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RESEARCH NOTE

Properties and Nutrient Status of Degraded Soils in Luzon, Philippines

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A prerequisite to soil management, particularly in degraded soils, is a good knowledge of the characteristics and fertility status of degraded soil, which is fundamental to planning suitable soil management strategies for crop production purposes. The aim of this study was to determine the physico-chemical and mineralogical properties and fertility constraints of degraded soils in Luzon, Philippines. Ten surface soil samples were collected from 10 degraded soils representing the dominant soil series in Luzon Island. These soils were analyzed for physical, chemical and mineralogical properties. Results revealed that all soils have high clay content (except Bantay soil), which impedes cultivation. All soils were acidic, have a very low organic matter (OM), total N, available P, and low to moderately low exchangeable cations. X-ray diffraction reveals the dominance of halloysite/kaolinite, quartz and hematite in all soils. Results further revealed that all soils have fertility constraints, particularly acidic soils, low OM, low total N, and low available P. All soils contain sufficient exchangeable Ca, but low to high exchangeable K, particularly in soils of Annam, Bolinao, Bantay and Cervantes. Together, these results suggest that all soils possess physical and chemical constraints to crop production and the occurrence of constraints varies with soil type, location in the landscape, slope and parent material. The recognition of these fertility constraints is essential for the long-term planning of soil management strategies essential to sustainable utilization of these degraded soils.

Key words: acid soil, degraded soils, fertility constraints, mineralogy, soil series

INTRODUCTION

Drastic use and poor management of soil resources for agriculture can lead to soil degradation, a process that lowers the capacity of soils to produce goods or services (Blum 1998). The soil deterioration process has tremendous consequences considering the important functions of soils for plant production, buffering, transformation, filtering, geogenic, cultural heritage and infrastructure (Blum 1998). While soil degradation studies have been widely conducted in other tropical areas (Scherr & Yadav 1996; Obalum et al. 2012; Pimentel & Burgess 2013; Constantini & Lorenzetti 2013; Liang et al. 2013), a generalized understanding and knowledge of degraded soil, including its assessment and management are limited in the Philippines (Asio et al. 2009; Navarrete et al. 2013). The Philippines National Action Plan (NAP 2004) for 2004 to 2010 considered soil degradation as a severe environmental problem in the country. They estimated that about 5.2 million hectares of land are seriously degraded mostly in upland areas, leading to 30-50% reduction in soil productivity and thus, a threat to national food security

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(NAP 2004). This is disturbing, however, considering that degraded soils are perceived to be the next frontier for future crop production (NAP 2004) because of the scarcity of fertile land and the pressure to increase crop production in these areas will bring persistent long-term problems. Continuous use of degraded soils without good knowledge of it (e.g., Navarrete et al. 2013) has resulted in serious ecological problems, including low crop yield (Garrity 1993) and failure of past forest rehabilitation projects (Alcala 1997). Also, introduced crop production technologies designed for degraded areas in the country are not successfully adapted by farmers or have failed to alleviate crop production (Cramb 2001). This has even intensified soil degradation processes that are now currently occurring in these areas (Asio et al. 2009; Navarrete et al. 2013).

The recurrent problems of soil degradation *vis-à-vis* soil fertility decline and soil erosion resulting in low agricultural production requires the development of better knowledge on degraded soils (Asio et al. 2009; Navarrete et al. 2013). It is perceived that a holistic rethinking of degraded land use in the Philippines will optimize their future use, sustain productivity, enhance ecosystem services, and will diminish the negative ecological impact of soil degradation leading to a sound and sustainable management of these degraded soils. Accordingly, detailed information on their properties and fertility status is needed to provide an accurate basis for the adoption of soils to crops needed for sustainable and suitable land management (Navarrete et al. 2013). Consistent with our previous study (e.g., Navarrete et al. 2013), we anticipate that the results of this study will provide adequate knowledge for the suitable management of similar degraded areas in the Philippines. This study aims to elucidate the properties of some degraded soils in Luzon and to evaluate their fertility constraints.

