Physicochemical Properties and Carbon and Nutrient Storages of Soils Derived from Volcanic Rock and Sandstone in Dry Dipterocarp Forest at Huai Hong Khrai Royal Development Study Center, Chiang Mai Province

คุณสมบัติทางกายภาพเคมีและการกักเก็บคาร์บอนและธาตุอาหาร ในดินที่เกิดจากหินภูเขาไฟและหินทรายในป่าเต็งรังที่ ศูนย์ศึกษาการพัฒนาห้วยฮ่องไคร้อันเนื่องมาจากพระราชดำริ จังหวัดเชียงใหม่

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บทคัดย่อ: การศึกษาเปรียบเทียบคุณสมบัติทางฟิสิกส์ เคมี การกักเก็บคาร์บอนและธาตุอาหารในดิน ที่เกิดจากหินวัตถุต้นกำเนิดดินต่างกัน 2 ชนิด คือ หินภูเขาไฟและหินทรายในป่าเต็งรัง ของศูนย์ศึกษาการพัฒนาห้วยฮ่องไคร้อันเนื่องมาจากพระราชดำริ โดยใช้หลุมศึกษาลักษณะของดิน จำนวน 8 หลุม เก็บตัวอย่างดินตามระดับความลึก และนำไปวิเคราะห์คุณสมบัติทางกายภาพ และเคมีในห้องปฏิบัติการ จากผลการศึกษาพบลักษณะของดิน 2 กลุ่ม คือ ดินตื้น (ความลึก<40 ซม.) จัดอยู่ในอันดับ Inceptisols และดินลึก (ความลึก >100 ซม. ขึ้นไป) จัดอยู่ในอันดับ Ultisols และ Oxisols โดยที่ดินส่วนใหญ่มีปริมาณกรวดปนมากและมีความหนาแน่นต่ำยกเว้น ดินในอันดับ Oxisols โดยทั่วไปลักษณะของเนื้อดินหยาบถึงปานกลางในดินบน และปานกลางถึงละเอียดในดินล่าง ค่าปฏิกิริยาดินของดินที่เกิดจากหินทรายจะมีค่าต่ำกว่าดินที่เกิดจากหินภูเขาไฟ ปริมาณอินทรียวัตถุ คาร์บอน และไนโตรเจนทั้งหมดในดิน มีค่าสูงในดินบน และลดลงในดินล่าง ปริมาณของฟอสฟอรัสที่เป็นประโยชน์ และแคตไอออนที่สกัดได้ (โพแทสเซียม แคลเซียม และแมกนีเซียม) มีค่าต่ำมากตลอดช่วงความลึกของดิน โดยที่ปริมาณอินทรียวัตถุ คาร์บอน ไนโตรเจน ฟอสฟอรัส และแคตไอออนที่สกัดได้ทั้งในดินตื้นและดินลึกบนหินภูเขาไฟมีค่าสูงกว่าหินทราย ซึ่งดินป่าเต็งรังที่เกิดจากหินทั้ง 2 ชนิดนี้ มีคุณสมบัติทางกายภาพและเคมีและการและความสามารถในการกักเก็บคาร์บอนและธาตุอาหารที่ต่างกัน ซึ่งเป็นปัจจัยมีผลต่อการเจริญเติบโต ผลผลิตและความหลากหลายของชนิดพืชในพื้นที่

คำสำคัญ: คาร์บอน ป่าเต็งรัง ธาตุอาหาร หินวัตถุต้นกำเนิด คุณสมบัติของดิน

Abstract: Comparison on physicochemical properties and carbon-nutrient storage in soils derived from two parent rocks, volcanic rock, and sandstone, under a dry dipterocarp forest (DDF) was studied in the Huai Hong Khrai Royal Development Study Center (HHK), northern Thailand. Eight soil pits were made in the DDF, and soil composite samples were collected along the depths. The samples were analyzed for physicochemical properties in a laboratory. Two groups of the soils were found; shallow (<40 cm depth) and deep (100 cm or more). The shallow soils were classified into Order Inceptisols, whereas deep soils were Ultisols, however, the soil pedon of volcanic rock was Oxisols. Most soils contained many gravels and very low bulk densities, except for the Oxisols. The textures of the soils were coarse to medium in topsoils and medium to fine in subsoils. Soil reaction of three soil pits on sandstone was more acid than those on volcanic rocks, except one pedon on sandstone had the neutral. The organic matter, carbon and total nitrogen content in all soils were high in surface soils and less in subsoils. Available phosphorus (P) and extractable cations of potassium (K), calcium (Ca) and magnesium (mg) were very low throughout the soil depths. Amounts of organic matter, carbon, nitrogen, available P and extractable cations in both shallow and deep soils on volcanic rocks were higher than those on sandstone. The DDF soils on two parent rocks had some differences in physicochemical properties and carbon-nutrient storages and are considered as the important factor on plant growth, production, and species diversity.

