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MORPHOLOGICAL, PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOILS DERIVED FROM LIMESTONE ROCKS IN BARILI, CEBU

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ABSTRACT

Until now little published data are available on the characteristics of soils derived from limestone rocks in the Philippines. This study was conducted to evaluate the chemical, physical and morphological properties of soils derived from limestone in Barili, Cebu, and determine their suitability for crop production. Representative soil profiles were described following the standard procedure. Soil samples were collected from all soil horizons of each profile and analyzed for physical and chemical properties. Soil suitability was determined by comparing the fertility properties of each soil with the optimum soil requirements of crops. Results showed no major differences in the morphological characteristics particularly in soil color, texture, structure, consistence and abundance of roots and pores. Both soils have high clay content, low to high bulk density and porosity in the subsurface and are slightly to moderately alkaline, low available P, high CEC and exchangeable bases as well as base saturation and calcium carbonate content. The results of the study would be useful for sustainable crop production and environmental conservation in the study area. To alleviate the identified soil constraints and minimize soil degradation, appropriate soil management strategies should be employed including the planting of crops tolerant to alkaline soils, application of phosphorus fertilizer to increase the available P in the soil and organic fertilization to address soil compaction and increase organic matter in the soil.

Keywords: soil color, texture and structure, soil consistency, soil horizons

INTRODUCTION

Limestone is widespread in many areas in the Philippines. It is defined as a rock of sedimentary origin composed primarily of more than 50% calcium carbonate ($CaCO_3$). Limestone areas, also called Karsts landscapes, are estimated to occupy an area of about 35,000 km² in the Philippines (SWCF-CFTU-IGCI, 2005).

According to Asio (2005), limestone soils are derived from the weathering or decomposition of limestone under the influence of climate, relief, plants and animals. In geologically young areas, these soils are poorly developed, shallow and calcareous. Because they have high initial productivity, limestone soils along coastal areas have a long history of cultivation and other anthropogenic influences, resulting in widespread land degradation (Urich *et al,.* 2001; Day and Chenoweth, 2004). This largely explains why most limestone areas in the country are degraded.

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In Barili, a municipality in the southwest of Cebu, the unproductive nature of its soil resources which are mostly calcareous belonging to Faraon and Bolinao series. According to Barrera *et al.,* (1954) Faraon series is a black to dark grayish black heavy clay soil found in rolling areas that are well drained. On the other hand, Bolinao series is a red soil that formed from white, hard and compact limestone. The two soils are found in undulating slopes that are well drained. Until now the characteristics of these soils have not yet been studied in detail and thus, are still poorly understood.

A detailed characterization of the soils in Barili is important for the formulation of appropriate and sustainable soil management strategies to improve crop productivity and minimize environmental problems. The results of such study will be useful for efforts to conserve or promote sustainable use of soil resources. In addition, the information gained can be used for other areas with comparable soils and site conditions to Barili, Cebu.

MATERIALS AND METHODS

Study Area

The study site is located in Brgy. Cagay, Barili, Cebu inside the experimental and production farm of Cebu Technological University. A catena consisting of eight soil profiles was selected for detailed field description and sampling (Figure1a and 1b).

In terms of geomorphology, the study area appears to be the lower portion of a sedimentary basin having an elevation of 70 to 150 m above sea level and underlain by Barili Formation. Slope characteristic of the area is generally gentle to moderately sloping. The area is drained by a first- order stream running in an east-west direction and located in the middle of the basin. The catena chosen traverses the stream perpendicularly.

