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Characteristics and fertility constraints of degraded soils in Leyte, Philippines

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Abstract

Knowledge on the characteristics and fertility status of degraded soil is fundamental in planning suitable soil management strategies for crop production purposes. Such relevant knowledge can be attained through quantitative appraisal of soil properties and assessment of fertility status. Sixty soil samples were collected from 5 locations such as Ormoc, Baybay, Bontoc, Bato, and Matalom in the western side of Leyte island, Philippines. The important physical constraint in most of the soils is the high clay content, particularly in the soils of Baybay and Bato since it is a problem for cultivation. The strongly acidic and strongly alkaline pH conditions, low available P, and in some cases low exchangeable K are the chemical constraints. The variation in physical and chemical constraints of these degraded soils is directly or indirectly related to the nature of the parent material, geomorphic position, and anthropogenic effect. The soil fertility characteristics are distinct within similar soil types, which is primarily due to their relations to dominant soil forming processes. Consideration of the soil physical and chemical constraints are essential for long-term planning of soil management strategies that will lead to sustainable utilitization of these problematic soils.

Keywords: degraded soils, fertility constraints, land use, Philippines, soil types

Introduction

Soil degradation, a process that lowers the capacity of the soil to produce goods or services, is a prevalent agricultural and environmental problem in the Philippines (Asio et al. 2009). This problem has tremendous consequences considering the important functions of soils for plant production, buffering, transformation, filtering, geogenic, cultural heritage, and infrastructure (Blum 1998). The National Action Plan (NAP 2004) of the Philippines reported that about 52,000 km^2 of land are serious degraded resulting in 30-50% decrease in soil productivity. Thus, it recognized the control of soil degradation as a main research priority in the Philippines. Ironically, the nature and characteristics of degraded soils in the country are until now poorly understood inasmuch only few researches have investigated this subject (Asio 1997; Asio et al. 2009; Navarrete et al. 2009). The utilitization of degraded lands has resulted in serious ecological problems (Asio 1997), low crop yield (Garrity 1993), and the failure of forest rehabilitation projects (e.g., Alcala 1997). Cramb (2001) described that various crop production technologies developed for marginal areas in the Philippines are not successfully adapted by farmers or have failed to alleviate crop production. He further stated that the introduction of unsuitable soil management technologies to farmers in degraded lands has even intensified soil degradation processes that are now currently occurring in these areas. Accordingly, detailed information on their properties, which can be done through more pedological researches, are needed for suitable land management.

Site qualities are complex collections of observable and measurable site characteristics that have to be appraised for specific land uses (FAO 1976). In appraising site qualities, several soil properties must be summarized in terms of rooting depth, rootability, moisture content, air capacity, and nutrient availability (Schlichting et al. 1995) including knowledge about geomorphological and pedological history of the landscape. Jahn and Stahr (1996) emphasized that, because most soil characteristics are the results of soil formation or pedogenesis, the progression of site qualities is closely related to the time-dependent development of the soils. They pointed out that in land evaluation, site characteristics are elucidated as time-dependent for the time of survey only, thus this period is comparatively concise in resemblance to the time needed for soil formation. Because the degree of soil degradation immensely varies among sites depending on soil forming factors, soil management strategies must be location specific. This suggests that every degraded soil has to be evaluated in terms of its properties and constraints. Such intention will diminish the negative ecological impact of soil degradation and may provide a sound and sustainable management of these marginal lands. It was anticipated that the results of this study will provide knowledge for suitable management in similar degraded areas in the Philippines. The aim of this study was to determine the characteristics of degraded soils in Leyte, Philippines, and to evaluate their fertility constraints.

Materials and methods

Description of the study area

The study area is located in the island of Leyte, Philippines, which lies between 124°17' and 125°18' east longitude and between 9°55' and 11°48' north latitude (Fig. 1a). Leyte island was formed from tectonic movement and plate convergence, which started in the Tertiary and

Quaternary (Wernstedt and Spencer 1967; Aurelio 2000). The uplift and block faulting and volcanism (Scott 2000) due to the Philippine Fault that treverses the central part of the island explained the widespread occurrence of volcanic rocks, except in the northeast and in the southwest of the island, where exposed limestone rock occur. Asio (1996) explained the importance of the geologic uplift to the occurrence of sedimentary rocks such as coralline limestone, sandstone, siltstone, and mudstone in the northeast and southwest part of the island. The mean annual rainfall is about 2800 mm, which fluctuates seasonally during the dry month that begins between March and May (115-118 mm) and wet months from October to January (300-403 mm). The higher annual rainfall resulted in moisture condition in soils all year round and gives a udic soil moisture regime (Soil Survey Staff 2006). The mean annual temperature is about 28°C, which is relatively constant throughout the year. The difference between the coldest (December) and the warmest month (April) is between 2 and 3°C and gives a isohyperthermic temperature regime (Soil Survey Staff 2006). According to Coronas (1920), two types of monsoonal winds blow in the island and in other parts of the archipelago. The southwest monsoon (locally called *Habagat*) that blows from the southwest direction from May to October, causing extreme clouds and rainfall at the western side of the island. From November to April, there is the northwest monsoon (locally called *Amihan*) that blows from the northwest direction, causing high rainfall at the eastern side of the island.