Keywords: Carbon, dry dipterocarp forest, nutrients, parent rocks, soil properties

Introduction

The dry dipterocarp forest is distributed widely on very dry areas in mainland of Southeast Asia. This forest composed of medium to tall trees which remain almost leafless during the dry season and had a closed to slightly open canopy (Bunyavejchewin, 1983). The DDF also covers large areas in northern Thailand. It is distributed on the undulating peneplain and ridges in the dry sites, sandy and lateritic soils. The dominant tree species in the forest are those in the family of Dipterocarpaceae including *Dipterocarpus tuberculatus*, *Dipterocarpus obtusifolius*, *Shorea obtusa* and *Shorea siamensis* (Phongkhamphanh *et al*., 2015). This forest covers an extensive area from a peneplain of about 150 m altitude to slopes and rides of up to 1,300 m (Smithinand *et al*., 1980). It is also the habitat of edible mushrooms, vegetables, medicinal plants, and woods, playing the ecological roles on carbon and nutrient cycles. The early record of the DDF area in Thailand was about 47% of the total forest area (Neal, 1967) and the current forest area has decreased dramatically due to forest clearing as a result of rapid expansion in the socioeconomic and increasing population of the country. The Royal Forest Department (RFD), Department of National Parks, Wildlife and Plant Conservation and other agencies, especially through the Royal Initiative Project, have implemented the conservation and sustainable uses of this forest to mitigate the harmful consequences of clearing forest. The Huai Hong Khrai Royal Development Study Center (HHK) was established in 1982 under the Royal Initiative of His Majesty King Bhumibol Adulyadej's in the Khun Mae Kuang National Forest Reserve, Chiang Mai, with objectives of creating center for studies, research and experimentation on appropriate methods for development of the northern region especially integrated watershed and forest management. The forest ecosystem can be divided into two main compartments; plants and soil system. In the DDF, the forest floor (organic layers) is usually thinned or disappeared due to forest fire and rapid litter decomposition. The carbon sequestration by the forest through photosynthesis and carbon accumulation as carbohydrate in plant tissues are considered as the carbon sink (Kimmins, 2004; Waring and Running, 1998). A part of carbon is moved to the forest floor through litterfall and later accumulated in the soil system. However, most carbon in the forest floor under the DDF is almost moved to atmosphere through a forest fire and to the stream by soil erosion. A small part of carbon may be moved into and stored in the soil with variable amounts in different locations of the DDF. The roles of different parent rocks on soil physicochemical properties will further affect carbon-nutrient storages. This research aims to study physicochemical properties and carbon-nutrient storage in soils from different parent rocks, volcanic rock, and sandstone, in the DDF.

Materials and Methods

Site description

This research was carried out in the HHK, Doi Sa Ket District, Chiang Mai Province, at an altitudinal range from 320 m to 600 m above mean sea level. The HHK has an area of 1,359 ha with monsoon climate: the rainy season, May to October; winter, November to February and summer, March to April. The mean annual air temperature and rainfall were 22.5 °C and 1,360.5 mm respectively (the data collected from 1985 to 2016 at HHK Meteorological Station). Soils are developed from the colluvium and residuum rocks in periods of Permo-Triassic (andesite, basalt, and associated pyroclastic rocks), Carboniferous (sandstone, quartzite, and shale) and Permian (sandstone, siltstone, tuff, and chert) (Department of Mineral Resources, 1999). Two deciduous forests are observed, the dry dipterocarp forest and mixed deciduous forest. The forests were very poor as a result of selective tree cutting during forest concession and illegal cutting before the establishment of the Center in 1982. The areas are different: the DDF (650 ha) on volcanic rock and sandstone, the mixed deciduous forest (416 ha) on shale and limestone, and the other land uses including reservoir, agricultural and urban area (293 ha).

Soil sampling and physicochemical analysis

Eight representative soil pits were made inside eight 40 x 40 m sampling plots used for vegetation study and soil profiles were characterized according to Schoeneberger *et al*. (2002) and Soil Survey Division (1993). The soil samples within each soil pit were collected with three replications from the depths of 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100 cm or depending on soil depths using disturbed and undisturbed (soil cores) method. The samples were air-dried and crushed to pass through a 2 mm sieve for analyzing soil physicochemical properties (Soil Survey Staff, 2004) including bulk density (BD by soil core method, gravel content (rock fragments larger than 2 mm), soil particle-size distribution by hydrometer method, pH by pH meter (soil and water at 1:1 ratio), organic carbon (C) by Walkley and Black titration method, total nitrogen (N) by Kjeldahl, available P by Bray II solution and spectrophotometer and extractable cations (K, Ca and mg) using 1N NH_4OAc, pH 7 and atomic absorption spectrometry (AAS). The carbon and nutrient storage were calculated from their contents multiplied by soil mass per hectare for each depth.

