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Chemical Properties Disparity of Forest Soils Derived from Ultramafic Rocks in Mindanao Island, Philippines

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ABSTRACT

There are several ophiolite complexes in the Philippines that serve as the birthplace of serpentinite derived soils which are generally described as infertile soils. In the northern part of Mindanao Island of the country a rainforest which sustains wild life and protects a vast watershed sits on this serpentinite environment. Thus, a study was made to assess the soil chemical properties in order to help in understanding the present condition of this forest. Soil samples were collected from four sites with different elevations but of similar topography. Soil samples were subjected to laboratory analysis for pH, organic matter content, total nitrogen, extractable phosphorous, exchangeable potassium and cation exchange capacity. Based on the values of the different soil chemical properties measured, soil fertility index was calculated. Result showed that there is significant variation of different soil chemical properties among sites. Soil fertility index among sites also varies and had showed low fertility index.

Keywords: Serpentinite, Forest soils, Soil Fertility Index

INTRODUCTION

The Philippines is composed of more than 7,000 islands of relative geologic origins. This in turns leads to the development of various types of soil sustaining an array of biota. In some parts of the country, soils originate from serpentine rocks or serpentinite. Serpentinite is ultramafic rock found in an ophiolite complex. There are several ophiolite complex in the country. Among these, are Zambales ophiolite and Palawan ophiolite. A considerable portion of northern part in Mindanao Island which includes the municipalities of Cantilan and Carascal also lay on an ophiolite complex.

Soils derived from serpentine rocks occur in isolated patches all over the world, particularly along continental margins (Brooks, 1987; Tahakor et al., 2013). Approximately 1% of the worlds' continental planes are covered with ultramafic rocks (Garnier, et al., 2009). In general, areas where serpentine rocks are found are gravelly texture low clay content and has a steep topography (Brady, et al., 2005). Serpentine rock is basically a magnesium iron silicate, from metamorphosis of peridotite and usually contains chromite, $FeCr_2O_4$ and significant portion of Ni and Mg (Whittaker, 1954). After the primary mineralization of the serpentine rock, the chemical composition and physical characteristics of the weathered material is also changed by vegetation (Chiarucci, et al., 1998 and Weerasinghe, et al., 2011). Climate also plays a significant role in physico-chemical condition of these rocks (Chiarucci, et al., 1998). Furthermore, weather in tropical humid climates is a vital factor in the formation of thick lateritic red soils (Baillie, et al., 2000).

Serpentinite derived soils are a model system for the study of plant adaptation, speciation, and species interactions (Brady, et al., 2005 and Anacker, 2014). These soils are harsh environment for plants because these soils are generally infertile (Tashakor, et al., 2013). The distinctive vegetation of soils from serpentinite and related rocks sharply set apart such areas from adjacent non-serpentine terrain in many regions of the world. The plant life of these serpentine areas varies greatly with location, topography, depth of soil and other factors (Brady, et al., 2005). Petrologic and structural diversity supports different plant communities based on soils evolved from ultramafic materials (Burgess, et al., 2009). Due to its edaphically stressful and low productivity soil type, it hosts stunted vegetation and a spectacular level of plant endemism (Anacker, 2014). Concentrations of potentially toxic metals such as Ni, Cr, and Co are usually considered as one of the main causes of the vegetation dynamics of ultramafic soils (Brooks, 1987; Brady, et la., 2005; Burgess, et al., 2009 and Tashakor, et al., 2014). Some continents (Australia, Europe, North America) serpentine rock derived soils are relatively well-studied, but many other areas (Asia, Africa, South America) are comparatively unknown (Harrison, et al., 2008).

Despite being described as generally infertile, a tropical rainforest acting as stronghold of wildlife and protects the vast Carac-an watershed sits on a serpentinite environment in the municipalities of Cantilan and Carascal. Information on soil quality in these areas is generally scarce making the current state of these soils is unknown. Thus, a study was made to determine the soil chemical properties to help in understanding the present condition of the forest.