The once dipterocarp rain forests in the uplands are now patches of secondary growth forest and coconut plantation, whereas the lowlands are used for cropland especially corn (*Zea mays*), sweet potato (*Ipomea batatas*), and rice (*Oryza sativa*). *Imperata cylindrica* grass is dominant in abandone croplands, which suggest the degraded nature of these areas.

Field description and soil sampling

Twelve well-drained soil profiles were sampled from 5 sites across an elevation gradient (between 97 and 735 m) on the western part of Leyte, Philippines (Fig. 1a). In this study, each site will be referred to by their location: Ormoc, Baybay, Bontoc, Bato, and Matalom, respectively (Table 1). The five profiles in Ormoc were located across a late Quaternary volcanic (basalt-andesite) landscape (Asio 1996; Jahn and Asio 1998; Navarrete et al. 2008) at an elevation between 630 and 730 m, while the four pedons in Baybay were located at an altitude of 75 to 112 m on a basaltic parent rock (Asio 1996; Navarrete et al. 2009). The soil profiles in Bontoc and Bato have an altitude of 97 and 120 m, respectively, on a coralline shale parent material. The calcareous limestone soil in Matalom was located at an elevation of 121 m on a grassland field. Based on the Soil Survey Staff (2006), the dominant soil types in the study sites were Andisols (n=18), Ultisols (n=20), Inceptisols (n=11), and Alfisols (n=11).

Bulked soil samples were taken from every horizon of each pedon, air-dried, freed of large plant residues, ground and allowed to pass through a 2-mm wire mesh.

Laboratory analyses

Particle size distribution was determined by pipette and wet sieving methods after pretreatment of soils with NaOAc (pH 5.0) for samples containing free carbonates and H_2O_2 to oxidize organic matter (ISRIC 1995). The pH of air-dried samples (<2 mm) was measured potentiometrically in soil/solution suspensions of 1:2.5 H_2O. Organic carbon (OC) was determined by a modified Tyurin method, while the total nitrogen was analyzed by dry combustion using C/N analyzer (Elementar Vario EL III, Hanau, Germany). Potential cation exchange capacity (CEC_{pot}) and exchangeable bases were measured by the NH_4OAc (pH 7.0). Free Fe (Fe_d) and Al (Al_d) were extracted by the dithionite-citrate and amorphous Fe (Fe_o) and Al (Al_o) were extracted by the ammonium oxalate all according to the method described by

Blakemore et al. (1987). Fe and Al in solutions were determined by ICP-AES (Shimadzu ICPS-8100). Element composition was obtained by X-ray fluorescence spectrometry (Rigaku 3070).

Fertility evaluation

Soil fertility evaluation was done by matching the values of selected soil property with the published threshold values or conditions of the same property for crop growth (Landon 1991; Schlichting et al. 1995). The suitability or constraints of a particular soil property to crop growth is expressed in *positive* (+) and *negative* (-) sign, wherein *positive* denotes a soil property that is favorable to crop growth or production, and *negative* denotes a soil property that is constraints to crop growth or production following the method used by Asio et al. (2006).

Statistical analysis

Statistical analyses were carried out using a JMP (Version 8, SAS Institute, Cary, NC, USA) software package. Significances of differences between mean values of selected soil properties were estimated by Tukey-Kramar and *t*-test at the 95% confidence level ($P<0.05$). Multivariate analysis by principal component analysis (PCA) and hierarchical cluster analysis (HCA) were extracted from the large data sets, to classify the samples according to the values of a set of variables into principal component (PC) and cluster, respectively. Prior to the PCA and HCA analysis, the set of data was mean centered and autoscaled to variance 1 to insure that all variables contributed equally to the model, independent of the scales with which they were measured (Sena et al. 2002).

Results and discussion

Soil characteristics

Because of the variety of parent materials, topography, soil types, and stage of soil development, the studied soils show great variations in terms of physical and chemical properties (Table 2). For instance, the Andisols of Ormoc which originated from volcanoclastic parent material possess markedly higher C_{org} ($P<0.001$), Nt ($P<0.001$), Fe_o ($P<0.001$), Al_d ($P<0.001$), sand ($P<0.05$), Al_2O_3 ($P<0.05$), but markedly lower exchangeable Ca and Mg ($P<0.05$), and clay ($P<0.05$) compared to those in the other sites. Shoji et al. (1993) explained that high C_{org} in Andisols is due to the formation of stable complexes between organic matter and Fe-, Al-oxides and short-range order minerals. Navarrete et al. (2008) reported that the progression of soil development in Ormoc site is greatly affected by topography, because of its influence on water movement, which determines the rate of weathering, runoff and soil erosion, and soil formation (Sommer and Schlichting 1997). For instance, the rapid leaching of basic cations have resulted in low exchangeable bases and acidic nature of the soils, implying a young volcanic soils (Shoji et al. 1993; Asio 1996; Navarrete et al. 2008). The intensely developed Ultisols in Baybay (Asio 1996; Navarrete et al. 2009) are reflected by markedly higher contents of clay ($P<0.05$), Fe_d ($P<0.001$), CEC_{pot} ($P<0.05$), and Fe_2O_3 ($P<0.001$), and low exchangeable K and Na ($P<0.05$) compared with the other sites. Based on gain and loss calculations, Navarrete et al. (2009) found that 32-80% CaO, 13-75% MgO, 57-70% K_2O, and 34-59% Na_2O has been lost throughout weathering of basalt rock into soils, and the amount of loss varies among soils depending on soil location along the landscape. On the other hand, Matalom soil had higher soil pH ($P<0.001$), silt ($P<0.05$), exchangeable Ca ($P<0.001$), and CEC_{pot} ($P<0.05$) compared with the other sites and is certainly from the coralline limestone parent rock. High exchangeable Ca, CEC_{pot}, and high pH suggest the young nature of these soils there. Despite a similarity in the parent material (calcareous shale) between Bontoc and Bato, the soils that developed were distinctly different from each other. In terms of sand contents ($P<0.001$), SiO_2 ($P<0.001$), and exchangeable Mg ($P<0.001$), the Bato soils have significantly higher values compared with the other studied soils. Soils in Bontoc, Bato, and Matalom have significantly lower amounts of Fe_d ($P<0.05$), Fe_o ($P<0.05$), Al_d ($P<0.05$), and Al_o ($P<0.05$) in comparison to that at Ormoc and Baybay soils.