Results and Discussion

Soil profiles and classification

Table 1 shows site features and soil types in the DDF on volcanic rock and sandstone. The soil profiles included typical horizons. The B horizon can vary among soil types: young developed subsoil contained many gravel and rocks (Bw), more developing subsoil with high clay contents (Bt) and containing plinthite (Btv), and more developed subsoil with high iron oxides or oxic horizon (Bo). ***Volcanic rock:*** Two soil groups located in the middle slope sites were found, shallow (40 cm depth) and deep (200+ cm) soils. The shallow soils (pedons 1 and 2) had different site features: altitude, 589 m and 504 m, and slope gradient, 20% and 21%, and classified into Order Inceptisols with A/Bw/C profile while deep soils (pedons 3 and 4) had different values: altitude, 521 m, and 473 m and slope gradient, 4% and 3% at the middle and lower slope sites. Pedon 3 was classified into order Oxisols (A/Bo1/Bo2) whereas pedon 4 was the Ultisols (A/Bt/Btv). ***Sandstone:*** Both shallow and deep soils were observed. The shallow soils located in the upper slopes (pedons 5 and 6) with different site features: altitude, 409 m, and 519 m; slope gradient, 12%, and 4%, and classified into Order Inceptisols (A/Bw/C). The deep soils (pedon 7 and 8) had different features: altitude, 484 m, and 404 m, slope gradient 3% and 6%, located in the lower and middle slopes. Pedon 7 was the deep soil (200+ cm) classified into the Ultisols (A/Bt1/Btv) while pedon 8 had the intermediate-deep (160 cm)(A/Bt1/Bt2).

The shallow soils on two parent rocks (pedons 1, 2 and pedons 5, 6) were the initial stage and classified into Order Inceptisols due to soil profile development particularly cambic (Bw) horizon (Soil Survey Staff, 2014). The deep soil of pedon 3 was classified into Order Oxisols according to deep weathering of iron-rich volcanic rock with more reddish color and unclear difference of oxic horizon. The deep soils, pedons 7 and 8, were classified into low base soils, Order Ultisols, with the clear clay accumulation in subsoils (Bt) (Soil Survey Staff, 2014). The subsoil containing plinthite (Btv) was observed in pedon 4 and pedon 7 caused by iron oxides in both volcanic rock and sandstone saturated with water in the rainy season (Soil Survey Staff, 1993).

Table 1. Site characteristics and soil types in the DDF on two different parent rocks

Parent rock	Altitude (meter)	Slope (%)	Slope position	Soil depth (cm)	Soil profile	Soil order
Volcanic rock						
Pedon 1	589	21	Middle slope	40, shallow	A-Bw-C	Inceptisols
Pedon 2	504	20	Middle slope	40, shallow	A-Bw-C	Inceptisols
Pedon 3	521	4	Middle slope	200^+, deep	A-Bo1-Bo2	Oxisols
Pedon 4	473	3	Lower slope	200^+, deep	A-Bt-Btv	Ultisols
Sandstone						
Pedon 5	409	12	Upper slope	40, shallow	A-Bw-C	Inceptisols
Pedon 6	519	4	Upper slope	40, shallow	A-Bw-C	Inceptisols
Pedon 7	484	3	Lower slope	200^+, deep	A-Bt-Btv	Ultisols
Pedon 8	404	6	Middle slope	160, deep	A-Bt1-Bt2	Ultisols

Soil physical properties

1. Gravel content

Volcanic rock: The shallow soils classified into the Inceptisols contained some gravel amounts in 40 cm depths; 29.65 to 55.40% in pedon 1 and 4.28 to 35.0% in pedon 2. The gravel amounts were very low throughout the soil profile of deep soil, pedon 3 (Oxisols), but some higher amounts were observed in pedon 4 (Ultisols). ***Sandstone:*** Both two pedons of shallow soils, the Inceptisols, composed of high gravel amounts in 40 cm depths; 58.23 to 66.61% in pedon 5 and 53.83 to 64.95% in pedon 6. The amounts were lower in 100 cm deep soil; pedon 7 (Ultisols), 2.24 to 41.85%, but the higher amounts (45.76% to 78.07%) were found in 100 cm depth of pedon 8 (Ultisols) (Figure 1).

