Relationships between mineralogical properties and carbon and nitrogen retention in upland soils of Thailand

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Abstract
Soil organic matter (SOM) is both a source and a sink for C and it plays an important role in enhancing fertility, productivity and sustainability of agro-ecosystems. The C and N retention capacity of soil is known to be related with soil environmental conditions and soil properties including mineralogical properties. Specific surface area (SSA) and cation exchange capacity (CEC) of clay minerals have been shown to be positively related with C and N contents of soils. However, such relations are not well established and understood particularly for soils in Thailand. The objective of this study is to make a detailed assessment of the relationships between relevant soil properties and C and N retention mechanisms in mineralogically contrasting upland soils from Thailand. Several mineralogically contrasting soils were collected from four cropping systems (corn, sorghum, sugarcane and cassava) in Northeast plateau region of Thailand. Soils were characterized for important physical, chemical and mineralogical properties. Total C and N and CEC are being analysed in bulk soils, and particle-size (sand, silt and clay), and density-separated fractions of soils. The findings from this study will have implications for optimal management of SOM to enhance agricultural productivity and sustainability of upland soils in Thailand.

Key Words
Smectite, kaolinite, clay-organic interaction.

Introduction

SOM is an important source and sink for C and also contributes to improving fertility, productivity and sustainability of soils and agriculture production. Unfortunately, under tropical climate including Thailand, high temperature and rainfall and widespread adoption of cultivated land uses have accelerated decomposition rate of SOM. Soil organic matter can be increased by practices that return greater quantities of organic matter in soil. The content and type of clay mineralogy can also play an important role in retaining the added organic C and N in soil (Christensen 1992; Cheshire *et al.* 2000) through physical-chemical stabilization and formation of soil aggregates (Krull *et al.* 2003). Among phyllosilicates, smectites have been shown to be more intimately associated with retaining and increasing SOM than the other clay minerals (Wattel-Koekkoek *et al.* 2003), mainly due to their high SSA and CEC (Kaiser and Guggenberger 2003). In contrast, several studies have found that Fe and/or Al oxides can also have a large influence on the retention of organic C in soil and usually are better adsorbents for organic C than phyllosilicates (Chorover and Amistadi 2001; Kaiser *et al.* 2002). This study is being conducted to understand the role of soil mineralogical and other properties in the retention of C and N in soil. The findings from this study will be useful for devising management practices that helps in improving soil organic matter in mineralogically contrasting cropping soils in Thailand.

Methods

Top three horizons of eight smectitic soils from Central plain and Central highland regions, and four kaolinitic, two mixed and two siliceous soils from Northeast plateau region were collected from four cropping systems (corn, sorghum, sugarcane and cassava). The soils were characterized for important physical, chemical and mineralogical properties. Soil pH was measured in 1:1 soil:solution in H_2O and organic carbon was determined by the Walkley and Black method and organic matter was calculated from the organic values. Exchangeable cations and CEC were determined by 1 M NH_4OAc at pH 7.0. Clay minerals in the soil are being analysed by the X-ray diffraction (XRD) and quantitative mineralogy of the clay fraction will be done the Rietveld method. Particle-size fractionation is being done by the pipette method. Total C and N in soil fractions will be measured by dry combustion method using a Elementar Vario Max CNS analyser.

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1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Results

Preliminary results obtained so far from this study are presented here. All smectitic soils selected for this study are classified as Vertisols. Local alluvium from alkaline rocks is the major parent materials of smectitic soils. All kaolinitic soils are highly weathered and highly developed soils from local alluvium and residuum derived from limestone. They are classified as Oxisols, Ultisols and Alfisols. Mixed soils were classified as Alfisols and Ultisols and parent materials are residuum and wash derived from sandstone. Siliceous soils were classified as Ultisols and Alfisols. They are residuum and wash derived from sandstone and granite. All soils represent ustic moisture regimes (Table 1).

Table 1. Parent material and classification of mineralogically contrasting upland soils of Thailand.

Soil series	Parent material	Classification
Smectitic soils		
Lop Buri (Lb)	Local alluvium derived from limestone	Typic Haplustert
Buri Ram (Br)	Local alluvium derived from limestone	Typic Haplustert
Chai Badan 1 (Cd1)	Local alluvium derived from lime producing rocks	Typic Haplustert
Chai Badan 2 (Cd2)	Local alluvium derived from weathered basalt	Typic Haplustert
Samo Thod 1 (Sat1)	Local alluvium on residuum derived from weathered andesite mixed with limestone	Typic chromustert
Samo Thod 2 (Sat2)	Local alluvium derived from limestone on residuum derived from weathered andesite	Typic chromustert
Wang Chomphu 1 (Wc1)	Local alluvium and wash over residuum derived from lime containing rock	Typic chromustert
Wang Chomphu 2 (Wc2)	Local alluvium on residuum derived from calcareous rock	Typic chromustert
Kaolinitic soils		
Pak Chong 1 (Pc1)	Local alluvium and residuum derived from weathered limestone	Typic Kandiustox
Pak Chong 2 (Pc2)	Mainly residuum derived from weathered limestone	Rhodic Kandiustox
Pak Chong 3 (Pc3)	Residuum derived from weathered limestone	Typic Paleustult
Loei (Lo)	Mixed wash and colluvium derived from limestone and metasedimentary rock	Typic Paleustalf
Mixed soils		
Sikhio (Si)	Residuum derived from weathered calcareous sandstone	Typic Rhodustalf
Borabu (Bb)	Wash over residuum derived from weathered sandstone	Typic Haplustult
Siliceous soils		
Chum Phung (Cpg)	Residuum and wash derived from weathered red sandstone	Typic Kandiustult
Chan Tuk (Cu)	Residuum derived from weathered granite	Arenic Haplustalf

Some chemical properties of the selected soils are shown in Table 2. All soils exhibit a wide range of chemical properties corresponding to their parent material properties. The mean OM content of the selected soils was highest (17.0 g/kg) in smectitic soils followed by kaolinitic soils (14.2 g/kg), mixed soils (7.4 g/kg), and siliceous soils (5.4 g/kg).