Ultisols, which comprises 33% of all samples, have appreciably higher CEC_{pot} ($P<0.001$) and contents of clay ($P<0.001$), Fe_d ($P<0.001$), Al_2O_3 ($P<0.001$), and Fe_2O_3 ($P<0.001$). The Andisols, which comprises 30% of the studied soils have appreciably higher C_{org} ($P<0.001$), sand ($P<0.001$), silt ($P<0.05$), exchangeable Na ($P<0.05$), Fe_o ($P<0.001$), Al_d ($P<0.001$), Al_o ($P<0.001$), SiO_2 ($P<0.05$), and Al_2O_3 compared with the other soils. In addition, Andisols have appreciably lower pH ($P<0.001$), exchangeable Mg ($P<0.05$), and CEC_{pot} ($P<0.05$). Another 18% of the studied soils are Alfisols and Inceptisols, respectively. Alfisols have higher Mg ($P<0.001$), but with lower SiO_2 ($P<0.001$), whereas Inceptisols have appreciably higher soil pH ($P<0.001$), silt ($P<0.001$), and exchangeable Ca and K ($P<0.001$) relative with the other soils. The soils in the island of Leyte, Philippines vary from the less-developed Inceptisols and Andisols to the well-developed Ultisols and Alfisols, respectively.

Differences in soil properties according to sites and soil types

PCA and CA analysis revealed groupings or clustering of soils as a function of study site and soil type (Figs. 2 and 3). In terms of PCA analysis, all sites were distinctly dispensed in the two principal components (PC1 and PC2). PC1 and PC2 explained 28 and 21% of total variability, respectively (Figs. 2a and 2b). PC1 of all data values used in the PCA analysis differentiates the parent materials of the soil (Fig. 2a). The soils originated from volcanic rocks (Ormoc, Baybay) contributed to the positive loading, while limestone and coralline shale originated soils contributed to the negative loadings in PC1, with the exclusion of a few overlapping. The typical features of limestone soils such as elevated soil pH (water), exchangeable Ca, and total CaO (pH factor, negative eigenvectors) were accountable for the largest negative loadings on PC1, whereas Al_o, Fe_o, C_{org}, N_t, and alkaline-earth metals (non-crystalline oxides, alkaline-earth metal factors, positive eigenvectors), which characterizes Andisols and Inceptisols contributed to the largest positive loadings in PC1 (Table 3; Fig. 2b). The result implied that PC1 increased by the contribution of OM, non-crystalline oxides, and alkaline-earth metals and decreased by the contribution of the pH factor. PC2 differentiated soils according to the degree of soil development. The well-developed Ultisols in Baybay contributed to the negative loadings, while the less-developed Andisols, Inceptisols, and Alfisols contributed to the positive loadings. The negative loadings in PC2 were contributed by crystalline and amorphous Fe oxides and the dominance of resistant oxides, particularly TiO_2 and Fe_2O_3 (Fig. 2b), implying the strongly weathered soils in Baybay (Navarrete et al. 2009) and Bato, respectively. In general, the PC1-PC2 plots revealed that changes in the distribution patterns of soils from the right to the (lower) left reflects depletion of exchangeable cations, decline in pH, and upsurge in the abundance of weathering-resistant oxides. The result suggests that continued weathering of Inceptisols, Alfisols, and Andisols will led to the formation of strongly weathered soils such as Ultisols of Baybay.

The results of the HCA are in conformity with PCA analysis. CA of the samples clearly clustered soils according to soil types, implying the importance of the soil forming processes and degree of weathering in every site. The first cluster is represented by Inceptisols with characteristic features of elevated soil pH, exchangeable Ca, and CaO, while Alfisols (high SiO_2) represented the second cluster. By contrast, the third cluster is represented by Ultisols, which have distinct characteristics of crystalline Fe oxides and resistant to weathering minerals, while the fourth cluster was typical for Andosols having high non-crystalline Al and Fe oxides, C_{org}, and N_t. PCA and CA analyses were applicable in differentiating study sites and soil types, and accordingly would be an important tool in designing suitable management practices of degraded soils.