2. Bulk density and soil mass

Volcanic rock: The shallow soils had low to very low bulk densities; pedon 1, 0.79 to 1.11 mg/m^3 and pedon 2, 0.87 to 1.32 mg/m^3. As for deep soils, the values were different; pedon 3, low (1.06 to 1.19 mg/m^3) and pedon 4, very low (0.59 to 0.83 mg/m^3). The shallow soils had low amounts of soil mass; pedon 1, 0.37 mg/m^2 and pedon 2, 0.43 mg/m^2. As for deep soils, the amounts were higher; pedon 3, 1.13 mg/m^2 and pedon 4, 0.72 mg/m^2. ***Sandstone:*** Very low densities were found in shallow soils; pedon 5, 0.47 to 0.57 mg/m^3 and pedon 4, 0.61 to 1.01 mg/m^3. In deep soils, pedon 7 had very low values in surface soil and increased to low (1.03 to 1.45 mg/m^3) in subsoil while pedon 8 had very low densities throughout soil depth (0.45 to 0.95 mg/m^3). The shallow soils contained the low amounts of soil mass; pedon 5, 0.21 mg/m^2 and pedon 6, 0.34 mg/m^2. The higher amounts were measured for deep soils; pedon 7, 1.18 mg/m^2 and pedon 8, 0.60 mg/m^2 (Figure 1).

3. Soil particle-size distribution and texture

Soil particles include sand, silt, and clay. Percentages of these particles along soil depth are used to identify soil texture.

Volcanic rock: The sand percentages in shallow soils were medium to high; pedon 1, 62.0 to 76.72% and pedon 2, 50.6 to 60.60%. The silt and clay percentages varied in ranges; pedon 1, 4.28 to 12.0% and 17.28 to 26.0% and pedon 2, 12.30 to 19.20% and 20.20 to 35.30%, respectively. There was no clear clay accumulation in the B horizon. As for deep soils, sand percentages were low to medium; pedon 3, 27.40 to 68.20% and pedon 4, 27.20 to 61.20%. The values for silt and clay in the following order; pedon3, 5.0% to 10.20% and 21.60% to 66.40% and pedon 4, 12.0 to 19.40% and 22.80 to 59.60%. The clay accumulation occurred in B horizon. The shallow soils had loamy texture; pedon 1, sandy loam in surface soil and sandy clay

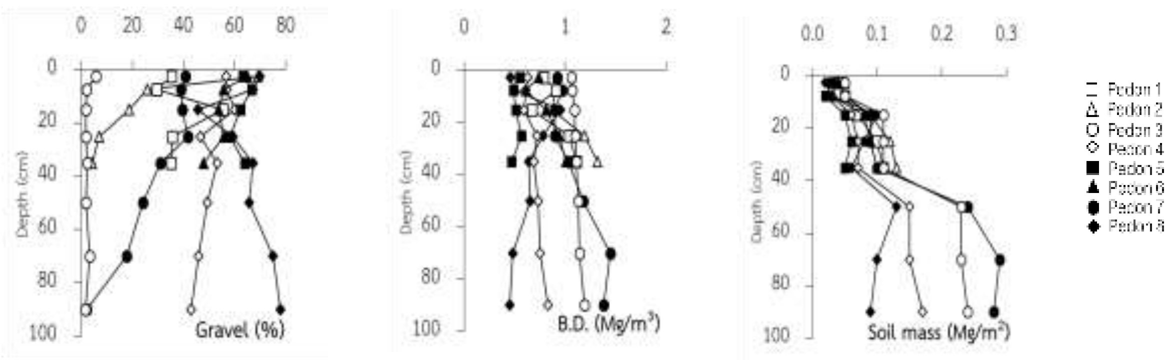

Figure 1. Some soil physical properties of eight soil pedons in the DDF

loam in the subsoil, and pedon 2, sandy clay loam in surface soil, and clay loam and sandy clay loam in the subsoil. Textures of deep soils were loamy and clayey; pedon 3, sandy clay loam and sandy clay in surface soil and clay in the subsoil, and pedon 4, sandy clay loam in surface soil and clay in the subsoil.

Sandstone: The sand percentages along soil depths of shallow soils were medium to high; pedon 5, 36.40 to 60.20% and pedon 6, 50.10 to 80.40%. The silt and clay percentages varied in ranges: pedon 5, 6.20 to 20.40% and 17.60 to 53.10%, and pedon 6, 12.0 to 23.40% and 7.60 to 33.60%, respectively. As for deep soils, the sand percentages were different; pedon 7, high in surface soil and low in the subsoil (28.76 to 74.16%) and pedon 8, high throughout the profile (63.12 to 83.34%). The silt and clay values were in the following order; pedon 7, 12.40 to 20.0% and 7.60% to 51.24%, and pedon 8, 3.50 to 24.20% and 6.44 to 29.40%. The clay content was increased in B horizon of deep soils. The shallow soils had loamy and sandy textures; pedon 5, sandy loam in surface soil and clay loam and clay in the subsoil, and pedon 6, loamy sand in surface soil and sandy loam and sandy clay loam in the subsoil. As for deep soils, they were loamy and clayey textures; pedon 7, sandy loam in surface soil and clay in the subsoil, and pedon 8, loamy sand in surface soil and sandy loam to sandy clay loam in the subsoil.