Table 2. Range and mean value of important chemical properties of soils.

Soil properties	Mineralogical group							
	Smectitic soils		Kaolinitic soils		Mixed soils		Siliceous soils	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
pH (1:1H_2O)	5.6-8.4	7.3	5.3-7.3	6.6	4.9-7.1	6.0	5.1-6.3	6.2
OM (g/kg)	5.3-30.3	17.0	6.1-34.1	14.2	1.9-9.8	7.4	1.1-13.6	5.4
Extractable bases ($cmol_+$/kg)								
Ca	18.2-132.2	45.0	3.7-12.3	9.0	0.6-21.3	6.6	0.2-4.4	1.6
Mg	1.6-16.7	7.2	0.5-2.4	1.3	0.2-0.9	0.6	0.1-0.6	0.3
Na	0.1-1.3	0.6	0.1-0.5	0.3	0.2-0.6	0.4	0.1-0.4	0.2
K	0.04-0.3	0.15	0.04-0.74	0.19	0.06-0.21	0.14	0.01-0.25	0.06
CEC (cmol/kg)	27.1-96.8	51.2	7.4-22.5	14.3	1.7-9.0	5.8	1.5-14.1	4.5

The correlation analysis (Table 3) suggests that OM content in all soils is significantly positively correlated with soil pH ($r = 0.41, P \leq 0.01$), extractable Ca ($r = 0.36, P \leq 0.05$) and CEC ($r = 0.51, P \leq 0.01$). At each soil level, a highly significant correlation was found between OM content and extractable K for smectitic ($r = 0.63, P \leq 0.01$), kaolinitic ($r = 0.91, P \leq 0.01$), and mixed soils ($r = 0.87, P \leq 0.05$), and between OM content and extractable Mg for kaolinitic ($r = 0.66, P \leq 0.05$) and mixed soils ($r = 0.83, P \leq 0.05$). Only smectitic and siliceous soils showed a significant positive correlation between OM content and soil pH (*r* = 0.39, $P \leq 0.10$; *r* = 0.73, $P \leq 0.10$, respectively) and only mixed soils showed a positive correlation between OM content and CEC (*r* = 0.88, $P \leq 0.05$). These relationships are consistent with the results of many other studies; for example, some studies concluded that pH is an important regulator of C and N dynamics in soil (Kemmitt *et al* 2006; Li *et al.* 2007; Leifeld *et al* 2008). Extractable bases in soil have been shown to enhance binding between SOM and clay minerals through cation bridges (Dontsova and Bigham 2005), and soil CEC has been shown to be related with OM content through SSA depending on properties of mineral surfaces (Kahle *et al* 2002). Some studies have shown that the content of Fe and/or Al oxides can control OM content in soil (Chorover and Amistadi 2001; Kaiser *et al.* 2002). Clearly there is a need for detailed evaluation of the role of soil mineralogy in controlling C and N retention in these uplands soils from Thailand.

Table 3. Correlation coefficients between SOM and measured soil properties.

Soil	pH (1:1 H_2O)	Ca	Mg	Na	K	CEC
All soils (n = 48)	0.41***	0.36**	-0.00	-0.15	-0.16	0.51***
Smectitic soils (n = 24)	0.39*	0.28	0.33	-0.25	0.63***	0.28
Kaolinitic soils (n = 12)	-0.42	0.19	0.66**	-0.30	0.91***	0.43
Mixed soils (n =6)	0.62	0.65	0.83**	0.21	0.87**	0.88**
Siliceous soils (n =6)	0.73*	0.09	0.06	0.06	0.06	0.15

Correlations are significant at ***$P \leq 0.01$, **$P \leq 0.05$, *$P \leq 0.10$

We propose to employ size- and density-fractionation together with analysis of CEC, total C and N and mineral content and composition of relevant separated fractions to acquire greater understanding of mineral controls on soil organic matter storage in these soils. These results will be presented at the conference.

Conclusions

Preliminary results on relationships between mineralogical properties and C and N retention in Upland soils of Thailand show that smectitic soils tend to have higher OM content than other soils. All soils exhibited a wide range of relationships between OM content and some important chemical properties such as pH, extractable bases and CEC. However, to address the objective of this study, we propose to undertake further evaluation of the role of soil mineralogy in controlling C and N retention in these uplands soils from Thailand, by employing size- and density-fractionation together with analysis of CEC, total C and N and mineral composition of the relevant separated fractions.

Acknowledgments

The authors are grateful to The Royal Golden Jubilee Ph.D. Program under the Thailand Research Fund for financial support

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