Fertility status

The matching of the values between selected soil properties and published threshold or favorable values/condition of the same properties for crop growth or crop production (Tisdale et al. 1985; Landon 1991) allows one to recognize potential fertility constraints to the production of agricultural crops (Asio et al. 2006). The comparison may provide bases in planning suitable soil management strategies for crop production in this problem soils such as in our study site.

All soils revealed distinctive fertility constraints as reflected by the *negative* (-) or *positive* (+) sign (Table 5). The rooting depth, which refers to the amount of space available for plant roots, was substantially high (>50 cm) in all soils. However, there were variations in the rooting depth among soils as affected by the position of the soils in the landscape (Table 1). For instance, soils in the upper slopes had thinner soils, whereas thicker soils were dominant in the lower slopes of Ormoc and Baybay sites, respectively (data not shown). Regardless of the disturbed nature of the soils in some sites probably due to human activities such as cultivation, their bulk density was low (0.50-1.21 g cm^{-3}). The low bulk density in the soils of Bontoc, Bato, and Matalom is evident by the very good granular structure, whereas in the soils of Ormoc and Baybay, it was partly due to isovolumetric weathering of the parent material (Navarrete et al. 2008; Navarrete et al. 2009). The dominance of noncrytalline components, particularly allophane and imogolite in the soils of Ormoc (Asio 1996; Navarrete et al. 2008) and the abundance of halloysite in the soils of Baybay (Asio 1996; Navarrete et al. 2009) contributed to low bulk density in these soils. Low bulk density in all soils indicates a high porosity and accordingly, gas exchange between roots and atmosphere is excellent. The major physical constraint that likely influences soil use and management in the soils of Baybay (sites 6, 7, and 9), Bontoc (site 10), and Bato (site 11) is the heavy clay, which becomes hard when the soil is dry and becomes very plastic and very sticky when the soil is wet. Corresponding to the very plastic and very sticky feature, the soil becomes troublesome for farm operations due to resistance and compression. On the other hand, soils in Ormoc (sites 1-5), Baybay (site 8), and Matalom (site 8) were mostly medium-textured containing elevated amounts of sand and silt, implying a favorable condition for crop production.

Soil reaction measured in terms of pH influences many soil properties including cation exchange capacity, nutrient availability, and aggregation of soil particles (Landon 1991). Soil pH is a very useful parameter in fertility evaluation because it provides information on the potential availability or phytotoxicity of plant nutrients and nonessential elements in the soil (Landon 1991; Sims 1999). The water pH values in the soils of Ormoc (site 3), Baybay (site 8), and Bontoc (site 10) were within the favorable values of 5.5-7.0 for crop growth (Landon 1991). The alkaline and acid pH conditions are constraints for crop growth in site 12 and sites 4, 5, 6, 7, 9, and 11, respectively. Sims (1999) explained that in alkaline pH condition, availability of plant nutrients is reduced due to the decreased solubility of P, Cu, Fe, Mn, and Zn or greater sorption of B, while in acidic pH condition, plant availability of Ca, Mg, Mo, and P decreased due to increased solubility of Al and Mn resulting in plant toxicity of Al. The large deviation in pH values among soils implies distinctive fertility status inasmuch as the solubility of micronutrients and various nonessential trace elements is highly pH dependent. In terms of soil fertility management, the large deviation in pH values implies different fertility management among different soils. The contents of C_{org} were high in the soils of Ormoc (average: 3.02%) and low in the soils of Baybay (average: 1.27%), Bato (average: 1.07%), and Matalom (average: 1.07%). The high C_{org} in the Andosols of Ormoc can be interpreted to the formation of organo-mineral compounds that restrains OM decomposition (Shoji et al. 1993), whereas the low C_{org} in the soils of Baybay, Bato, and Matalom can be due to the past land use and varied human activities. Nitrogen turnover in tropical soils is elevated by high temperature and moisture (Jahn 1999), and accordingly the availability of N is not a limiting factor in the soils as has been observed in this study, except in site 11 of Matalom site. P availability (<3 mg kg^{-1}) in all soils was notably below the suitable amounts of 8-15 mg kg^{-1} (Landon 1991), suggesting that P is mainly the restricting nutrient in these degraded soils (Siebert 1987; Asio 1996; Navarrete et al. 2007). Low P availability in the soil can be explained by the low P content of the parent material, by the alkaline or acidic chemical condition of the soils, and in volcanic soils particularly Andisols in Ormoc, to the reaction of with non-crystalline Al and Fe oxides, resulting in the formation of insoluble metal-P compounds (Shoji et al. 1993). The capability of native vegetation to succeed in low P availability, particularly in Baybay (sites 6, 7, and 8) may partly be due to the external input of P into the forest ecosystem (Zikeli et al. 2000; Sueta et al. 2007) and to mycorrhizal association (Jordan 1985).