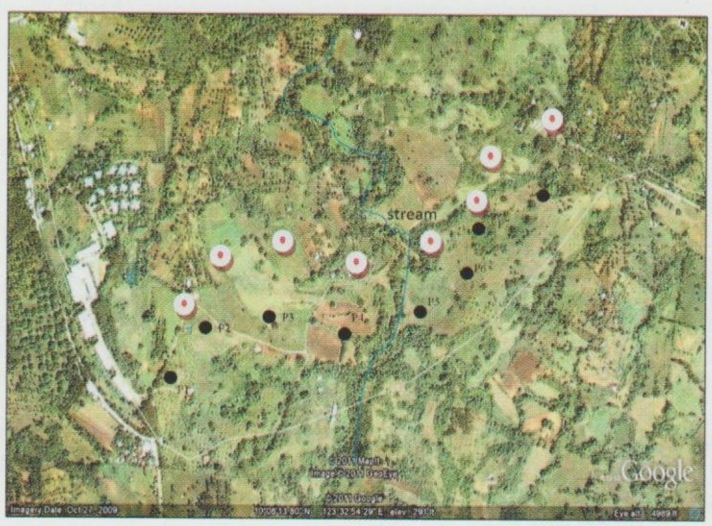

Figure 1a. Map showing the location of soil profiles that were studied in Cagay, Barili, Cebu.

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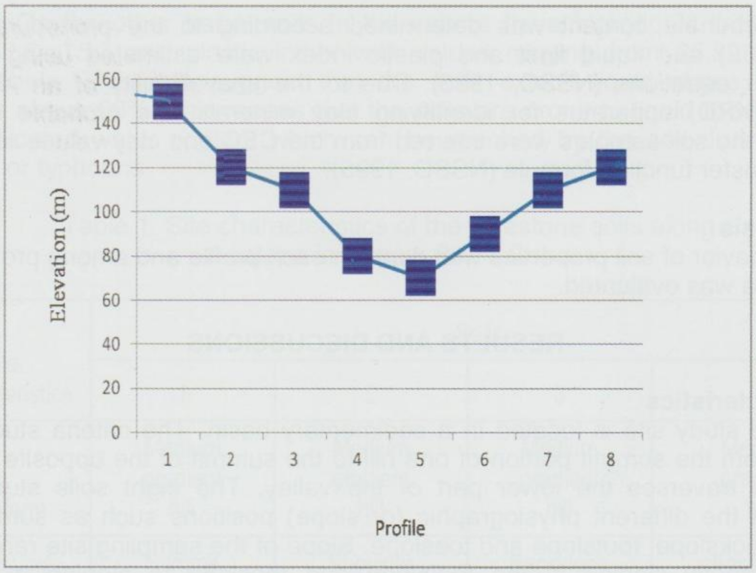

Figure 1b. Topographical sketch of the catena in Cagay, Barili, Cebu.

Field Soil Description and Sampling

A pit measuring approximately 1m x 1m and having a depth of at least 1m was dug. Site and soil profile descriptions were conducted following the standard procedure of FAO (2006). About one-half kilogram of composite soil sample was obtained and collected from every horizon of each soil profile according to the quantitative sampling procedure of Schlichting *et al,*. (1995).

Preparation of Soil Samples

Soil samples were air dried, freed of rocks and plant materials, ground using a wooden mallet and allowed to pass through a 2-mm and 0.425 mm sieve for coarse and fine samples, respectively.

Laboratory Analysis

Particle size distribution was determined by pipette method (ISRIC, 1995; USDA-NRCS, 2004). Bulk density was determined using the paraffin clod method (Blake and Hartge, 1986). Soil pH (H_2O and $CaCl_2$) was analyzed potentiometrically using a soil: solution ratio of 1:2.5 (ISRIC, 1995). Soil organic matter was analyzed following the Modified Walkley Black method (Nelson and Sommers, 1982) and Total Nitrogen by the micro- Kjeldahl method whereby 1 g of soil that passed through a 0.425 mm sieve was added with selenium mixture and concentrated H_2SO_4 acid and was digested using Kjeldahl digestion heaters (ISRIC, 1995). Extraction of phosphorus was done according to the Olsen method (Olsen and Sommers, 1982) while CEC was determined using the ammonium acetate (NH_4OAc) method at pH 7.0 (ISRIC, 1995). The extracts collected from CEC analyses using 1 N NH_4OAc (pH 7.0) were analyzed for potassium, calcium, magnesium and sodium using atomic absorption spectrometry (Varian FS 220).