MATERIALS AND METHODS

Four sites were identified prior to soil collection. The sites were situated near Carac-an and Alamio river with varied elevations but of similar topographic features. Each sampling site has three 10m x 10m plot. Samples were collected using soil probe at a depth of 20cm. Sample collection in each plot followed a zigzag pattern with 100 probe holes and a 1 kg of composite soil sample was obtained. Soil samples were then air dried for 5 days and sieved through 2mm sieve plate to obtain fine earth in preparation for chemical analysis.

Soil pH was measured using potentiometric method. Soil organic matter content was analysed through Walkley and Black method or wet combustion. Total Nitrogen (N) was analysed through Kieldhal method. Available phosphorous (P) was analysed using Bray method for acidic soils while, exchangeable Potassium (P) concentration was analysed using ammonium acetate method (flame photometer). Furthermore, Cation Exchange Capacity (CEC) was analysed through ammonium acetate method and soil texture was analysed using hydrometer method.

In order to understand the soil condition, a soil fertility index (SFI) was calculated. Soil fertility index is used to correlate the different parameters. This was made by creating a range of values of the soil chemical properties parameters and designating a score in every range (Table 1). Soil Fertility Index was then calculated based on the equivalent score of each parameter. Moreover, soil fertility index is ranged and is given a corresponding description (Table 2). Analysis of variance and Tukey HSD was used to analyse the variation of fertility index among sites.

Table 1. Equivalent score of different soil chemical properties.

Score	Ph	OM %	Total N (mg/kg)	Extractable P (mg/kg)	Exchaneable K (mg/kg)	CEC (cmol$_c$ /kg soil
1	<5.4	<0.5	<2000	3 below	50 below	0 - 20
2	5.5 to 6.9	0.51 to 1.9	2100 to 5000	3 to 8	50 to 149	20 - 60
3	>7	>2	>5000	8	150	60 - 300

$$\text{Soil Fertility Index} = \frac{\text{pH} + \text{OM\%} + \text{TotalN} + \text{ExtractableP} + \text{Exchangeable K} + \text{CEC}}{\text{Total Number of Parameters}}$$

Figure 1. Formula for calculating soil fertility index.

Table 2. Soil fertility index range and its corresponding value.

Fertility Index	Description
1 - 1.66	Low to Very Low
1.67 - 2.32	Average
2.33 - 3	Sufficient

Table 3. Mean of values of soil chemical properties.

Sites	pH	OM %	Total N (mg/kg)	Extractable P (mg/kg)	Exchaneable K (mg/kg)	CEC (cmol c/kg soil
1	4.43^{a}	3.24^{a}	1366.67^{ac}	1.74^{a}	53.00^{a}	19.10^{a}
2	7.10^{b}	7.53^{b}	2566.67^{bcd}	0.29^{b}	30.00^{a}	28.87^{a}
3	5.47^{c}	4.58^{ab}	2033.33^{abc}	0.27^{b}	23.67^{a}	23.67^{a}
4	4.67^{a}	5.99^{ab}	3033.33^{bd}	0.27^{b}	90.00^{b}	61.67^{b}

1) Up-stream of Alamo River 2) Mid-stream of Alamo River 3) Up-stream of Carac-an River 4) Mid-stream of Carac-an River

Means of the same letters are not significantly different at 5% level with Tukeys HSD

RESULTS AND DISCUSSIONS

Soil pH among sites falls at different range. Though basic soils are not typical in a tropical rainforest, interestingly, soil samples collected from the midstream of Alamio river has an average pH value of 7.1 (Table 3). Soil samples collected from upstream of Alamio river and mid-stream of Carac-an river are the most acidic. Tropical soils were moderately acidic, with a mean soil pH of 5.9 (Joergensen, 2012). In forest soils, acidity affects several ecological processes including the solubility and exchange reactions of plant nutrients and toxic metals, soil biological act:vity and soil mineral weathering (Binkley and Richter, 1987). Acid soils comprise approximately 63% of the land area in the humid tropics (Sanchez, 1987). Due to large amounts of precipitation, increased soil acidification and nutrient loss through weathering and leaching is typical in humid tropical areas (Fujii, et al. 2010). Furthermore, soil acidification is also promoted by plants and microorganisms as a nutrient acquisition strategy (Harter, 2002 and Fujii, 2014).