In terms of nutrient availability, exchangeable Ca was suitable (> 0.40 cmol/kg) in all soils, except in the soils of Matalom, that have been remarkably high exchangeable Ca due to the limestone parent material. Conforming to Tisdale et al. (1985), excess Ca as in the case of Matalom soils is a constraint because as the Ca/Mg ratio exceeds 7:1, Mg becomes deficient. Sites 1, 2, 4, and 12 exhibited constraint of exchangeable Mg as reflected by its low amount in the soils, while exchangeable K was not limiting in sites 1, 2, 3, 6, 9, and 11. Cu and Zn levels were suitable to crop growth as reflected by their high quantities in the soil. Although it was not observed in the calcareous soil of Matalom, Tisdale et al. (1985) stated that Zn is deficient in calcareous soil since it is adsorbed on carbonates.

Conclusion

Findings showed that most of the soil physical and chemical constraints are directly or indirectly related to the nature and qualities of the parent material, geomorphic position, and anthropogenic effect such as land use conversion. In addition, the soil fertility characteristics assessed have distinctive dynamics even within similar soil types, which is primarily due to their distinct relations to the dominant soil forming processes. The careful consideration of the soil physical and chemical constraints are essential in planning long-term soil management strategies that will lead to sustainable utilitization of these problem soils.

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Table 1. General site characteristics of the degraded soils in Leyte, Philippines

	Location		Altitude				
Study sites	Latitude (N)	Longitude (E)	(m)	Slope position	Parent material	Soil type[#]	Land use
Ormoc							
1	11° 05.565'	124° 40.096'	735	Shoulder	Basalt and Andesite	Typic Hapludand	Cultivated land
2	11° 05.581'	124° 40.052'	702	Backslope	Basalt and Andesite	Typic Hapludand	Cultivated land
3	11° 05.614'	124° 40.015'	671	Middle backslope	Basalt and Andesite	Andic Dystrudept	Cultivated land
4	11° 05.643'	124° 39.967'	660	Lower backslope	Basalt and Andesite	Acrudoxic Hapludand	Reforestation
5	11° 05.751'	124° 39.858'	666	Middle backslope	Basalt and Andesite	Typic Hapludand	Grassland
Baybay							
6	10° 44.905'	124° 48.262'	112	Upper backslope	Basalt	Typic Hapludult	Primary forest
7	10°44.688'	124°48.329'	107	Middle backslope	Basalt	Typic Hapludult	Reforestation
8	10° 44.753'	124°48.229'	99	Lower footslope	Basalt	Typic Haplohumult	Mahogany plantation
9	10° 44.614'	124°48.138'	75	Flat toeslope	Basalt	Typic Hapludult	Coffee plantation
Bontoc							
10	10° 16.794'	124° 49.085'	97	Upper backslope	Coralline shale	Typic Hapludalf	Secondary forest
Bato							
11	10° 19.884'	124° 56.535'	120	Lower footslope	Coralline shale	Typic Hapludalf	Secondary forest
Matalom							
12	10° 18.468'	124° 53.531'	121	Lower footslope	Coralline limestone	Rendollic Eutrudept	Grassland

[#] Soil Survey Staff (2006).

Table 2. Mean values of selected soil properties according to study sites and soil types

	Study site					Dominant soil type			
Soil properties	Ormoc (*n*=23)	Baybay (*n*=20)	Bontoc (*n*=5)	Bato (*n*=6)	Matalom (*n*=6)	Alfisols (*n*=11)	Andisols (*n*=18)	Inceptisols (*n*=11)	Ultisols (*n*=20)
pH-H_2O	5.28^{c}	5.41^{c}	6.47^{b}	5.23^{c}	8.14^{a}	5.79^{b}	5.25^{c}	6.89^{a}	5.41^{bc}
C_{org} (%)	3.03^{a}	1.27^{b}	1.77^{ab}	1.07^{b}	1.07^{b}	1.39^{b}	2.93^{a}	2.12^{ab}	1.28^{b}
N_t (%)	0.35^{a}	0.16^{b}	0.19^{b}	0.11^{b}	0.15^{b}	0.14^{b}	0.30^{a}	0.31^{a}	0.15^{b}
Sand (%)	40.5^{a}	22.3^{b}	30.3^{ab}	38.5^{a}	20.6^{b}	34.8^{ab}	41.43^{a}	28.14^{bc}	22.30^{c}
Silt (%)	38.4^{a}	17.6^{b}	25.1^{b}	15.9^{b}	41.7^{a}	20.10^{b}	39.46^{a}	38.57^{a}	17.63^{b}
Clay (%)	21.0^{c}	60.1^{a}	44.5^{b}	45.6^{b}	37.7^{b}	45.09^{b}	19.10^{c}	33.29^{b}	60.07^{a}
Exch Ca (cmol kg^{-1})	1.06^{c}	1.55^{c}	5.02^{b}	4.87^{b}	84.97^{a}	4.93^{b}	0.56^{b}	47.6^{a}	1.55^{b}
Exch Mg (cmol kg^{-1})	0.34^{c}	0.98^{b}	1.945^{a}	1.56^{a}	0.11^{c}	1.73^{a}	0.19^{c}	0.46^{c}	0.98^{b}
Exch K (cmol kg^{-1})	0.63^{a}	0.13^{b}	0.46^{ab}	0.50^{ab}	0.16^{ab}	0.48^{b}	0.18^{b}	1.11^{a}	0.13^{b}
Exch Na (cmol kg^{-1})	0.36^{a}	0.11^{b}	0.26^{a}	0.11^{bc}	0.00^{c}	0.18^{b}	0.36^{a}	0.16^{b}	0.11^{b}
CEC_{pot} (cmol kg^{-1})	13.85^{b}	20.09^{a}	16.61^{ab}	14.90^{ab}	20.66^{a}	15.68^{bc}	12.18^{c}	20.31^{ab}	20.09^{a}
Fe_d (g kg^{-1})	22.5^{b}	50.2^{a}	12.3^{bc}	16.5^{bc}	6.5^{c}	14.60^{c}	23.27^{b}	12.60^{c}	50.20^{a}
Fe_o (g kg^{-1})	9.0^{a}	7.0^{b}	4.1^{c}	3.5^{c}	1.3^{c}	3.76^{c}	9.47^{a}	4.13^{c}	6.95^{b}
Al_d (g kg^{-1})	13.0^{a}	7.2^{b}	2.1^{c}	2.0^{c}	1.22^{c}	2.42^{c}	14.28^{a}	4.37^{c}	7.21^{b}
Al_o (g kg^{-1})	27.0^{a}	6.7^{b}	3.7^{b}	2.7^{b}	2.0^{b}	3.15^{b}	30.40^{a}	7.73^{b}	6.75^{b}
SiO_2 (g kg^{-1})	498^{c}	428^{d}	599^{b}	690^{a}	263^{e}	65^{d}	499^{a}	240^{c}	428^{b}
Al_2O_3 (g kg^{-1})	296^{a}	295^{a}	227^{b}	183^{c}	116^{d}	20^{c}	299^{a}	137^{b}	296^{a}
Fe_2O_3 (g kg^{-1})	127^{b}	199^{a}	105^{c}	107^{c}	33^{d}	11^{d}	125^{b}	71^{c}	200^{a}

