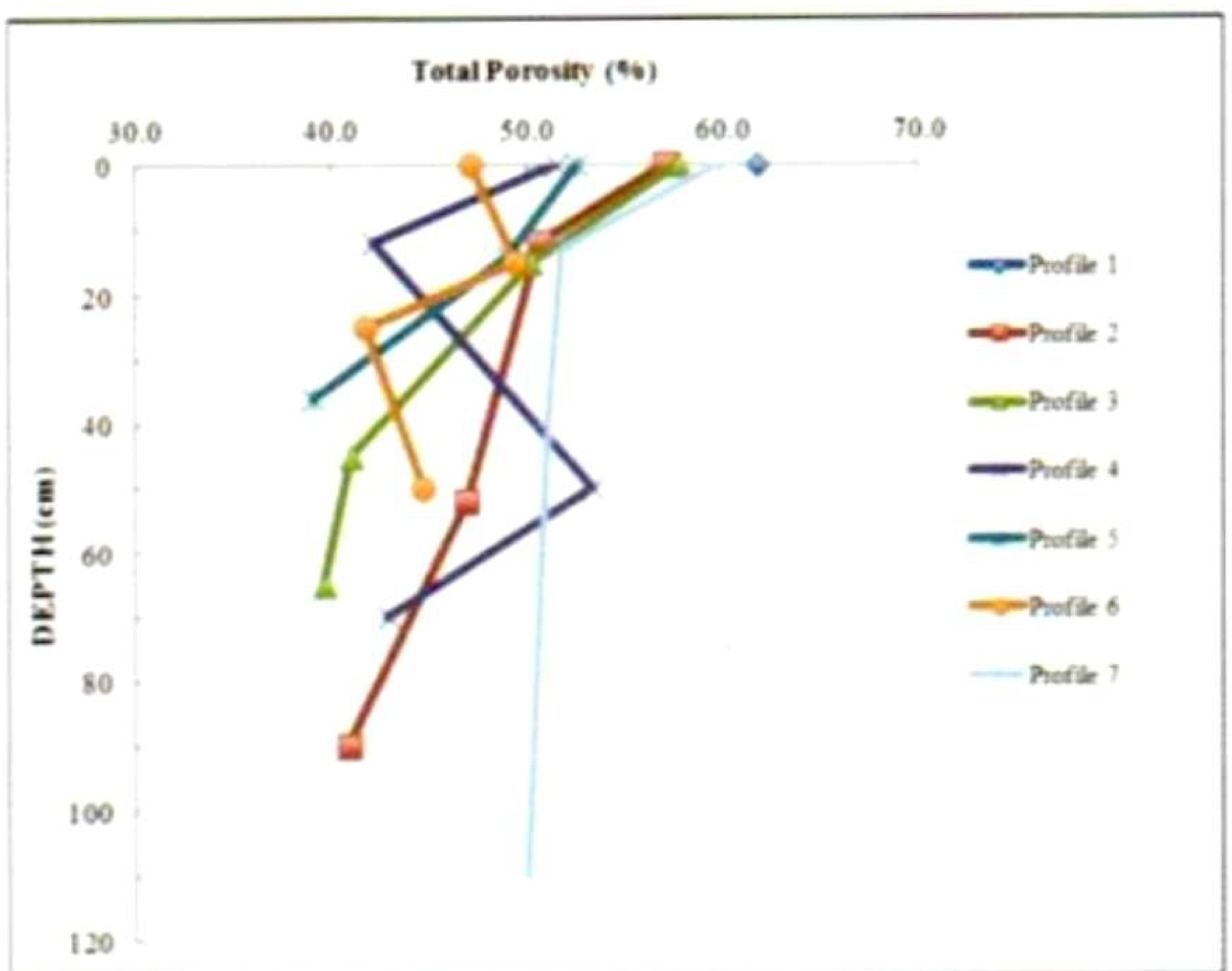

Figure 5. Depth function of total porosity (%) of soils developed from ultramafic rock in Basper, Tacloban, Northeastern Leyte (n=49)

4. *Saturated hydraulic conductivity (Ksat)*

Water in soils is seldom in equilibrium since rainfall and evapotranspiration always disturb any equilibrium. Thus, soil water is commonly in motion and always towards the lowest potential. There are three types of water movement in soils: saturated flow, unsaturated flow, and vapor flow (Kutilek and Nielsen, 1994).

Ksat is the most common reference datum to compare water movement in different soils, layers, or materials. It is a quantitative measure that has become the industry standard. The following classes are given by the USDA Soil Survey Manual (Soil Survey Staff, 1993) for different values of Ksat (cm hr^{-1}) measured in the field: very high (>36.0), high (3.60-36.0), moderately high (0.360-3.60), moderately low (0.0360-0.360), low (0.00360-0.0360), very low (<0.00360).