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Calcium carbonate content was determined according to the procedure of Nelson (1982) and liquid limit and plastic index were estimated using the pedotransfer equations (NSSC, 1995). Due to the unavailability of an X-ray diffraction (XRD) apparatus for identifying clay minerals, the probable clay minerals in the soil samples were inferred from the CEC and clay values using the pedotransfer function formula (NSSC, 1995).

Data Analysis

Behavior of soil properties with depth in each profile and among profiles in the catena was evaluated.

RESULTS AND DISCUSSIONS

Site Characteristics

The study site is located in a sedimentary basin. The catena studied extended from the summit portion of one hill to the summit of the opposite hill. The catena traverses the lower part of the valley. The eight soils studied represented the different physiographic (or slope) positions such as summit, shoulder, backslope, footslope and toeslope. Slope of the sampling site ranged from very gently sloping in the footslope and toeslope to sloping in the backslope and gently sloping in the summit. All soils showed good to excellent drainage. *Chromolaena odorata* and *Paspalum conjugatum* are the dominant vegetation species suggesting the degraded nature of the area (Table 1).

Soil Morphological Characteristics

All soils exhibited a horizon sequence of Ap-Bw-BC horizon except profile 4 (footslope) with Ah-Bw-BC horizon suggesting that the soils in the catena are moderately developed. Soils have a color hue of 10YR, in which surface horizons were dark brown to dark yellowish brown turning to grayish, brownish and yellowish in the subsoil. Soil texture ranges from silty clay to clayey throughout the soil profiles indicating the clay contribution of the parent material which is marl (a clayey limestone). Soil structure was granular in the upper portion of the footslopes and subangular blocky throughout the rest of the profile. The soil consistence was plastic and sticky in all soils due to the high clay content. Very fine to fine roots were found on the surface horizons and could no longer be observed in the lower portion of the soil profiles. Rock fragments were many and abundant in the lower horizons although some occurrences of small rock fragments can be observed in the upper parts of the profile.

Soil Physical Characteristics

All the soils in the catena are clayey with clay contents ranging from 46 to 70 percent. Bulk density values are lower in upper horizons but tend to increase in subsurface horizons ranging from 1.05 to 1.86 g/cm^3. The lower bulk density values maybe attributed to the high organic matter coming from the decomposed root system of grasses as well as the contribution from the tree leaf litters (Navarrete *et al.*, 2000). The increasing bulk density values with depth can be attributed to the high clay content of the soil. In terms of water holding capacity, all soils showed high WHC values above 40% due to the high clay content of the soils. The high water holding capacity can be expected due to its high clay content and its porous nature.

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On the other hand, soils in the catena have high liquid limit ranging from 52.2- 75.3 and plastic index with values ranging from 25.89 to 57.56 respectively. The data suggest that the soils exhibit liquid states at water content above 50%. This means that the soils are prone to liquid movement at this indicated water content which can be reached by the soil during heavy storms or typhoons.

Table 1. Site characteristics of the limestone soils along a catena in Cagay, Barili, Cebu.

Site Characteristics	Soils			
	1	2	3	4
Landform	Medium gradient hill	Medium gradient hill	Medium gradient hill	Medium gradient hill
Slope Position	Summit	Shoulder	Backslope	Footslope
Slope Gradient	Gently sloping	Gently sloping	Sloping	Very gently sloping
Parent Material	Limestone	Limestone	Limestone	Limestone
Soil moisture regime	Udic	Udic	Udic	Udic
Soil temperature regime	Isohyperthermic	Isohyperthermic	Isohyperthermic	Isohyperthermic
Elevation	150m asl	120m asl	110m asl	80m asl
Vegetation	*Imperata cylindrica* *Acacia mangium* *Chromolaena odorata*	*Mimosa pudica* *Imperata cylindrical* *Chromolaena odorata*	*Tamarindus indica* *Psidium guajava* *Imperata cylindrica* *Chromolaena odorata*	*Imperata cylindrica* *Acacia auriculiformis* *Paspalum conjugatum* *Chrysopogon zizanioides*

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Table 2. Morphological characteristics of soils in Cagay, Barili, Cebu.