Different letter subscripts on the same properties indicate differences at significant ($P<0.05$).

n= number of samples.

Table 3. Loadings of the first three principal components with eigenvalue, cummulative percentage of variation, and estimated communalities of the variables

Variables	PC 1	PC 2	PC 3	Communality
pH	**-0,70**	0,50	-0,25	0,80
C_{org}	**0,66**	0,25	-0,28	0,58
N_t	**0,66**	0,26	-0,32	0,60
Exch Ca	**-0,74**	0,46	-0,43	0,95
Exch Mg	-0,01	-0,03	0,71	0,51
Exch K	0,35	0,23	-0,01	0,18
Exch Na	**0,69**	0,22	-0,03	0,52
CEC_{pot}	-0,28	-0,15	-0,07	0,11
Fe_d	-0,02	**-0,91**	-0,01	0,83
Fe_o	**0,72**	-0,22	-0,22	0,61
Al_d	**0,69**	-0,18	-0,39	0,65
Al_o	**0,68**	0,18	-0,38	0,63
$Feo_{/d}$	**0,60**	0,47	-0,15	0,61
SiO_2	0,45	0,21	0,74	0,79
Al_2O_3	0,59	-0,59	-0,08	0,70
Fe_2O_3	0,25	**-0,92**	0,13	0,94
MnO	**0,82**	-0,05	-0,26	0,74
TiO_2	0,19	**-0,89**	0,21	0,86
CaO	**-0,71**	0,46	-0,49	0,96
MgO	0,54	0,48	-0,24	0,58
K_2O	**0,65**	0,58	0,22	0,81
Na_2O	0,57	0,53	0,27	0,68
P_2O_5	**0,64**	0,21	-0,49	0,68
As	0,19	0,48	0,48	0,49
Co	0,46	-0,38	0,37	0,50
Cr	-0,22	0,12	0,90	0,87
Cu	0,09	-0,08	0,24	0,07
Ni	-0,03	0,55	0,63	0,71
Pb	0,27	**0,67**	0,50	0,77
Zn	0,47	-0,35	0,26	0,41
Eigenvalue	7,34	6,61	5,20	19,14
Cummulative % of variation	24	46	64	

Note: The major contributions of the original variables on each PC are printed in bold type.