Table 4 presents the Ksat in Basper determined by Amoozemeter in the field and by permeameter in the laboratory after collection of soil cores from the study site. As shown in Table 4, Ksat values measured by the permeameter in the laboratory are generally higher for a given soil than the Ksat determined in the field by the Amoozemeter. Ksat values of the surface soil horizons determined by the Amoozemeter are moderately low to moderately high except for Soil Profile 6 which has very low (zero) values in the entire soil profile. The Ksat values of the surface horizons of most soils in the watershed are also higher than those of the subsurface horizons. This is attributed to better aggregation of the soil surface brought about by higher organic C content (see discussion on bulk density and porosity). This condition enhances relatively fast water infiltration but because the subsoil is compact, water tends to move laterally (also enhanced by sloping topography) which partly explains the landslide-prone nature of the soils in the watershed. It can also be seen that the Ksat measured both in the field and in the laboratory slightly agree with common Ksat values obtained in soils with different textures (Table 5).

Table 4. Saturated hydraulic conductivity (Ksat) measurements of soils developed from ultramafic rock in Basper, Tacloban, Northeastern Leyte

Profile No.	Depth (cm)	Permeameter	Profile No.	Depth (cm)	Amoozemeter
		Ksat (cm hr^{-1})			Ksat (cm hr^{-1})
Profile 1			Profile 1		
A	0-12	0.065		0-25	0.931
C	40-60	0.000		25-50	0.081
R	>60	4.432		50-75	0.095
Profile 2			Profile 2		
Ap	0-12	1.108		0-25	0.194
Bt	12-52	0.292		25-50	0.429
BC	52-90	0.000		50-75	0.004
C	> 90	0.013		75-100	0.026
Profile 3			Profile 3		
Ap	0-15	0.183		0-30	0.040
Bt	15-45	0.008		30-60	0.123
BC	45-65	0.317		60-85	0.106
C	>65	1.629		85-100	0.171
Profile 4			Profile 4		
Ap	0-12	0.921		0-30	0.038
Bt	12-50	0.004		30-60	0.085
Profile 5			Profile 5		
Ap	0-14	11.750		0-30	0.785
Bw	14-36	7.479		30-50	3.553

Table. 4 Continuation.

Profile No.	Depth (cm)	Permeameter Ksat (cm hr^{-1})	Profile No.	Depth (cm)	Amoozemeter Ksat (cm hr^{-1})
Profile 6			Profile 6		
Ap	0-15	2.117		0-25	0.000
BC1	15-37	0.000		25-60	0.000
BC2	37-85	0.004			
C	>85	1.233			
Profile 7			Profile 7		
Ah	0-15	11.917		0-30	0.105
Bt	15-40	69.583		30-50	0.797
Bw	60-105	0.000		50-90	0.006

Table 5. Saturated hydraulic conductivity of soils of various textures from field measurements (Radcliffe and Rasmussen, 2000)

Soil Texture	Ksat (cm hr^{-1})	Soil Texture	Ksat (cm hr^{-1})
Sand	21.00	Clay loam	0.23
Loamy sand	6.11	Sandy clay	0.12
Sandy loam	2.59	Silty clay loam	0.15
Sandy clay loam	0.43	Silty clay	0.09
Loam	1.32	Clay	0.06
Silt loam	0.68		

D. *Soil Chemical Properties*

1. *Soil pH*

By definition, soil pH is a measure of the negative logarithm of the hydrogen ion activity in the soil solution (Robarge, 2008). In simple words, it is an indicator of the relative acidity and alkalinity of the soil and is a key soil property that regulates nutrient availability, soil microorganism activity, and many soil chemical processes.

Figure 6 reveals that the ophiolitic soils in the study site have generally near neutral pH (H_2O) ranging between 5.90 and 7.10 with a mean of 6.69. On one hand, values tend to increase with depth suggesting the effect of Ca and Mg from the ultramafic rock on the pH of the soils (Fig. 6). On the other hand, pH values measured in 0.01M $CaCl_2$ are 0.70 to 1.70 pH units lower than those determined using water (Fig. 7). As observed, less variation of either pH occurs with soil depth. Our values correspond to those reported from the dark clay ultramafic soils in Palawan (Baillie et al., 2000).

2. *Soil Organic C and Total N*

Figure 8 presents the depth function of soil organic carbon (SOC) in the different soil profiles in the Basper watershed. As can be seen, SOC contents range from 0.14 to 3.15 percent which can be considered as low (Fig. 8). SOC can be converted into soil organic matter by multiplying with a factor of 1.724.