MATERIALS AND METHODS

Soils

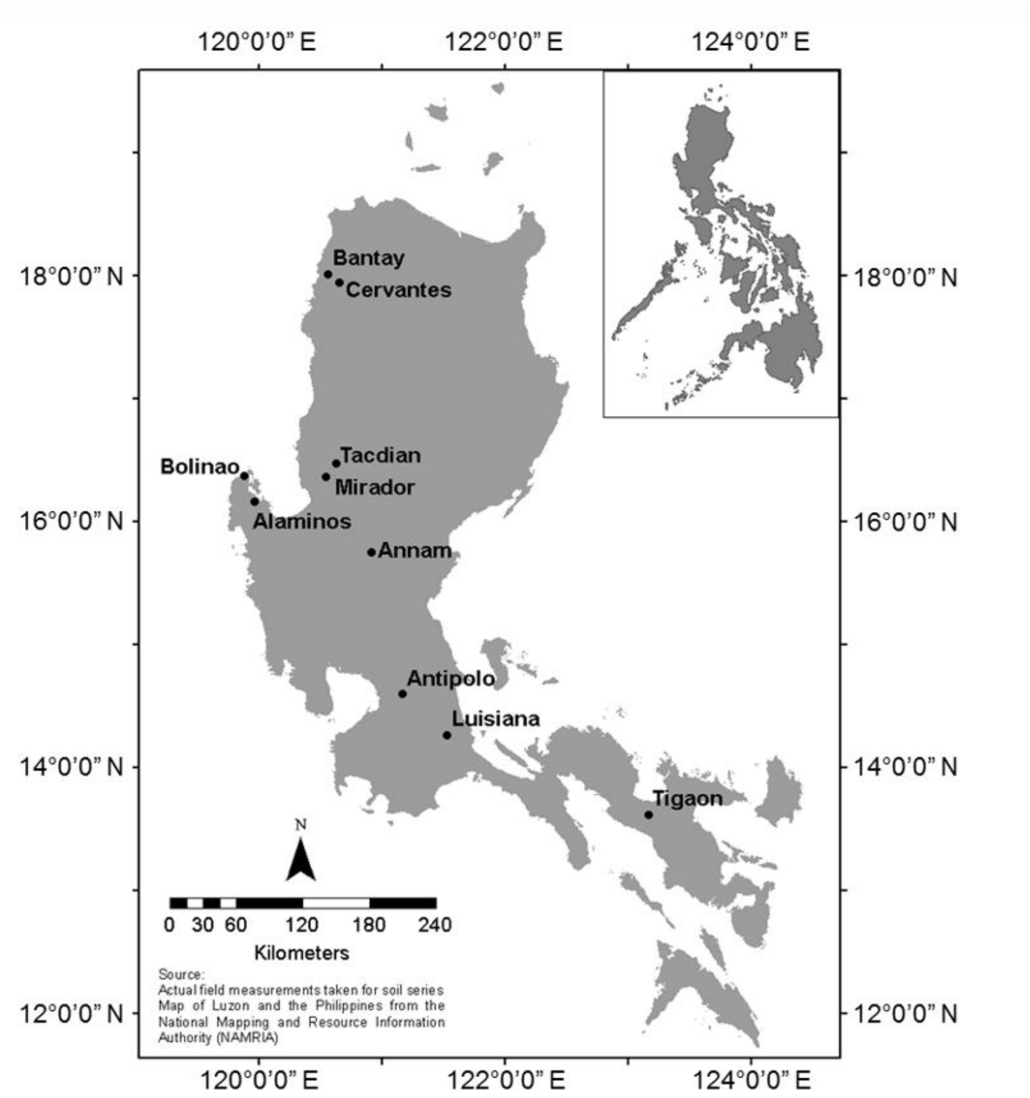
The study was conducted in selected areas on Luzon Island, where there is the degraded soil (Figure 1). Alaminos soil derived from basaltic rocks was collected in Alaminos, Pangasinan. The soil is considerably deep with no horizon differentiation from the surface down to the substratum. The area is rolling and hilly and the dominant vegetation consists of grasses with patches of trees. Annam soil was collected from Carangalan, Nueva Ecija. It has a light reddish brown surface soil to brick red subsoil developed from the weathering of basalt, andesite and shale (Carating et al. 2014). The soil has no distinct horizon differentiation, except in the concretions and gravel accumulation in the lower subsoil. Antipolo soil is moderately deep to deep mostly occurring on undulating to rolling basaltic hills in Antipolo, Rizal (Carating et al. 2014). The dominant vegetation of the area consists of fruit trees, root crops and bamboo. Bantay soil derived from Tertiary sediments of weathered shale and sandstone and mixtures of coralline limestone (Carating et al. 2014) was collected in Bantay, Ilocos Sur. The area is undulating, gently rolling to rolling and hilly. The dominant vegetation consists of grasses with patches of mango trees. Bolinao soil collected from Bolinao, Pangasinan is derived from coralline limestone and occupies the nearly level to undulating rolling and hilly areas. The dominant vegetation is grasses, corn and rice. Cervantes soil developed from old alluvium of shale was collected in Ilocos Sur. The dominant vegetation of the area consists of Imperata grasses with patches of trees. Mirador soil developed from unconsolidated sedimentary rocks was collected from Baguio City. Luisiana soil was collected in Laguna. The soil is well-drained occurring on a slightly dissected volcanic plateau with moderate to strong relief formed by the weathering of andesitic and basaltic parent materials. Tigaon soil was collected from Naga City. The soil was developed from volcanic ash and pyroclastic materials coming from Mt. Mayon. Tacdian soil developed from limestone was collected in La Trinidad, Benguet. A general description of the sampling locations, parent materials and soil classification using the USDA classification system (Soil Survey Staff 2014) are summarized in Table 1.