The young developing soils, Order Inceptisols, were shallowly containing large amounts of gravel and rocks. The more developing soils, Ultisols, were deeper and had smaller amounts of gravel and rocks. As for more developed soils, Order Oxisols, gravel and rocks were almost seen minimum caused by deep weathering. The volcanic rock is formed by crystallization from magma cooled at the earth's surface whereas most sandstones in Thailand are formed from all rock types deposited after being after transported by water that has been cemented together (Pye, 2007). The high content of sand and gravels in soils resulted from quartz which was difficult to weather at the beginning stage of soil development, it produces little residuum and soils tend to be shallow (Schaetzl and Anderson, 2005). In this study area, the soils on the volcanic rock were divided into shallow soils (pedon 1 and 2, Inceptisols) and deep soils (pedon 3, Oxisols and pedon 4, Ultisols). The shallow soils composed of mainly andesite and rhyolite which were difficult to weathering and thus many gravel and rocks have accumulated along the depth and resulted in low to very low bulk densities. The deep weathering was occurred in the Oxisols (pedon 3) and resulted in the fine-textured reddish profile. The Ultisols (pedon 4) had some remained gravel and rocks, and very low bulk densities. The shallow soils on sandstone (Pedon 5 and 6, Inceptisols) developed on the upper slope sites where moisture conditions were usually lower with higher soil erosion than the deep soils (pedons 7 and 8, Ultisols) located in the lower slopes. The sandstone soils were very fine sand cemented together and difficult to weather and contained the large amounts of gravel with low to very low bulk densities. The shallow soils have a course to intermediate textures. The variable topographic conditions might influence on different soil profiles between pedons 7 and 8; pedon 7 had loamy over clayey and pedon 8 had loamy and sandy over loam. The waterlogged condition might have occurred in the subsoil of pedon 7 indicated by the observation of plinthite (Btv) and grey color (Figure 2).

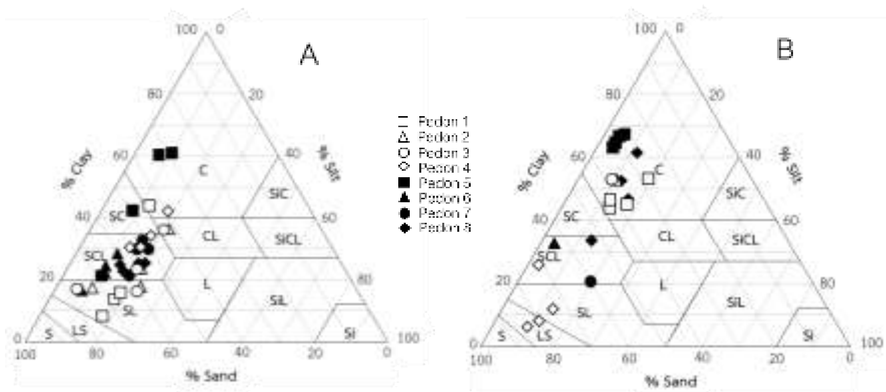

Figure 2. Soil particle size distribution of soil pedons at 0-30 cm (A) and 30-100 cm (B) in the DDF

Soil chemical properties

1. pH, *Volcanic rock:* The shallow soils (pedon 1) had slightly acid (pH, 6.10-6.42) throughout the depths. It varied from moderate acid to strong acid (5.27 to 5.65) for pedon 2. As for deep soils of pedon 3, the surface soil (0-20 cm) had moderate acid (5.71 to 5.85) and slightly acidic in the subsoil (6.21 to 6.31) whereas pedon 4 (Order Ultisols) had moderate acid to strong acid (5.24 to 5.96) in the surface soil and moderate to slight acid (5.62 to 6.12) in the subsoil. ***Sandstone:*** The shallow soils (pedons 5 and 6) had very strong acid (pH, 4.88 to 4.51) throughout the depths, except for extremely acidic at 5-10 cm depth. In deep soil of pedon 7 had very strongly acid (4.47 to 5.05) throughout the soil profile while pedon 8 had neutral (6.58 to 6.74).

2. Organic matter and carbon

The average content of soil organic carbon is calculated as 58% of organic matter (Nelson and Sommers, 1996). The carbon contents were usually moderate to high and very high in surface soils and less in the subsoils. *Volcanic rock:* In shallow soils (pedon 1 and 2), the carbon content was very high (31.64 to 33.96 g/kg) at 0-5 cm depth, moderate to high at 5-10 cm (12.02 to 21.94 g/kg) and moderately low to very low in the deeper horizon. In deep soils (pedons 3 and 4), it was high (21.29 to 25.19 g/kg) at 0-5 cm, moderate to moderately high (11.93 to 12.72 g/kg) at 5-10 cm, and low to very low in deeper layers. ***Sandstone:*** In shallow soils (pedons 5 and 6), the content was moderate (10.00 to 12.75 g/kg) at 0-5 cm depth, moderately low (6.90 to 7.40 g/kg) at 5-10 cm and low to very low in deeper horizons. In deep soils (pedon 7), it was moderate (12.91g/kg) at 0-5 cm depth, moderate low (8.57 g/kg) at 5-10 cm) and low to very low in deeper layers whereas pedon 8 had the high carbon contents (20.62 to 23.49 g/kg) at 0-10 cm depth, and low to very low in deeper soils.