Table 4. Selected soil properties of the surface soil layer of all studied sites

							Exchangeable						
			Depth	pH	C_{org}	N_t	Ca	Mg	K	Na	CEC_{pot}	Cu	Zn
Location	Site No	Horizon	(cm)	(water)	(%)		(cmol kg^{-1})					(mg kg^{-1})	
Ormoc	1	Ap	0-10	4,8	6,3	0,62	0,79	0,30	0,42	0,34	18,2	58	71
Ormoc	2	Ap	0-16	5,1	4,9	0,45	1,18	0,31	0,20	0,49	14,2	55	49
Ormoc	3	Ap	0-12	5,7	7,3	0,85	4,28	1,83	2,19	0,27	19,0	68	89
Ormoc	4	Ap	0-15	5,0	4,7	0,44	0,27	0,19	0,16	0,34	20,5	52	56
Ormoc	5	Ap	0-8	4,7	5,2	0,53	1,20	0,45	0,29	0,33	19,3	51	54
Baybay	6	Ah	0-8	5,1	2,9	0,33	1,28	0,95	0,26	0,05	15,6	54	78
Baybay	7	Ah	0-20	5,1	1,7	0,21	1,21	0,66	0,17	0,07	11,1	52	70
Baybay	8	Ah	0-10	5,7	2,1	0,24	4,97	2,02	0,19	0,07	33,5	49	88
Baybay	9	Ap	0-11	5,2	2,7	0,30	1,01	0,86	0,50	0,02	17,2	63	88
Bontoc	10	Ah	0-11	6,9	4,9	0,36	3,6	1,99	0,61	0,02	16,0	60	86
Bato	11	Ah	0-12	5,1	1,5	0,16	4,9	1,50	0,56	0,03	15,2	43	40
Matalom	12	Ah	0-7	7,8	3,6	0,44	89,3	0,20	0,08	0,00	11,3	60	40

Table 5. Fertility contraints to crop growth or production of degraded upland soils based on the surface layer of the soil*

				Bulk					Available	Exchangeable				
	Site	Depth		density		pH	C_{org}[§]	Nt[§]	P	Ca[§]	Mg[≠]	K[§]	Cu[&]	Zn[&]
Soil properties	No.	(cm)[†]	Texture[‡]	(g cm^{-3})[#]	Consistence	(water)[§]	(%)		(mg kg^{-1})[§]	(cmol kg^{-1})			(mg kg^{-1})	
Threshold value[¶]		> 50	Medium	< 1.45	fr, np, ns	5.5-7.0	> 3.0	> 0.2	> 8-15	> 0.40	> 0.50	> 0.20	40	> 10
Ormoc	1	+	+	+	+	-	+	+	-	+	-	+	+	+
Ormoc	2	+	+	+	+	-	+	+	-	+	-	+	+	+
Ormoc	3	+	+	+	+	+	+	+	-	+	+	+	+	+
Ormoc	4	+	+	+	+	-	+	+	-	+	-	-	+	+
Ormoc	5	+	+	+	+	-	+	+	-	+	+	-	+	+
Baybay	6	+	-	+	-	-	-	+	-	+	+	+	+	+
Baybay	7	+	-	+	-	-	-	+	-	+	+	-	+	+
Baybay	8	+	+	+	+	+	-	+	-	+	+	-	+	+
Baybay	9	+	-	+	+	-	-	+	-	+	+	+	+	+
Bontoc	10	+	-	+	+	+	+	+	-	+	+	+	+	+
Bato	11	+	+	+	+	-	-	-	-	+	+	+	+	+
Matalom	12	+	+	+	+	-	+	+	-	-	-	-	+	+

*Except for depth, which considers solum thickness.

fr, friable; np, non plastic; ns, nonsticky.

[¶] It can also be called "favorable value or condition".

[†] Based on Schlichting et al. (1995).

[‡] Based on Landon (1991). Clay texture with granular structure is favorable.

[#] Based on Arshad et al. (1996).

[§] Based on Landon (1991).

[≠] Based on Haby et al. (1990).

&Based on Sims (1999).

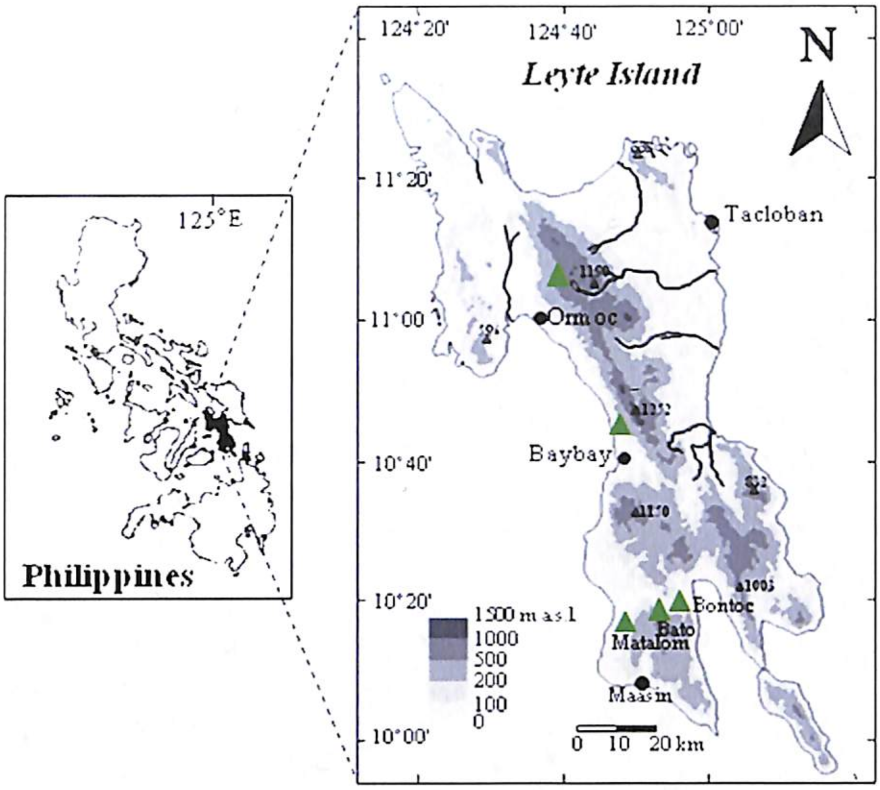

Fig. 1. Map of Leyte showing the approximate location of the study sites.