Soil sample collection and preparation

In each soil, ten representative sampling points that were randomly scattered approximately 25 m apart were selected. The sampling distance was used to attain wide variability in soil properties in each soil and to preclude possible autocorrelation in soil properties within sampling points. At each sampling point, we collected surface soil (0-25 cm) using a soil auger (7 cm diameter) and were composited in the field. Collected soil samples were brought to the Soils and Agroecosystems Division, University of the Philippines Los Baños, air-dried, freed of gravel, plant roots and other large organic residues, and was ground and allowed to pass through a 2-mm wire mesh and stored in plastic containers.

Physical, chemical and mineralogical analyses

Particle size distribution (i.e., clay, < 2 μm; silt, 2-200 μm; sand, 200-2000 μm) was determined by hydrometer method. Soil pH was measured potentiometrically in soil/suspensions of 1:1 1 M KCl and H_2O. Organic matter (OM) was analyzed by Walkley-Black method; total N was determined by the Kjeldahl method; available P



Source:
Actual field measurements taken for soil series
Map of Luzon and the Philippines from the National Mapping and Resource Information Authority (NAMRIA)

Figure 1. Map of the Luzon, Philippines and the location of the studied soils marked with a black solid circle.

Table 1. Location and parent material of selected degraded soils in Luzon, Philippines.

Location	Coordinates				
	Latitude (N)	Longitude (E)	Soil	Parent Material[a]	USDA classification[b]
Alaminos, Pangasinan	16°09'39.8"	119°58'17.9"	Alaminos	Old alluvium, Basalt	Typic Hapludults
Caranglan, Nueva Ecija	15°45'00"	120°55'00"	Annam	Basalt, andesite, shale	Typic Hapludults
Antipolo, Rizal	14°35'40.9"	121°10'4.6"	Antipolo	Basalt	Typic Hapludults
Payao, Ilocos Norte	18°0'46.61"	120°34'5.84"	Bantay	Old alluvium, sandstone, shale	Typic Hapludults
Bolinao, Pangasinan	16°22'18"	119°53'12"	Bolinao	Limestone	Typic Hapludults
Banna, Ilocos Norte	17°56'39.64"	120°39'34.71"	Vervantes	Old alluvium, shale	Typic Hapludults
Baguio city	16°21'35"	120°32'51"	Mirador	Sedimentary materials on limestone	Typic Hapludults
Cavinti, Laguna	14°15'39.1"	121°31'58.1"	Luisiana	Old alluvium, andesite	Orthoxic Palehumults
La Trinidad , Benguet	16°28'20"	120°37'59"	Tacdian	Limestone	Typic Eutrodepts
Carolina, Naga City	13°39'38.7"	123°16'50.3"	Tigaon	Volcanic ash, pyroclastic material	Typic Hapludults

[a] Fernandez and De Jesus (1980), [b] Soil Taxonomy (2014)

was extracted using 0.03 M NH_4F in 0.1 M NaF (Bray 2 method) and by the method of Murphy and Riley for color development and phosphate retention was determined following the method described by Blakemore et al. (1987). Exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ were extracted using 1 M NH_4OAc (pH 7.0) and the amounts were quantified by atomic absorption spectroscopy (AAS). Potential cation exchange capacity (CEC_{pot}) was determined by the steam distillation method. Effective cation exchange capacity (CEC_{ef}) was calculated as the sum of exchangeable Ca, Mg, K, Na, and exchangeable acidity (exch. Al^{3+} and H^+); percent base saturation ($\%BS_{pot}$) was calculated using the formula $\%BS_{pot} = (\Sigma$ of exch. Ca, Mg, K, and Na$)/CEC_{pot} \times 100$. Exchangeable Al^{3+} and H^+ were extracted by displacement with 1 M KCl (Thomas 1982). Available iron (Fe) was extracted with a diethylene tetramine penta acetic acid (DTPA) following the method described by Lindsay & Norvell (1978). Iron (Fe) in solution was determined by AAS.