Profile 1(Summit)									
Ap	0-20	10YR 3/3 (dark brown)	C	1fsbk	h p & s	cf	cv	c	n	mo
Bw1	20-48	10YR 4/3 (dark brown)	C	2msbk	hp & s	ff	fv	c	v	sl
Bw2	48-73	10YR 5/6 (yellowish brown)	C	2msbk	h p & s	ff	cv	c	m	st
BC	73	10YR 5/6 (yellowish brown)	SiC	2msbk	h p & s	0	fv	d	m	ex
Profile 6(Backslope)										
Ap	0-18	10YR 3/4 (dark yellowish brown)	SiC	1fsbk	shhp & s	cf	cv	c	f	sl
Bw1	18-38	10YR 5/6 (yellowish brown)	C	1fsbk	shhp & s	fvf	cv	c	f	ex
Bw2	38-58	10YR 5/6 (yellowish brown)	SiC	2msbk	shhp & s	fvf	ff	c	c	st
Bw3	58-83	10YR 5/8 (yellowish brown)	SiC	2msbk	shhp & s	0	ff	d	m	st
BC	83-100	10YR 7/2 (yellow)	SiC	1msbk	shhp & s	0	fv	d	m	mo
Bw2	35-50	10YR4/6 (dark yellowish brown)	SiC	2msbk	shhp & s	fvf	fv	c	c	mo
Bw3	50-66	10YR 6/6 (brownish yellow)	C	1msbk	shhp & s	fvf	fv	d	c	st
BC	66-100	10YR 6/8 (brownish yellow)	C	1msbk	shhp & s	0	fv	d	m	ex

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Table 3. Physical characteristics of limestone soils along a catena in Cagay, Barili,Cebu.

Profile 1 (Summit)

Soil profile	Depth (cm)	PSA (%) sand	silt	clay	Textural class	Bulk Density (g/cm^3)	Porosity (%)	Water Holding Capacity (%)	Liquid * Limit	Plastic ** Index
Ap	0-20	1.23	38.17	60.60	clay	1.32	50.38	61.19	64.54	45.6
Bw1	20-48	1.29	37.56	59.39	clay	1.58	40.38	61.89	63.45	44.39
Bw2	48-73	1.29	35.92	62.79	clay	1.61	39.25	45.4	66.51	47.79
BC	73-100	0.71	42.04	57.25	silty clay	1.42	46.42	51.37	61.53	42.25

Table 4. Chemical characteristics of limestone soils along a catena in Cagay, Brili,Cebu.

Profile 2 (Shoulder)

Ap	0-20	2.83	37.27	59.9	clay	1.37	48.3	46.32	63.91	44.9
Bw1	20-40	1.42	39.95	58.63	clay	1.05	60.38	46.01	62.77	43.63
Bw2	40-58	1.22	42.40	56.38	silty clay	1.69	36.23	44.18	60.74	41.38
BC	58-	1.54	38.39	60.07	clay	1.74	34.34	50.91	64.06	45.07

Profile 3 (Backslope)

Ap	0-25	1.66	44.48	53.86	silty clay	1.57	40.75	60.24	58.47	32.86
Bw1	25-49	0.67	39.37	59.96	clay	1.77	33.21	62.99	63.96	44.96
Bw2	49-65	0.40	39.83	59.77	clay	1.36	48.68	51.58	63.79	44.77
BC	65-	1.05	41.77	57.18	silty clay	1.70	35.85	49.50	61.46	42.18
BC	66-	1.18	28.54	70.28	clay	1.83	30.94	61.31	73.25	55.28

Profile 4 (Footslope)