3. Total N, *Volcanic rock:* The nitrogen contents in shallow soils (pedons 1 and 2) were almost very low throughout 40 cm depth. The low to very low contents were also observed in deep soils (pedons 3 and 4). *Sandstone:* The shallow soils (pedons 5 and 6) and deep soils (pedons 7 and 8) contained very low nitrogen contents throughout their profiles.

4. Available P and extractable K, Ca and Mg

Both shallow and deep soils on the two parent rocks contained very low concentrations of available phosphorus (P) and extractable potassium (K), calcium (Ca) and magnesium (mg).

The pH values (5.27 to 6.42) of soils on volcanic rock varied from slightly acidic to moderately and strongly acidic. These might be the effects of different mineral composition in parent rocks. The soils in pedons 1 and 2 derived from andesite and rhyolite while pedon 3 composed of mainly iron oxides and pedon 4 derived from other intermediate acid rocks. Three soil pedons on sandstone had more acid properties than those on volcanic rocks. They might contain the sand particles of more acid rocks. One pedon (pedon 8) had neutral properties due to sand deposit with limestone. The organic matter and carbon in soils on both rocks varied from moderate to high in surface soil and decreased to low and very low in subsoils. Decomposing above-ground litter and dead roots of ground-covered species resulted in the accumulations of organic matter and carbon in surface soils. However, most organic matters were lost through soil erosion and some were retained in the surface soil, and very small amounts were moved into the deeper soil horizons. The contents of total nitrogen and concentrations of available P and extractable K, Ca and mg were low to very low throughout the soil profiles. These soils had high soil erosion and most nutrients from decomposing litter were difficult to move into the subsoils (Figure 3).

Amounts of carbon and nutrient storage in soils

Carbon, *Volcanic rock:* Carbon amounts stored of shallow soils were estimated; pedon 1, 50.15 mg/ha and redon 2, 37.18 Mg/ha. As for deep soils, the amount was higher in pedon 3 (64.93 Mg/ha) and lower (33.30 Mg/ha) in pedon 4. The average carbon amount the soils derived from a volcanic rock was 46.39. ***Sandstone***: The carbon amounts in shallow soils were lower than those on volcanic rock; pedon 5, 40.95 Mg/ha and pedon 6, 19.14 Mg/ha. The amounts were higher in deep soils; pedon 7, 31.08 Mg/ha and pedon 8, 43.51 Mg/ha. The average carbon amount in the soils on sandstone was 26.17 Mg/ha. The DDF soils in other locations could store the variable carbon amounts. Naimphulthong (2011) reported that the soil on conglomerate, cloud store the carbon amount at 19.04 Mg/ha. The soil in community forest on sandstone, Lamphun, had the amount at 74.05 Mg/ha (Phonchaluen, 2009). As for the soils on