For the mineralogical analyses, we submitted powdered fine soil to the National Institute of Geological Sciences, University of the Philippines, Diliman for the determination of the dominant minerals present in the samples. The X-ray diffractogram (full pattern fitting) of powdered fine-earth samples was determined using a Shimadzu XRD 7000 X-ray instrument equipped with CuKα radiation generated at 30 kV and 30 mA with a scan speed of $2°2\theta$ min^{-1}. Powdered samples were step-scanned from 3 to $50°2\theta$.

Soil fertility evaluation

Fertility evaluation of the soil was done by matching the values of selected soil properties with published threshold values of the same property for crop production (Tisdale et al. 1985; Landon 1991; Schlichting et al. 1995). Following the method used by Asio et al. (2006) and Navarrete et al. (2013) in their study of degraded soils in Leyte, the suitability or the constraints of a particular soil property for crop growth were expressed by a *positive* (+) or *negative* (-) sign. Positive denotes a favorable soil property for crop production and negative denotes a constraint to crop production.

Statistical analysis

Principal component analysis (PCA) was carried out using the SPSS Program (Version 16, SPSS Inc, Chicago, USA). All values used in the PCA analysis followed a normal distribution, which was confirmed by the shape of the histogram and the normal quantile plots using the above statistical software. The first and second principal component (PC) accounted for 50% of the total variance and the relevant components reported were those whose eigenvalues > 0.5.

RESULTS

Physico-chemical characteristics

Except for Bantay soil (sandy loam), all soils were generally clayey (Figure 2 & Table 1). Among soils, clay content was highest in Bolinao soil and lowest in Bantay soil.

All soils are acidic and have negative ΔpH (pH-KCl < pH-H_2O) (Table 3). OM was higher in Tigaon soil and is low in Antipolo soil. The C/N ratio in soils ranged from 9 to 17, with Alaminos, Antipolo, Bantay, Luisiana, Bolinao, Cervantes, and Tacdian having <14. Both the available P (2-7 mg/kg) and exchangeable bases (e.g. Ca, Mg, Na, and K) were very low in all soils. Results further revealed

Table 2. Physical and phylosilicate mineral characteristics of selected degraded soils in Luzon, Philippines.

Soil	Sand	Silt	Clay	Textural class [a]	Bulk sample phylosilicate minerals
		(g./kg)			
Alaminos	270	330	400	Clay	Quartz, Kaolinete, Halloysite, Hemite
Annam	170	310	520	Clay	Quartz, Kaolinete, Halloysite
Antipolo	260	280	460	Clay	Quartz, Kaolinete
Bantay	690	140	170	Sandy Loam	Quartz, Kaolinete, Halloysite
Bolinao	90	120	790	Clay	Kaolinete, Hematite, Halloysite
Vervantes	280	320	400	Clay	Quartz, Kaolinete, Halloysite
Mirador	190	300	510	Clay	Quartz, Kaolinete, Hematite
Luisiana	30	240	730	Clay	Quartsz, Halloysite, Kaolinite
Tacdian	230	370	400	Clay	Quartz, Kaolinite
Tigaon	200	300	500	Clay	Quartz, Kaolinete, Halloysite