Ah	0-25	0.89	41.28	57.83	silty clay	1.2	54.72	50.69	62.05	42.83
Bw1	25-50	0.81	41.28	57.91	silty clay	1.14	56.98	53.26	62.12	42.91
Bw2	50-67	1.22	39.10	59.68	clay	1.77	33.21	62.73	63.71	44.68
Bw3	67-78	0.99	37.87	61.14	clay	1.51	43.02	51.43	65.03	46.14
BC	78-	0.99	39.19	59.82	clay	1.58	40.38	56.52	63.84	44.82

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Profile 5 (Toeslope)

Ap	0-19	1.24	40.56	58.2	silty clay	1.43	46.04	63.75	62.38	43.2
Bw1	19-40	1.14	40.37	58.49	silty clay	1.85	30.19	63.02	62.64	43.49
Bw2	40-77	0.73	38.72	60.55	clay	1.68	36.6	58.22	64.5	45.55
BC	77-	1	36.82	62.18	clay	1.65	37.74	59.1	65.96	47.18

Profile 6 (Backslope)

Ap	0-18	1.18	40.37	58.45	silty clay	1.42	46.42	55.35	62.61	43.45
Bw1	18-38	3.09	37.78	59.13	clay	1.76	33.58	49.98	63.22	44.13
Bw2	50-67	1.22	39.10	59.68	clay	1.77	33.21	62.73	63.71	44.68
Bw3	58-83	1.07	47.21	51.73	silty clay	1.82	31.32	52.80	56.56	30.73
BC	83-	1.07	47.26	51.68	silty clay	1.69	36.23	58.04	56.51	30.68

Profile 7 (Shoulder)

Ap	0-22	1.36	41.42	57.22	silty clay	1.41	46.79	68.70	61.50	42.22
Bw1	22-42	0.82	35.09	64.09	clay	1.22	53.96	76.71	67.68	49.09
Bw2	42-56	0.90	37.47	61.63	clay	1.58	40.38	69.28	65.47	46.63
Bw3	56-74	1.05	39.14	59.81	clay	1.73	34.72	63.68	63.83	44.81
BC	74-	1.04	40.02	58.94	silty clay	1.66	37.36	59.88	63.05	43.94

Profile 8 (Summit)

Ap	0-20	2.14	48.84	49.02	silty clay	1.36	48.68	72.21	54.12	28.02
Bw1	20-35	1.99	51.12	46.89	silty clay	1.24	53.21	62.56	52.20	25.89
Bw2	35-50	2.14	43.62	54.25	silty clay	1.86	29.81	65.79	58.83	33.25
Bw3	50-66	1.49	25.95	72.56	clay	1.40	47.17	80.84	75.30	57.56
BC	66-	1.18	28.54	70.28	clay	1.83	30.94	61.31	73.25	55.28

* Calculated using the pedotransfer equation; LL= 0.9 clay % +10
** Calculated using the pedotransfer equation; PI= clay-21 (35-55% clay) PI= clay-15 (>55% clay)

Soil Chemical Characteristics

Results showed that all soils have high pH H_2O values (>7.79), with the tendency to be slightly higher in the subsurface than in the surface horizons. As expected, pH in $CaCl_2$ is lower than pH H_2O in all soils. The high pH values of the soils are apparently due to the presence of high amounts of $CaCO_3$ coming from the limestone parent material. Ulrich (1986) reported that the soil pH value does not drop below 7.0 in the presence of $CaCO_2$ because of its buffering capacity. Organic matter and total nitrogen contents are high in the upper horizons and then decreases with depth in all soils in the catena. There is a very close relationship between OM and N content of soils, since more than 95% of N is bounded to the organic substance (Pagel *et al.,* 1982). Available Phosphorus contents are low in all soils in the catena due to the alkaline condition of the soils which causes precipitation of the element. Exchangeable Ca was the dominant exchangeable base in all the soils followed by Mg, K, and Na. The higher amount of Ca relative to the other bases was due to the high $CaCO_3$ content of the limestone parent material. As observed, Mg follows Ca which was due to the effect of parent materials since limestone has high amounts of Ca and Mg (Asio *et al,.* 2006). The CEC of the soils studied ranges from moderate to high (21.12 to 53.6 meq/100g soil). These values were possibly due to the clayey texture of the soil. High CEC on the surface horizons may have been also contributed by the organic matter which was much higher in the upper than in the lower horizons.