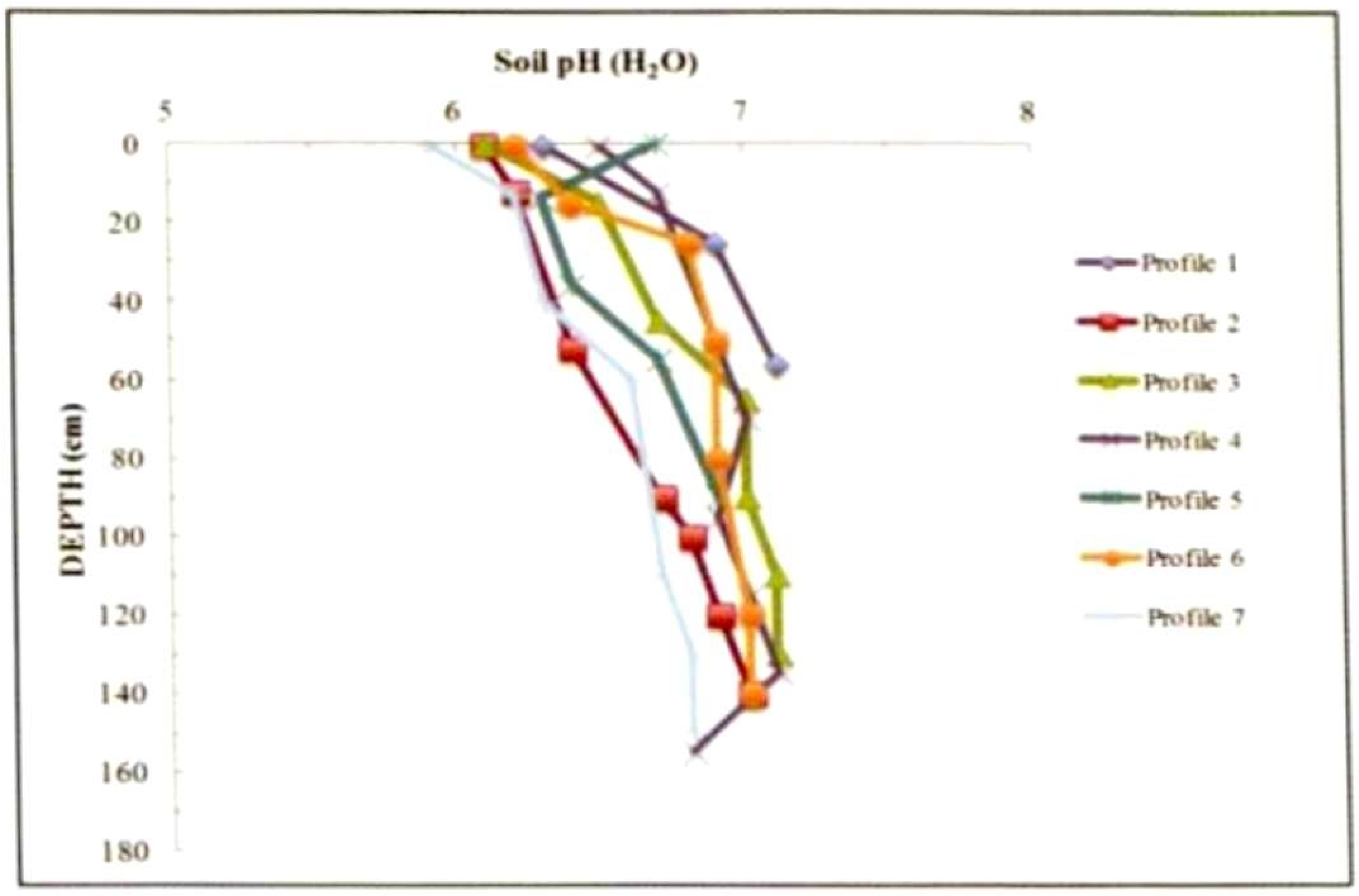

Figure 6. Depth function of pH (1:2.5) of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte (n=45)