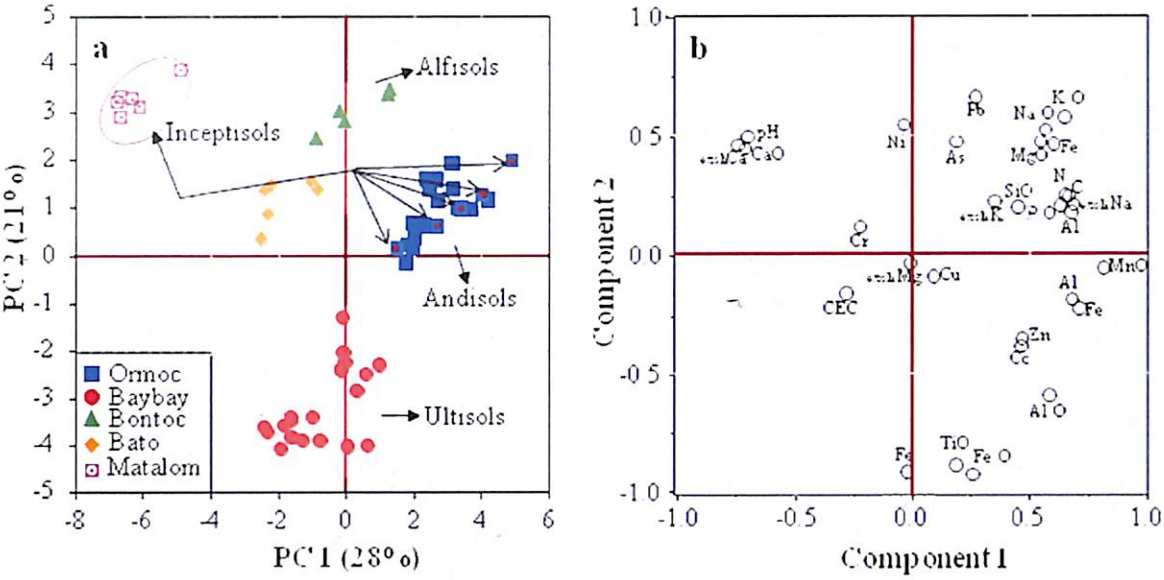

Fig. 2. Plots of the first and second principal components (PC) extracted from the principal component analysis (PCA) of all selected.

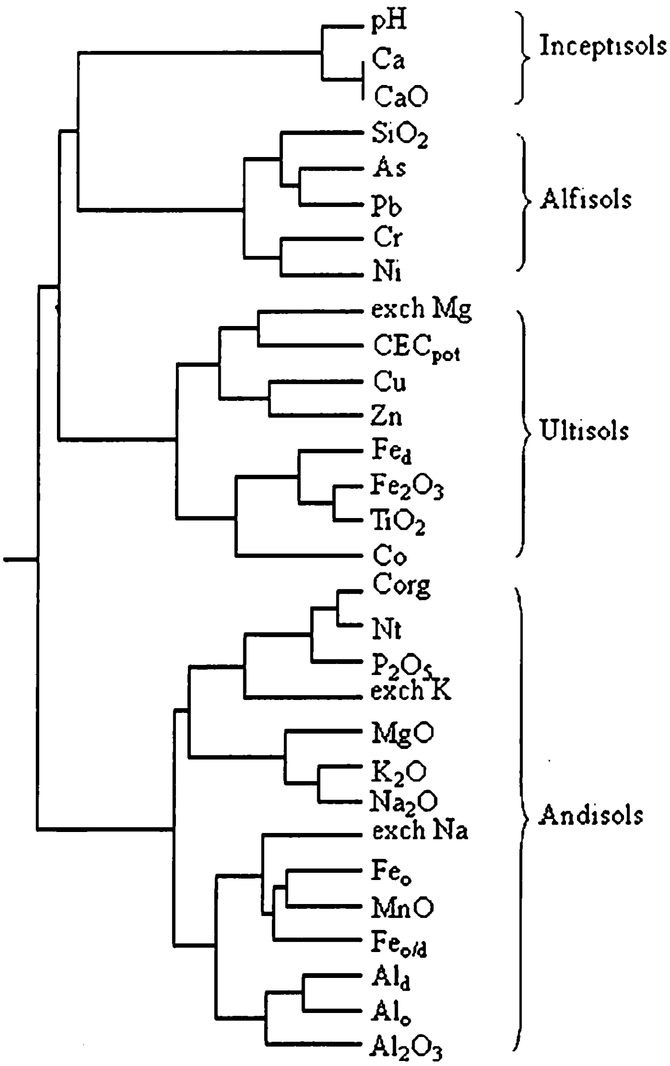

Fig. 3. Result of hierarchical cluster analysis for all soil properties (Ward's method, $n = 60$).