Clay, <2 µm; silt, 2-200 µm; sand, 200-2000 µm
[a] USDA system

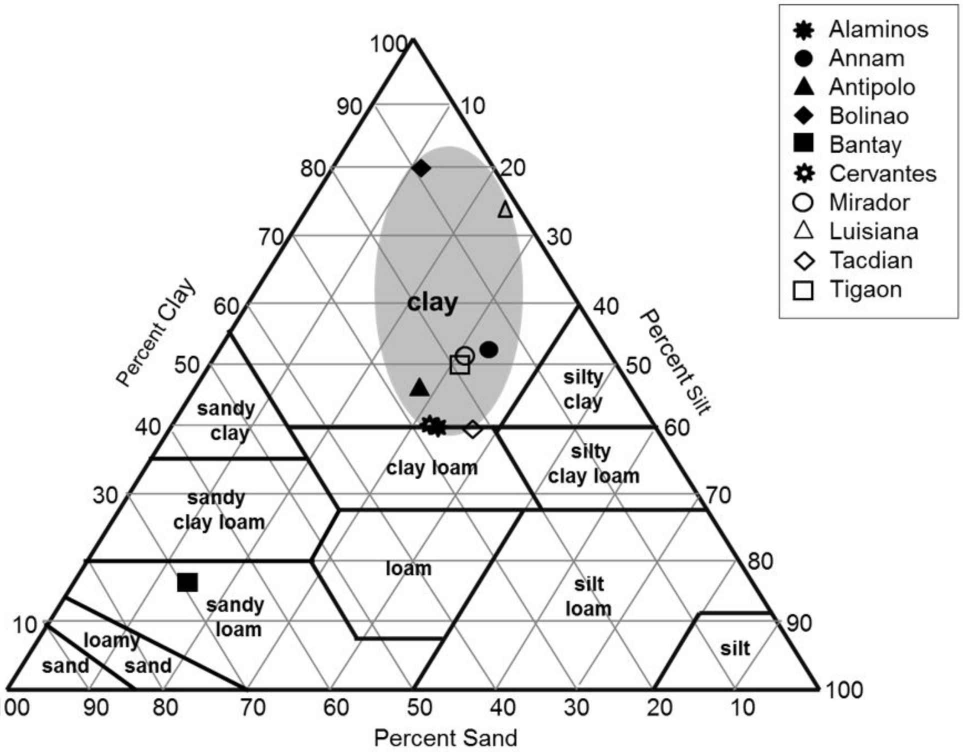


Figure 2. Particle size distribution and textural classes of soils studied based on the USDA textural triangle.

that the exchangeable Al^{3+} is the major component of exchangeable acidity in all soils, with Tacdian soil had the highest exchangeable acidity. The CEC_{pot} is 3 to 5 times higher than CEC_{ef} in Alaminos, Bolinao, Mirador, and Tigaon soils. Available Fe ranged from 11 (Annam) to 125 (Tigaon) mg/kg.

Mineralogical characteristics

Semiqualitative determination of minerals on powder specimens by X-ray diffraction technique reveals the dominance of halloysite/kaolinite (0.73 and 0.36 nm), quartz (0.44 and 0.33 nm) and hematite (0.25 nm) (Figure 3). The slight hump between 1 and 0.7 nm in Alaminos, Antipolo, Bantay, Bolinao, Luisiana and Tigaon soils, but is completely absent in Annam soil, indicate the presence of halloysite and kaolinite. All soils contain substantial amounts of quartz (0.44 and 0.33 nm) although soils from Alaminos, Annam, Antipolo, Bantay and Cervantes (Fig. 2a) contains 2 times more compared to other soils (Fig. 2b). Hematite (0.25 nm) peaks were observable in Bolinao, Luisiana, Mirador, Tacdian, and Tigaon soils (Fig. 2b) but were not observed in other soils (Fig. 2a).

Soil fertility

Except for Bantay soil, which is a medium-textured soil, all other soils have high clay content. The acidic condition of soils, which is below the favorable values of 5.5-7.0 for crop growth is a constraint for crop growth. However, it should be noted that the acidic condition of the soil may be a major limitation of productivity of one crop, but may pose only a minor limitation to another crop. As the available P is much lower than the favorable amount of available P in soils (8-15 mg/k) it appears to be the most limiting nutrients in these degraded soils. In terms of nutrient availability, exchangeable Ca in all soils was suitable to crop growth. Bantay and Luisiana soils exhibited constraints of exchangeable Mg as reflected by its low amount in soils. Exchangeable K was limiting (<0.20 cmol/kg) in Annam, Bolinao, Bantay, and Cervantes soils, suggesting that it is not suitable to crop growth. Contents of OM and total N were below the favorable values of >3% and >0.2%, respectively.

DISCUSSION

Soil characteristics

The wide variations in OM contents among soils can be explained by the differences in vegetation cover and from the compounding influence of the past and current land use and soil management practices. Positive relationship (r=0.808; p<0.001; n=10) between OM and total N