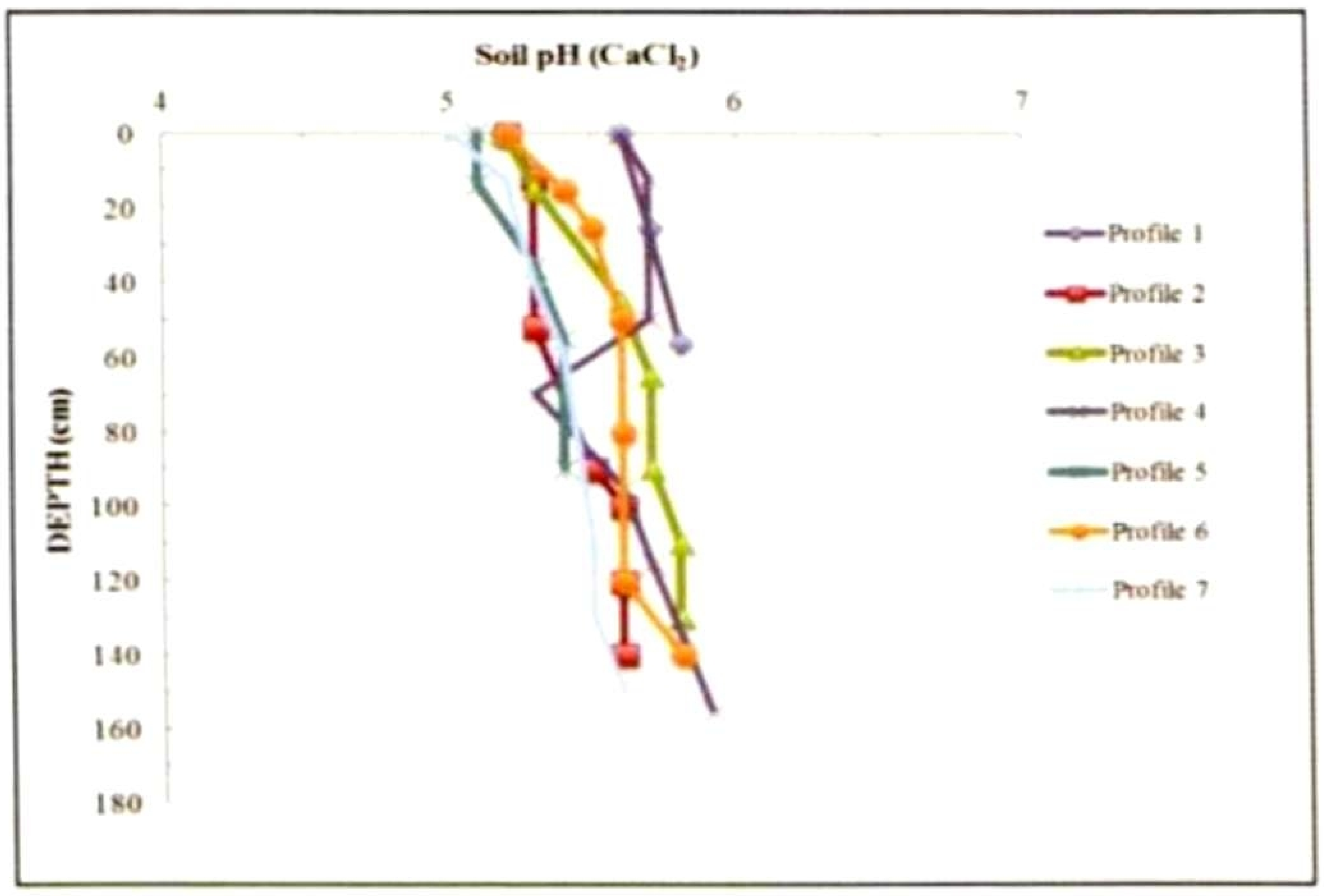

Figure 7. Depth function of pH in 0.01M CaCl(1:2.5) of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte (n=45)