$CaCO_3$ content was very high (>70%) in all soils, particularly in the subsoils because of the contribution of the limestone rock in the subsoil. During field examination, $CaCO_3$ particles were observed in the lower portion of the profiles and a few particles of limestone were found on the upper horizons which may be due to the effect of cultivation.

Soil Suitability to crop production

Soils in different slope positions in the study site vary in their fertility characteristics on the basis of the presence or absence of soil fertilityconstraints. All the soils possess at least five physical and chemical soil fertility constraints to crop production. The clayey texture coupled by blocky structure that turns hard upon drying is a limitation for the soils in the entire catena. The sticky and plastic consistency of the soils is a problem for farm operations during dry periods and in the rainy season. Because of the high $CaCO_3$ content, the pH level is also a constraint, in addition to the deficiency of the mineral nutrients P and N. (Braschiet *et al.,* 2003) reported that the precipitation of insoluble Ca-P phases is the predominant process that reduces P availability to plants for calcareous soils with a large reservoir of exchangeable Ca. Organic matter is also limiting in the lower slopes.

The results indicate that most of the fertility constraints of the soils studied are directly or indirectly related to the composition of the limestone parent material. Contrary to common notion, limestone soils also have physical fertility constraints (Lal, 2000) aside from the nutrient imbalances associated with the alkaline pH. Results of this study imply that agronomic and plant nutrition research, which focuses on only one or two deficient mineral nutrients in calcareous soils, as is commonly practiced, is too simplistic and will contribute little for the sustainable crop production in such soils. Soil management strategies should consider the physical and chemical characteristics and the site conditions.

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Table 5. Soil Suitability to crop production.

Soil Properties	Threshold Pedon value**	Profile 1	2	3	4	5	6	7	8
Texture**	medium	-	-	-	-	-	-	-	-
Bulk density (g/cm3)**	< 1.45	+	+	-	+	+	+	+	+
Consistence	fr;np;ns	-	-	-	-	-	-	-	-
pH water	5.5-7.0	-	-	-	-	-	-	-	-
OM (%)**	> 3.0	+	-	-	+	+	-	-	+
Total N (%)**	>0.2	-	-	-	-	-	-	-	-
Available P (mg/kg)**	> 8-15	-	-	-	-	-	-	-	-
Exch. Ca (meq/100 g)**	>0.40	+	n.d.	+	+	+	+	+	n.d.
Exch.Mg (meq/100 g)**	> 0.50	+	n.d.	+	+	+	-	-	n.d.
Exch. K (meq/100 g)**	> 0.20	+	n.d.	-	+	-	-	-	n.d.

Plus sign (+) indicates that soil property is favorable for crop growth; minus sign (-), soil property is a constraint to crop growth/crop production; fr, friable; np, nonplastic; ns, nonsticky; n.d.,not determined

**Based on Asio *et al.,* (2006).

CONCLUSION

The limestone soils in the catena have closely related properties. They all have an Ap-Bw-BC horizon sequence indicating that they are relatively poorly developed. The soils have color ranging from dark brown to yellowish brown, are hard when dry but plastic and sticky when wet, have high clay content (46-70%) and water holding capacity (>40%). In terms of chemical characteristics, the soils have alkaline pH (>7.5) due to their very high $CaCO_3$ content (>60%), have moderate to high CEC (21-53 meq/100 g), have high base saturation (>50%) but have low to medium organic matter content (0.20-4.36%) and extremely low available P (<1 mg/kg).

The soils are relatively young and many of their characteristics are directly related to the composition of the limestone parent material. In particular, the high clay content and alkaline pH are due to the high clay and $CaCO_3$ contents of the limestone parent material.

All the soils possess several physical and chemical constraints to crop production which are directly or indirectly influenced by their limestone parent material.

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