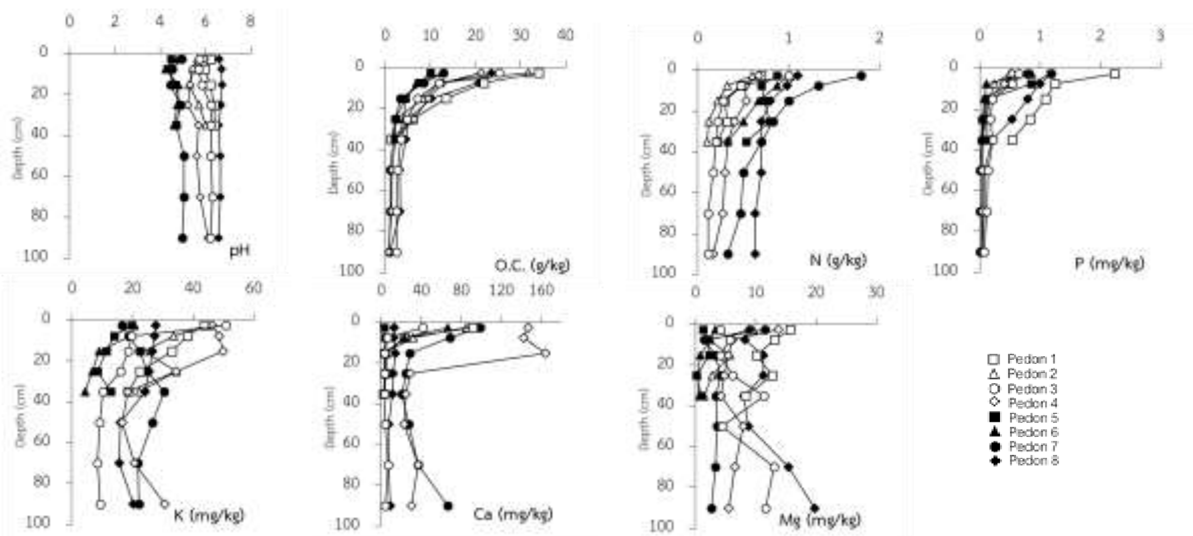

Figure 3. Some soil chemical properties of eight soil pedons in the DDF

a granitic rock, the amounts were in a range of 31.22-74.05 Mg/ha (Phongkhamphanh *et al*., 2015; Serامethakun, 2012; Wongin, 2011). The DDF soils contained the low carbon amount as compared to other forest soils. The community forest of lower montane forest could store the high carbon (2 m soil depth) at 322.71 Mg/ha. The amount of 262.47 Mg/ha (1 m depth) was found in the upper montane forest at the summit the highest mountain in Thailand, Doi Inthanon (Khamyong *and* Anongrak, 2016).

Nitrogen, *Volcanic rock:* The total nitrogen stored in shallow soils (pedon 1 and 2) were nearly the same, 2.86 Mg/ha to 2.88 Mg/ha. They were higher in deep soils; pedon 3, 8.92 Mg/ha and pedon 4, 5.90 Mg/ha. ***Sandstone:*** The nitrogen amount in shallow soils (pedons 5 and 6) were lower than those on volcanic rock; pedon 5, 0.87 Mg/ha and pedon 6, 0.81 Mg/ha. The amounts were higher in deep soils; pedon 7, 2.80 Mg/ha and pedon 8, 2.45 Mg/ha. The nitrogen storage in soils on a volcanic rock was higher than those on sandstone. In other locations, the amount in soil on conglomerate was 3.13 Mg/ha (Naimphulthong, 2011) while the sandstone soil in community forest had the value at 6.17 Mg/ha (Phonchaluen, 2009). As for granitic rock, the amounts varied between 3.30 Mg/ha and 7.47 Mg/ha (Phongkhamphanh *et al*., 2015; Seramethakun, 2012; Wongin, 2011). The higher amounts in lower and upper montane forests were reported as 17.19 Mg/ha and 10.21 mg/ha, respectively (Khamyong and Anongrak, 2016; Seeloy-ounkeaw *et al*., 2014).

Available P, *Volcanic rock:* The amounts of available P in shallow soils were 4.23 kg/ha in pedon 1 and 0.78 kg/ha in pedon 2. In deep soils, the amounts were 2.59 kg/ha in pedon 3 and 0.86 in pedon 4. The average amount in these soils was 2.12 kg/ha. ***Sandstone:*** The available P in shallow soils was 0.95 kg/ha in pedon 5 and 0.55 kg/ha in pedon 6. In deep soils, the amount was 1.15 kg/ha in pedon 7 and 2.43 kg/ha in pedon 8. The soils on volcanic rock and sandstone contained the low amounts of available P. In other locations, Naimphulthong (2011) found that the soil on conglomerate stored the amount at 7.87 kg/ha while the soil on sandstone in community forest was 6.36 kg/ha (Phonchaluen, 2009). As for granitic rock, the values varied from 4.0 kg/ha to 29.10 kg/ha (Phongkhamphanh *et al*., 2015; Seramethakun, 2012; Wongin, 2011). The higher amounts in lower and upper montane forests were reported as 65.70 kg/ha and 87.71 kg/ha, respectively (Khamyong and Anongrak, 2016; Seeloy-ounkeaw *et al*., 2014).

Extractable K, *Volcanic rock:* In shallow soils, the amount of ext. K was 118.03 kg/ha in pedon 1 and 141.74 kg/ha in pedon 2. They were higher in deep soils, 170.55 kg/ha in pedon 3 and 229.48 kg/ha in pedon 4. The average amount in these soils was 164.95 kg/ha. ***Sandstone:*** The amount of ext. K in shallow soils was lower than those on volcanic rock, 28.73 kg/ha in pedon 5 and 37.12 kg/ka in pedon 6. In deep soils, the amount was 317.53 kg/ha in pedon 7 and 154.03 kg/ha in pedon 8. The potassium in soils on a volcanic rock was higher than those on sandstone. The soil on conglomerate had the amount at 432.99 kg/ha (Naimphulthong, 2011) while the higher amount in sandstone soil was found, 977.38 kg/ha (Phonchaluen, 2009). They varied from 372.40 kg/ha in granite soil to 1,328.90 kg/ha in granodiorite soil (Phongkhamphanh *et al*., 2015; Seramethakun, 2012; Wongin, 2011). In lower and upper montane forests, the amounts were 2,261.19 kg/ha and 227.2 kg/ha, respectively (Khamyong and Anongrak, 2016; Seeloy-ounkeaw *et al*., 2014).