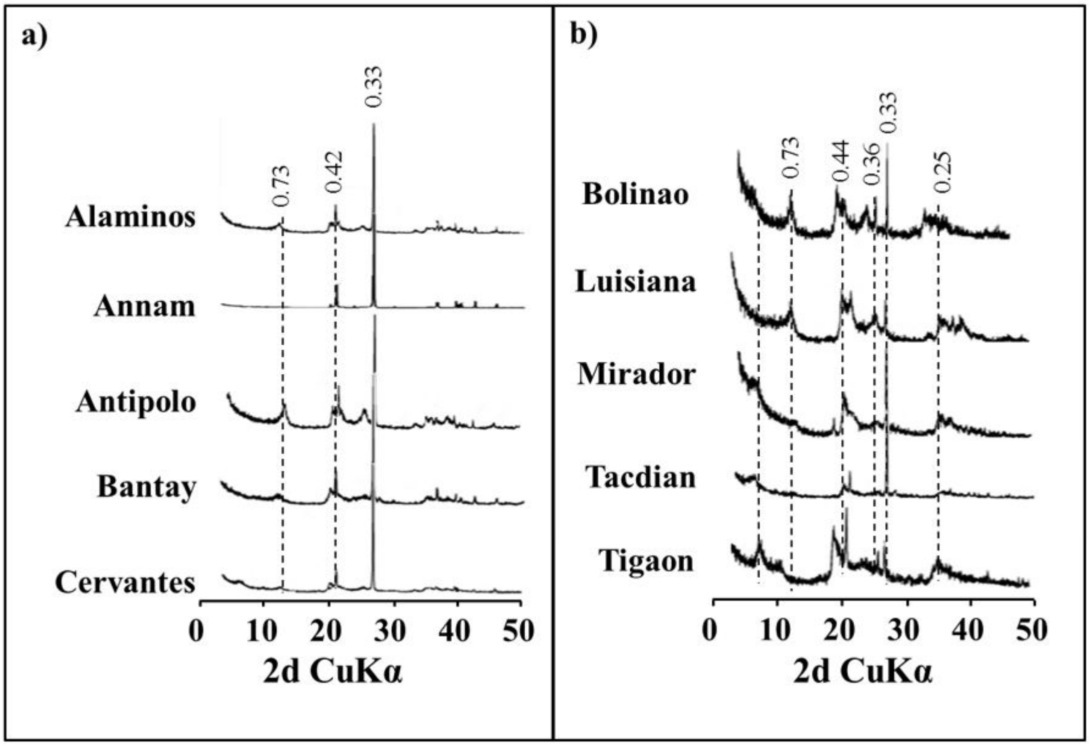


Figure 3. X-ray diffractograms of powdered fine earth samples.

contents of soils studied can be explained by the fact that >95% of N is bound in OM (Scheffer & Schachtscabel 1992). The very low P in these soils is in agreement with many other degraded soils in the Philippines (e.g., Asio et al. 2009). The exchangeable acidity, which is the amount of H^+ and Al^{3+} in the exchange complex, is an important feature of acid soil, because it is the major factor limiting plant growth. All soils have very high exchangeable acidity and is mostly dominated by exchangeable Al, which is another indication of the degraded nature of the soil. The dominance of halloysite/kaolinite, quartz and hematite in all soils are all indicative of the late weathering stage of the soil. Quantin (1990) observed that in strongly weathered soils such as in these soils, halloysite is more common than kaolinite, but as the weathering progresses, the former is less stable, and hence, it gives way to kaolinite and later to gibbsite. The abundance of quartz is probably inherited from the parent material or has formed through authegenic process. The presence of hematite corresponds to the red color of the soil.

Differentiating soils according to soil properties

All soils were distinctly distributed in the two PC, which explained 27 and 23% of the total variance, respectively (Figs. 2a and 2b). PC1 increased (positive eigenvectors) by the contribution of exchangeable acidity (Al^{3+} and H^+) and CEC_{ef} and decreased (negative eigenvectors) by the contribution of pH factors (pH KCl and ΔpH). These results imply that under acidic condition, exchangeable acidity increases in soils, which in turn influences soil fertility. PC 2 increased (positive eigenvectors) by the contribution of OM, exchangeable K and Na and available Fe (exchangeable bases factor) and decreased (negative eigenvectors) by the contribution of the BS_{pot} factor. PC 2 loading indicates the degree of OM decomposition and loss of cations in soils. In addition, PC2 differentiated soils according to their mineralogy (*see, for example*, Figs. 2a and 2b). Luisiana, Mirador, Tacdian and Tigaon soils, which are dominated by halloysite/kaolinite and hematite (Fig. 2b) contributed to positive loading, with the exclusion of Bolinao soil overlapping, whereas Alaminos, Annam, Antipolo, Bantay and Cervantes soils were dominated by quartz that contributed to the negative loading (Fig. 2a). Interestingly, PCA analyses did not differentiate soils according to soil or parent materials. It appears that soil pH has a controlling influence on fertility and constraints of soils. Overall, PC1-PC2 plots revealed that changes in the distribution patterns of soils from left to upper right indicates increases in exchangeable acidity and acidic condition of soils and thus, CEC_{ef} is dominated by exchangeable Al^{3+}. Distribution patterns of soils from lower to upper directions result to increases in halloysite/kaolinite and hematite, suggesting that continues weathering of Alaminos, Annam, Antipolo, Bantay and Cervantes soils will lead to the formation of strongly weathered soils such as Bolinao, Luisiana, Mirador, Tacdian and Tigaon soils. PCA analysis was successful in differentiating soils according to mineralogy, which directly influence CEC of soils, and would be a robust tool in designing suitable management practices for degraded soils.

Fertility constraints and implications

All soils possess physical and chemical fertility constraints for crop production as revealed by *negative* (-) or *positive* (+) sign (Table 4). Higher sand content in Bantay soil could be derived from the weathering of the sandstone parent material, whereas the high clay content in most of soils indicates a physical constraint that will influence soil use and management. For example, the high clay content becomes hard when the soil is dry and becomes very plastic and very sticky (*data not shown*) when the soil is wet is troublesome for farm operations due to mechanical resistance and compression. Also, clayey soil has low infiltration rate, thus often poorly drained, but is favorable for cultivation of paddy rice.