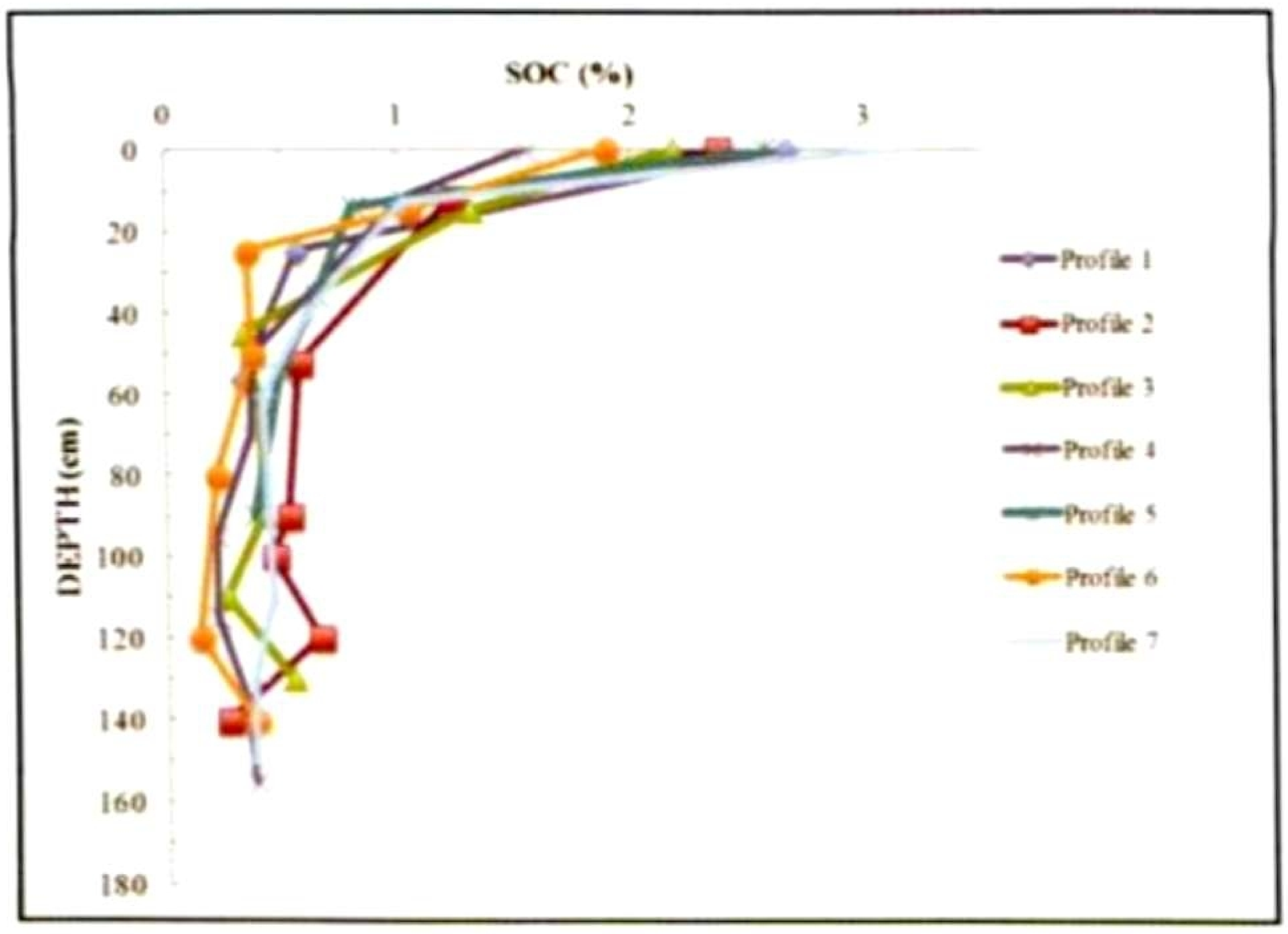

Figure 8. Depth function of SOC (%) of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte (n=45)

As illustrated from the figure, there is a smooth decrease of SOC with depth. Topsoil (A horizon) SOC values from this study are comparable with those from the ophiolitic soils in Palawan (Baillie et al., 2000) while subsoil SOC values are within the range of the serpentinic soils from Taiwan (Hsue et al., 2007). The low SOC contents of the soils studied suggest the influence of vegetation cover and land use. The site experienced shifting cultivation in the past which resulted in soil degradation and the persistence of cogon grass. As is widely known, cogonal areas are regularly subjected to periodic burning which depletes the organic carbon content of the soil.

Due to the fact that soil organic matter is the primary source of soil N, SOC and total N share a similar pattern with soil depth. Total N values range from 0.03 to 0.31 percent with an average of 0.10 percent and are higher, as expected, in the surface horizons (Fig. 10).