Soil organic matter (SOM) among sites has large degree of variation. Soils collected from the midstream of Alamio river has the highest SOM meanwhile, soils from up-stream of Alamio river has the lowest SOM. Variations of soil organic matter can be attributed to soil mineralogy, climate, landuse, soil physical properties (Feller and Bealer, 1996; Adachi, et al., 2011). Soil organic matter consists of a variety of components. These include, in varying proportions and many intermediate stages, an active organic fraction including microorganisms, and resistant or stable organic matter (FAO, 2005). Because of high rainfall frequency in tropical rainforest, large amount organic matter in the form of dissolved organic matter are found in the soil layer (Cleveland, et al., 2006; Zhou, et al., 2014). Because of dynamism of SOM partitioning the different SOM fraction in the soil is challenging (von Lutzow, et al., 2007). Furthermore, there is significant negative correlation between soil pH and soil organic C in tropical rainforest soils derived from metamorphic parent materials but not for soils derived from basalt, granite, acidic volcanic materials or alluvium (Spain, 1990).

Acidic soil pH affects organic C though reduction of solubility of organic C compounds (Vance and David, 1991) and alterations in organo-mineral interactions in tropical soils with variable-charge (Oades, 1988 and Oades, 1989).

Total soil nitrogen (N) significantly varies among parameters though, it can be observed that soils from the mid-streams of both rivers have the highest content of soil N. Interestingly, the variation of extractable phosphorous of soils from up-stream of Alamio river is very much different from the three other sites. Soils from mid-stream of Carac-an river have significantly higher exchangeable potassium and cation exchange capacity in comparison with the other three sites. Concentrations of total N in the soil from a range of lowland rain forests around the world were 0.02-1.0% (Proctor, 1983). Soil nutrient composition has a direct correlation with respect to organic matter content in the soil (Cleveland, et al., 2006).In tropical forest ecosystems, a paradoxical relationship is commonly observed between massive biomass production and low soil fertility. (Harter, 2002 and Fujii, 2014). N,P, and K had shown to be a limiting factor on a tropical ultramafic soil (Brearley, et al., 2005). Serpentine soils are often deficient in essential plant nutrients such as nitrogen, potassium, and phosphorus (Brady, et al., 2005; Brooks 1987).

Table 4. Soil fertility index among sites.

Sites	Replication			Total	Mean
	1	2	3		
Up-stream of Alamio River	1.67	1.50	1.33	4.50	1.50[a]*
Mid-stream of Alamio River	2.00	1.83	1.67	5.50	1.83[ab]
Up-stream of Carac-an River	1.67	1.50	1.67	4.83	1.61[a]
Mid-stream of Carac-an River	1.83	1.83	2.17	5.83	1.94[b]

*Means of the same letters are not significantly different at 5% level with Tukeys HSD

Soil fertility index (SFI) from up-stream sites is low in contrast to mid-stream sites which is average (Table 4). Despite having the highest index among sites, the value SFI of soils from midstream of Carac-an river is quite far from the boundary of average and sufficient soil fertility index. Soils from serpentine rocks creates harsh environment for plants because these soils are generally infertile (Tashakor, et al., 2013). Their infertility seems to be due to locally variable combinations of droughtiness, susceptibility to fire, imbalances in the cationic nutrients, heavy metal toxicities, and phosphorus fixation (Baillie, et al., 2000). This edaphically stressful and low productivity soil type leads to stunted vegetation (Oze, et al., 2008; Anacker, 2014). Furthermore, the variations on different soil chemical properties in a specific area can be attributed to some factors such as specific topography, animals and vegetation (Fisher and Binkey, 2000).

CONCLUSION

The disparity of the result in chemical analysis of soil samples in all sites suggests that there is differentiation of soil chemical characteristics despite of originating from the same parent material though, factors contributing to these variations have yet to be identified. Furthermore, low soil fertility index suggest the state of vulnerability of the forest ecosystem from any destructive activities because rejuvenation of its vegetation may take a very long period due to its inherent soil infertility. Lastly, studies on other factors that may significantly affect soil fertility such as solubility of heavy metals and immobilization of primary nutrients.
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