The acidic nature of all soils can be explained to the intensive leaching of the basic cations and is favored by the high rainfall and stable land surface. Under this condition, exchangeable Al^{3+} is the major cation in the soil (Kamprath 1980). The high acidity in the soils makes it more difficult to neutralize its acidity because

Table 3. Chemical characteristics of selected degraded soil in Luzon, Philippines.

							P								Exchangable					
	pH			OM	Nt		avail	P-ret	Exch. bases (cmol$_c$/kg)					(cmol$_c$/kg)			CEC$_{eff}$	CEC$_{pot}$	BS$_{pot}$	Avail Fe
Soil	H_20	KCl	ΔpH	(g/kg)		C/N	(mg/kg)	(%)	Ca	Mg	Na	K	∑EB	Al^{3+}	H^+	EA	(cmol$_c$/kg)		(%)	(mg/kg)
Alaminos	5.4	4.3	-1.1	14.3	0.8	10	2.2	29	1.8	0.9	0.5	0.2	3.4	0.12	0.01	0.1	3.5	9.7	34.8	30.0
Annam	5.0	3.6	-1.4	20.0	0.7	17	7.0	43	3.8	0.9	0.2	0.1	5.0	6.70	0.00	6.7	11.7	14.7	34.3	11.1
Antipolo	4.9	3.5	-1.4	10.7	0.6	10	2.9	40	4.6	1.3	0.3	0.4	6.6	2.77	0.33	3.1	9.7	19.6	33.9	33.3
Bantay	4.9	3.7	-1.2	14.3	0.6	14	1.7	19	1.6	0.5	0.4	0.1	2.6	1.26	0.44	1.7	4.3	7.9	32.9	18.4
Bolinao	5.4	4.2	-1.2	19.9	0.9	13	4.5	44	9.4	1.4	0.4	0.1	11.3	0.21	0.02	0.2	11.5	30.2	37.4	27.1
Cervantes	5.0	3.5	-1.5	22.3	0.9	14	2.2	60	3.4	1.6	0.4	0.2	5.6	10.16	1.97	12.1	17.7	30.3	18.3	14.7
Mirador	5.4	4.2	-1.2	26.9	1.0	16	5.8	67	7.1	1.2	0.6	0.6	9.4	0.21	0.02	0.2	9.7	36.0	26.2	26.4
Luisiana	4.5	3.3	-1.2	19.2	1.3	9	4.7	61	0.8	0.2	0.5	0.2	1.7	7.82	1.58	9.4	11.1	18.7	8.8	78.2
Tacdian	5.0	3.4	-1.6	29.2	1.3	13	4.5	76	5.0	3.1	0.6	0.6	9.3	13.20	2.27	15.5	24.8	30.6	30.3	45.6
Tigaon	4.9	4.0	-0.9	36.0	1.4	15	3.8	55	2.5	1.0	0.6	1.1	5.1	0.33	0.14	0.5	5.6	26.6	19.2	125.1

0.6OM: organic matter; Nt: total nitrogen; P-ret: phosphate retention; EB: exchangable bases; EA: exchangable acidity

Table 4. Nutrient status of selected degraded soils based on the properties of soil surface layer.

						Exchangeable bases		
		Soil pH				Ca ^{c}	Mg ^{d}	K ^{c}
Soil properties	Texture ^{c}	(H_2O) ^{c}	C_{org} ^{c}	N_{total} ^{c}	Available P	>0.40	>0.50	>0.20
Threshold value ^{a}	Medium	5.5 – 7.0	>3%	>0.2%	8 – 15 ppm	cmol$_c$/kg		
Alaminos	−	−	−	−	−	+	+	+
Annam	−	−	−	−	−	+	+	−
Antipolo	−	−	−	−	−	+	+	+
Bantay	−	−	−	−	−	+	−	−
Bolinao	−	−	−	−	−	+	+	−
Cervantes	+	−	−	−	−	+	+	−
Mirador	−	−	−	−	−	+	+	+
Luisiana	−	−	−	−	−	+	−	+
Tacdian	−	−	−	−	−	+	+	+
Tigaon	−	−	−	−	−	+	+	+

a It can also be called "favorable value or condition"; b Based on Schlichting et al.; (1995). c Based on Landon (1991); d Based on Haby et al. (1990). Plus sign (+) indicates that soil property is favourable for crop growth; minus sign (-); soil property is a constraint to crop production.