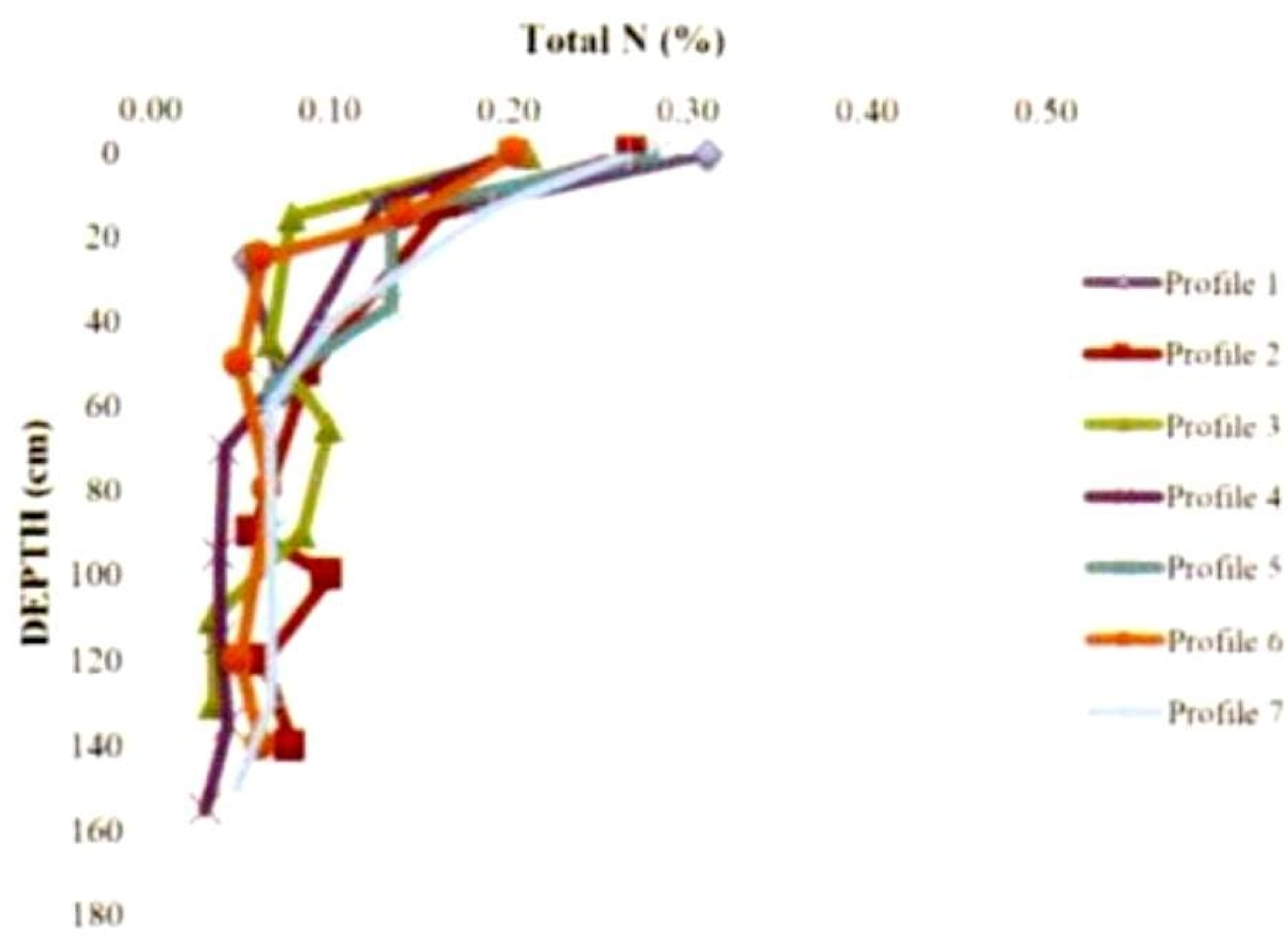

Figure 9. Depth function of Total N (%) of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte (n=45)

3. *Available P*

Table 6 shows the quantity of available P present in the ultramafic soils located at different slope positions. The solubility of P from the surface soils and subsoils differ between 0.12 to 8.16 mg kg^{-1} which represents the deficiency of the nutrient at any horizon. This indicates that P is a limiting nutrient for plant growth in the degraded ecosystem but there is moderate P stock in the lower part of the soil profile coming from the parent rock which could be brought into the soil surface by biogeocycling processes. Our results agree with the studies on other ultramafic soils from the Philippines (Baillie et al., 2000; Proctor, 2003) and from the serpentine soils of California (Oze et al., 2004) which revealed low available P.

Table 6. Available P contents of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte

Slope Position	Depth (cm)	Available P (mg kg^{-1})
Shoulder		
Ap	0-12	0.20
Bw	12-50	0.21
BC_1	50-70	2.56
BC_2	70-95	4.14
CB_1	95-115	3.45
CB_2	115-135	8.16

Table 6. Continuation.

Slope Position	Depth (cm)	Available P (mg kg^{-1})
Shoulder		
CB_3	135-155	7.06
CB_4	155-175	7.93
Upper backslope		
Ap	0-15	0.15
AB	15-25	0.19
Bw	25-50	0.12
BC_1	50-80	0.26
BC_2	80-120	6.57
BC_3	120-140	5.53
BC_4	140-160	4.42
Lower slope		
Ap	0-12	0.20
Bt	12-52	0.13
BC	52-90	0.42
C_1	90-100	1.35
C_2	100-120	0.16
C_3	120-140	0.49
C_4	140-160	0.82

4. *Exchangeable bases and acidity*

The amounts of the exchangeable basic cations Na, K, Ca, and Mg in the soil control soil reaction and thus influence many soil bio-chemical processes. Except for Na, K, Ca, and Mg are also essential elements for the growth of plants.