Extractable Ca, ***Volcanic rock:*** The amount in shallow soils was 66.39 kg/ha in pedon 1 and 77.01 kg/ha in pedon 2. As for deep soils, the amount was 78.66 kg/ha in pedon 3 and higher in pedon 4 (424.30 kg/ha). The average amount in these soils was 161.59 kg/ha. ***Sandstone:*** The amount in shallow soils was 7.75 kg/ha in pedon 5 and 51.0 kg/ha in pedon 2. In deep soils, the amount was 548.63 kg/ha in pedon 7 and 70.55 kg/ha in pedon 8. The calcium in soils on a volcanic rock was nearly the same as those on sandstone. Naimphulthong (2011) reported that the soil on the conglomerate cloud store the amount 1,738.24 kg/ha. The amounts in DDF soils on a granitic rock with granodiorite had varied greatly in the range of 372.40-3,896.13 kg/ha (Phongkhamphanh *et al*., 2015; Serамethakun, 2012; Wongin, 2011). The calcium in the soil on sandstone in Ban Sai Thong community forest was measured 1,234.31 kg/ha (Phonchaluen, 2009). The amounts in a lower and upper montane forest were 885.0 kg/ha. and 270.76 kg/ha, respectively (Khamyong and Anongrak, 2016; Seeloy-ounkeaw *et al*., 2014).

Extractable mg, *Volcanic rock:* The amounts in shallow soils was 47.36 kg/ha in pedon 1 and 16.49 kg/ha in pedon 2. In deep soils, the amount was 111.77 kg/ha in pedon 3 while 51.06 kg/ha in pedon 4. The average amount in these soils was 56.62 kg/ha. *Sandstone:* In shallow soils, the quantity was 3.02 kg/ha in pedon 5 and 4.32 in pedon 6. As for deep soils, the amount was 45.65 kg/ha in pedon 7 and 79.77 kg/ha in pedon 8. The magnesium amount in soils on a volcanic rock was higher than those on sandstone. The amount in soil on conglomerate was 563.0 kg/ha (Naimphulthong (2011) and in sandstone soil was 427.05 kg/ha (Phonchaluen, 2009). On granitic rock, they varied between 514.90 kg/ha and 1,287.50 kg/ha (Phongkhamphanh *et al*., 2015; Seramethakun, 2012; Wongin, 2011). In the lower and upper montane forests, the amounts were 885.0 kg/ha and 270.76 kg/ha, respectively, were measured (Khamyong and Anongrak, 2016; Seeloy-ounkeaw *et al*., 2014) (Figure 4).

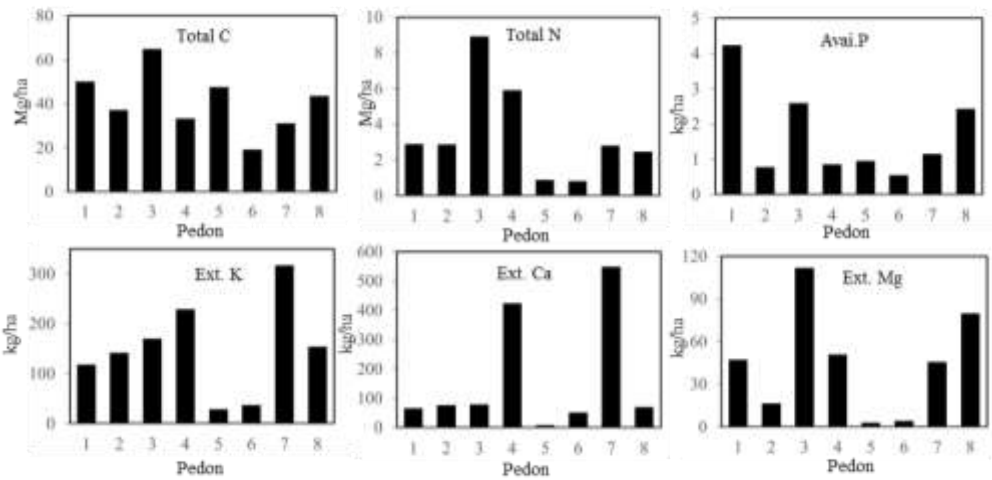

Figure 4. Carbon and nutrient storages in the DDF soils on volcanic rock and sandstone

Conclusions

Different parent rocks, volcanic rock, and sandstone had influenced on variations of soil physicochemical properties in the DDF including soil depth, types, bulk density, texture, acidity, contents, and amounts of carbon and macronutrients. Either shallow or deep soils could occur in the volcanic rock and sandstone areas. The shallow soils were classified into Order Inceptisols. The soil types of deep soils on volcanic rocks were Order Oxisols and Ultisols whereas those on sandstone were the Ultisols. The average amounts of carbon nitrogen and most extractable macronutrients except for calcium in soils on the volcanic rock were higher than the sandstone area. However, the amounts of carbon and macronutrient storage in the DDF soils on these parent rocks were low compared to other forest soils.

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