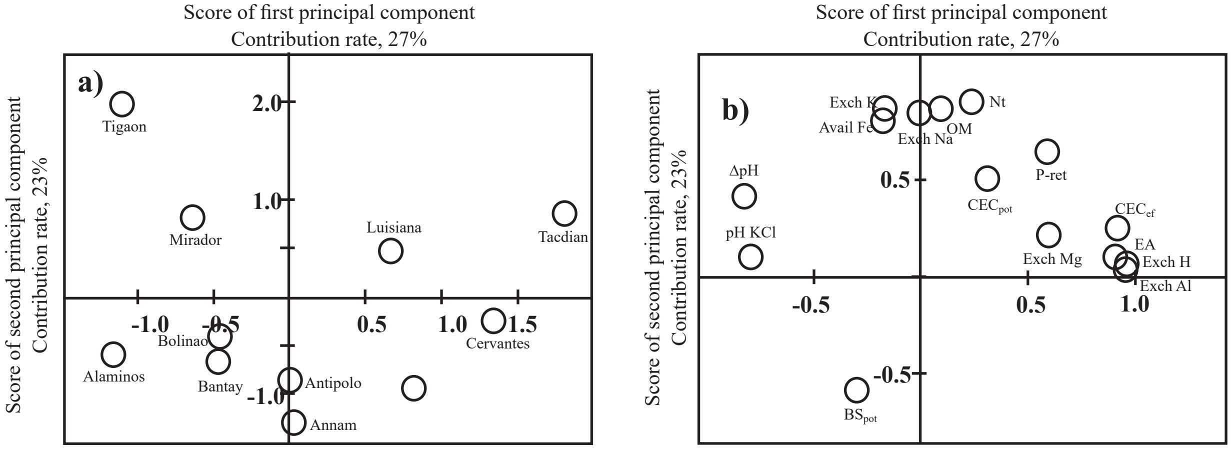


Figure 4. Plots of the first and second principal components (PC) extracted from the principal component analysis (PCA) of all selected properties. (a) distribution of soil samples and (b) distribution of soil properties (only eigenvalues >0.5 were included).

of the high buffering capacity and consequently would require higher lime requirement. In addition, the low exchangeable bases in all soils were expected considering that these soils were under long history of cultivation before they were turned to the present land use. The large difference between CEC$_{pot}$ and CEC$_{ef}$ (Table 3), indicates the amount of variable charge in soils (Sanchez 1976). Bautista & Briones (1988) reported that based on their evaluation of the different methods for CEC$_{pot}$ determination in some degraded soils in the Philippines found that CEC (determined by 1 M NH_4OAc at pH 7) is higher than the sum of exchangeable bases, including exchangeable Al extracted by 1 M KCl. This is because of the overestimation of CEC$_{pot}$ due to the changes of the original pH of the soil. Driessen & Dudal (1991) pointed out that CEC$_{ef}$ represents the CEC at field conditions, thus, is of great practical importance particularly to plant nutrition. Interesting to note that despite differences in the parent materials, all soils showed less variability in its mineralogical characteristics, which suggests that different parent materials may develop into closely related soils at the advanced stage of soil development and weathering as predicted by Chesworth (1973).

The standard practices of soil fertility research in the country are focused on three mineral nutrients, namely N, P and K. Our results suggest that such standard practice may have limitations for fertility evaluation of degraded soils because there are also other important soil properties that also influence crop growth and is one of the many reasons why alleviation of crop production in these areas has failed in the past. 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 agricultural crop production (e.g. Asio et al. 2006). Such approach provides valuable information on designing appropriate soil management strategies for sustainable crop production (Navarrete et al. 2013), particularly in problem soils such as in our study sites. This simple method of fertility evaluation is robust and we anticipate it will be useful in fertility evaluation of other degraded soils in the Philippines.

CONCLUSION

Based on the results of the study, it may be concluded that in terms of physical properties, except for Bantay soils, all soils have a high amount of clay. For Bantay soils which have a sandy top soil, a surface cover should be maintained to reduce risk of wind erosion and soluble fertilizers should be applied in split applications to minimize leaching of nutrients. All soils are acidic, have low exchangeable bases, low available P, and high exchangeable Al, which are constraints for crop growth. In this regard, for all soils studied, lime should be applied to raise the soil pH within the range 5.5-6.0. Application of lime increases soil available P, CEC and reduce the activity of Al and/or Fe which may consequently decrease P fixation. Farming systems that include highly acid tolerant plant species may be used where liming is not practical. Also, addition of OM to mineral soils may help ameliorate soil acidity. Understanding both the physical and chemical constraints is essential in planning long-term soil management strategies that will lead to the sustainable utilization of these degraded soils.

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