The amounts of these cations from the soil profiles investigated are presented in Table 7. Exchangeable Ca and Mg are found in high amounts than Na and K following the sequence: Mg>Ca>Na>K. These results suggest the contribution of the ultramafic ophiolitic rock to the amounts of exchangeable bases in the soil. In particular, the low amounts of exchangeable Na and K can be due to the lack of K-and Na- bearing minerals in the ultramafic parent rock (Garcia, 2009). The present study conforms with other studies done in the ultramafic areas of Palawan which revealed higher levels of Mg than Ca. Briefly, the amounts of exchangeable bases followed the order of Mg>Ca>K (Baillie *et al.,* 2000; Proctor, 2003). The exchangeable acidity (H and Al) of the ophiolitic soils in Basper are also presented (Table 7). The values are generally low (<0.4 $cmol_c\ kg^{-1}$) which can be due to the insolubility of Al at near neutral pH condition of the soils.

5. *Effective Cation Exchange Capacity (CEC)*

CEC, either potential or effective, measures the capacity of the soil to adsorb cations and corresponds to the negative charge of the soil (Bache, 2008). The potential CEC, determined using 1N NH_4OAc at pH 7.0 according to Metson (1956), is particularly important for pedological and soil classification studies as it can provide baseline comparisons of CEC at a specified pH. However, it does not correlate with the fertility status of the soil because the adjusted pH to 7.0 changes the soil reaction of the soil. In contrast, effective CEC determined by summing up the amounts of exchangeable bases plus exchangeable acidity (Na+K+Ca+Mg+H+Al), can effectively evaluate fertility as it gauges the extent to which essential exchangeable nutrients are supplied at the inherent pH of the soil. Effective CEC of the soils investigated range between 10.61 and 25.81 $cmol_c$ kg with an overall average of 18.96 $cmol_c$ kg^{-1} (Table 7). The higher effective CEC in some subsoils compared to the topsoils can be due to the higher exchangeable Mg contributed by the ultramafic parent material at the deeper section of the soil profiles.

6. *Clay mineralogy and soil systematics*

Due to unavoidable factors, the soil samples sent abroad for clay mineralogical analysis were not analyzed. But a previous soil study done in another portion of the Tacloban Ophiolite Complex in Tanauan, Leyte, located a few kilometers from the Basper study site revealed the abundance of smectite in the clay fraction of the ultramafic soils investigated (Garcia, 2009).

The seven soil profiles can be classified according to the World Reference Base (WRB) (FAO, 1998) and the Soil Taxonomy (ST) (Soil Survey Staff, 1996) as follows: soil profile 1- Gleyic Leptosol (WRB), Lithic Endoaquent (ST); soil profile 2- Haplic Luvisol (WRB), Mollic Hapludalf (ST); soil profiles 3, 4, 5, 6 and 7- Humic Cambisol (WRB), Typic Eutropept (ST).

Table 7. Chemical properties of soils developed from ophiolitic rock in Basper, Tacloban, Northeastern Leyte

Soil Profile Horizon	Depth (cm)	Exchangeable bases ($cmol_c$ kg^{-1})				Exchangeable acidity ($cmol_c$ kg^{-1})		Effective CEC ($cmol_c$ kg^{-1})
		Na	K	Mg	Ca	H	Al	
Profile 1 (Foot slope)								
Ap	0 - 25	0.14	0.07	11.44	5.56	0.06	0.11	17.37
C	25 - 56	0.15	0.13	9.05	4.98	0.11	0.05	14.47
R	> 56	0.05	0.00	9.82	5.11	0.11	0.10	15.19
Profile 2 (Lower backslope)								
Ap	0 - 12	0.10	0.05	10.81	5.37	0.16	0.10	16.60
Bt	12 - 52	0.14	0.01	13.70	5.29	0.21	0.05	19.40
BC	52 - 90	0.16	0.01	14.04	4.82	0.16	0.05	19.24
C_1	90 - 100	0.09	0.04	10.43	3.98	0.21	0.41	15.16
C_2	100 - 120	0.13	0.00	14.49	4.95	0.16	0.00	19.72
C_3	120 - 140	0.11	0.03	14.22	4.86	0.26	0.10	19.57
C_4	140 - 160	0.11	0.00	13.99	4.72	0.31	0.21	19.34
Profile 3 (Upper backslope)								
Ap	0-15	0.11	0.02	10.15	5.21	0.16	0.16	15.81
Bw	15 - 45	0.25	0.08	15.18	5.59	0.21	0.05	21.36
BC	45 - 65	0.27	0.02	14.18	5.58	0.16	0.16	20.38
C_1	65 - 90	0.13	0.00	12.89	5.44	0.21	0.16	18.83
C_2	90 - 110	0.25	0.12	15.47	5.81	0.16	0.16	21.96
C_3	110 - 130	0.23	0.01	15.84	5.84	0.21	0.16	22.29
C_4	130 - 150	0.25	0.00	16.03	5.82	0.21	0.21	22.52
Profile 4 (Shoulder)								
Ap	0 - 12	0.09	0.03	13.20	5.43	0.06	0.00	18.82
Bw	12 - 50	0.13	0.00	15.47	5.24	0.11	0.05	20.99
BC_1	50 - 70	0.13	0.09	15.44	4.73	0.11	0.05	20.55
BC_2	70 - 95	0.06	0.00	17.66	4.83	0.16	0.05	22.76
CB_1	95 - 115	0.08	0.00	17.82	5.04	0.16	0.11	23.20
CB_2	115 - 135	0.13	0.08	16.24	5.03	0.16	0.11	21.73
CB_3	135 - 155	0.08	0.00	19.96	5.47	0.16	0.05	25.72
CB_4	155 - 175	0.06	0.00	13.82	4.82	0.16	0.10	18.96
Profile 5 (Summit)								
Ap	0 - 14	0.06	0.10	10.37	5.38	0.16	0.16	16.22
Bw	14 - 36	0.08	0.00	11.77	5.32	0.31	0.31	17.79

Table 7. Continuation.

Soil Profile Horizon	Depth (cm)	Exchangeable bases ($cmol_c\ kg^{-1}$)				Exchangeable acidity ($cmol_c\ kg^{-1}$)		Effective CEC ($cmol_c\ kg^{-1}$)
		Na	K	Mg	Ca	H	Al	
Profile 5 (Summit)								
BC	36 - 55	0.15	0.00	12.60	5.40	0.26	0.16	18.56
C_1	55 - 90	0.12	0.00	12.50	5.62	0.26	0.26	18.76
C_2	90 - 110	0.07	0.01	11.21	5.53	0.06	0.16	17.04
Profile 6 (Upper backslope)								
Ap	0 - 15	0.18	0.04	10.68	5.31	0.16	0.10	16.48
AB	15 - 25	0.19	0.00	12.65	5.43	0.11	0.21	18.59
Bw	25 - 50	0.34	0.06	15.17	5.81	0.26	0.32	21.95
BC_1	50 - 80	0.20	0.00	14.72	5.87	0.36	0.37	21.52
BC_2	80 - 120	0.16	0.03	11.64	5.67	0.31	0.63	18.44
BC_3	120 - 140	0.04	0.00	11.77	5.51	0.25	0.16	17.74
BC_4	140 - 160	0.12	0.00	11.25	5.48	0.16	0.21	17.21
Profile 7 (Lower backslope)								
Ah	0 - 13	0.15	0.05	9.60	5.11	0.21	0.32	15.43
AB	13 - 40	0.22	0.01	13.15	4.96	0.26	0.16	18.76
Bw	40 - 60	0.21	0.00	14.89	4.95	0.26	0.16	20.46
CB_1	60 - 110	0.33	0.09	13.59	4.90	0.36	0.21	19.47
CB_2	110 - 130	0.23	0.00	14.88	5.26	0.26	0.16	20.79
CB_3	130 - 150	0.22	0.00	13.75	5.12	0.21	0.16	19.46
C	150 - 170	0.15	0.00	11.40	4.87	0.26	0.10	16.78

CONCLUSION

The results of the study support the following conclusions:

1. The ophiolitic soils in the Basper watershed range from poorly to moderately developed and from shallow particularly in the lower slopes and summit positions to deep soils in the lower backslope positions. The soil in the footslope position was the least developed and shallowest.
2. The soils in the study site have lower bulk density values on their surface horizons than in their subsurface horizons implying higher porosity and good aeration in the former than in the latter. Also, Ksat values in the surface horizons were generally higher than in the subsurface horizons indicating good water movement on the surface but slow movement in the lower part of the soil profile.
3. In terms of fertility, the ophiolitic soils can support a variety of vegetation from grasses, shrubs to trees although they have low available P, total N, exchangeable K, and CEC. Despite these, soil pH is moderately acidic to neutral and exchangeable Ca and Mg are high.
4. The exchangeable Mg contents of the soils studied were much higher than the exchangeable Ca contents reflecting the ultramafic nature of the ophiolitic parent material.
5. The characteristics of the ophiolitic soils showed clear influence of their physiographic position and parent material.

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