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VARIATIONS OF SOIL CHEMICAL PROPERTIES AT DIFFERENT HORIZONS UNDER NATURAL FOREST CANOPY IN KON KA KINH NATIONAL PARK, GIA LAI

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Từ khóa: Soil organic carbon, soil chemical properties, natural forest types, Kon Ka Kinh national park

TÓM TẮT

Forests contribute an important role in mitigating atmospheric CO_2 because forest ecosystems are paramount elements of carbon cycle and carbon sequestration in soil, detritus and vegetation. The research which carried out in 14 plots with area of $2000m^2$ has compared and discussed the differences in soil organic carbon (SOC) distribution, some macronutrients and mobility Fe ion at different vertical soil horizons (0 - 10cm, 10 - 20cm, 20 - 30cm, 30 - 50cm) between old-growth and secondary forests in Kon Ka Kinh National Park. The results show that the content of all properties has a significant difference between the two forest types (Sig values of linear tmixed effect models < 0.05). Most of the indicators are significantly different between soil layers (Sig. < 0.05) while total phosphorus content is less changed and total potassium content increases with vertical soil depths. The principal component analysis diagram also indicates that the soil properties closely related, especially soil organic carbon, total nitrogen and total phosphorus.

Key words: Các bon hữu cơ đất, tính chất hóa học đất, các trạng thái rừng tự nhiên, Vườn quốc gia Kon Ka Kinh

Biến động tính chất hóa học đất ở các độ sâu dưới tán rừng tự nhiên tại Vườn quốc gia Kon Ka Kinh, Gia Lai

Rừng đóng góp vai trò quan trọng vào việc giảm thiểu khí CO_2 khí quyển bởi vì rừng là một thành tố cực kỳ quan trọng của vòng tuần hoàn cacbon và là bể chứa cacbon trong đất, vật rơi rụng và thảm thực vật. Kết quả nghiên cứu trên 14 ÔTC diện tích $2000m^2$ chỉ ra sự khác biệt về phân bố theo độ sâu tầng đất (0 - 10cm, 10 - 20cm, 20 - 30cm, 30 - 50cm) của cacbon hữu cơ, một số nguyên tố dinh dưỡng đa lượng, hàm lượng ion Fe di động trong đất giữa rừng thứ sinh và rừng già tại Vườn quốc gia Kon Ka Kinh, đồng thời, nghiên cứu cũng chỉ ra sự biến động các biến đó giữa các độ sâu tầng đất. Kết quả nghiên cứu chỉ ra rằng, hàm lượng tất cả các biến đều có sự khác biệt rõ rệt giữa hai trạng thái rừng (Giá trị Sig của mô hình tuyến tính hỗn hợp < 0,05). Hầu hết hàm lượng các biến nghiên cứu khác nhau rõ rệt giữa các tầng đất (Sig. < 0,05) trong khi đó hàm lượng photpho ít có sự thay đổi theo độ sâu tầng đất và hàm lượng kali là tăng dần theo độ sâu tầng đất. Biểu đồ phân tích thành phần chính của các nhân tố nghiên cứu của hai trạng thái rừng cũng chỉ ra rằng giữa các biến có mối quan hệ chặt chẽ với nhau, đặc biệt là hàm lượng cacbon hữu cơ, đạm và lân.

I. INTRODUCTION

Generally, tropical forests lack mineral nutrients and are mainly dependent on nutrient cycling from soil organic matter (SOM) to maintain soil fertility (Tiessen *et al.*, 1994). The organic matter accumulation under forests primarily depends on the balance between carbon input and carbon output. The main sources of carbon supply for soils are derived from photosynthetic sources which exist above and below the ground (Hendrickson, 2003) which play a very important role in maintaining and improving soil properties. The relationship between surfaces of mineral elements, especially small particles smaller than 2µm and organic carbon content makes the persistence of organic matter in soil (Tiessen *et al.*, 1994) by the formation of organo-mineral compounds and stable soil aggregates. Furthermore, soil aggregates is an important determinant of soil properties such as aeration, soil fertility, protection of SOC (Christensen, 2001) carbon dynamics and sequestration in soil (Balesdent *et al.*, 2000).

The organic matter mineralization contributes in various the nutrient supplies, improving soil fertility (Tiessen *et al.*, 1994). These are the important soil physical and chemical conditions for maintaining and promoting the growth of overstorey and reforestation growth rates.

The strict protection regime of the National Park is an important factor for the accumulation and decomposition of SOM. As a result, the carbon dynamics and nutrients at vertical soil depths in forest types will be adequately assessed.

Kon Ka Kinh National Park is located in Gia Lai province, the Central Highlands. It is the place to maintain, protect and preserve old-growth, secondary and regenerated forests. This National Park contributes to preserving the diversity of species including plant and animal species and soil ecosystems. Therefore, the status of organic matter accumulation under different forest types in general and soil layers in particular is excellent to analyze and understand, because of their unaffected status in a long time period.

However, Kon Ka Kinh National Park currently lacks a scientific based on soil quality and soil changes under different forest types. A few studies have been conducted this place. There are only three major studies conducted after the establishment of the park and no studies on soil properties (Hung, 2016). Therefore, this research is necessary and urgent to provide some vital information for forest resources management here.

By analyzing some soil chemical properties such as: SOC content, macronutrients, ion mobilized Fe, this paper will focus on: (1) description of soil chemical properties at different soil horizons under two forest types; (2) analyzing differences of those soil properties and (3) analyzing the correlation between investigated soil parameters in Kon Ka Kinh National Park, Central Highlands, Vietnam.

II. METHODOLOGY

2.1. Data collection methods

All soil samples were collected under the old-growth (Type IV) and secondary forest (Type IIb) in Kon Ka Kinh National Park, Gia Lai province, Central Highlands. 7 plots were established under each forest type with an area of 2000m^2 (40m × 50m). The study site was selected by applying stratified random sampling method (Fig.1) to ensure sample homogeneity through two forest types because the forest site is not homogeneous (Shiver and Borders, 1996; Hung, 2016).

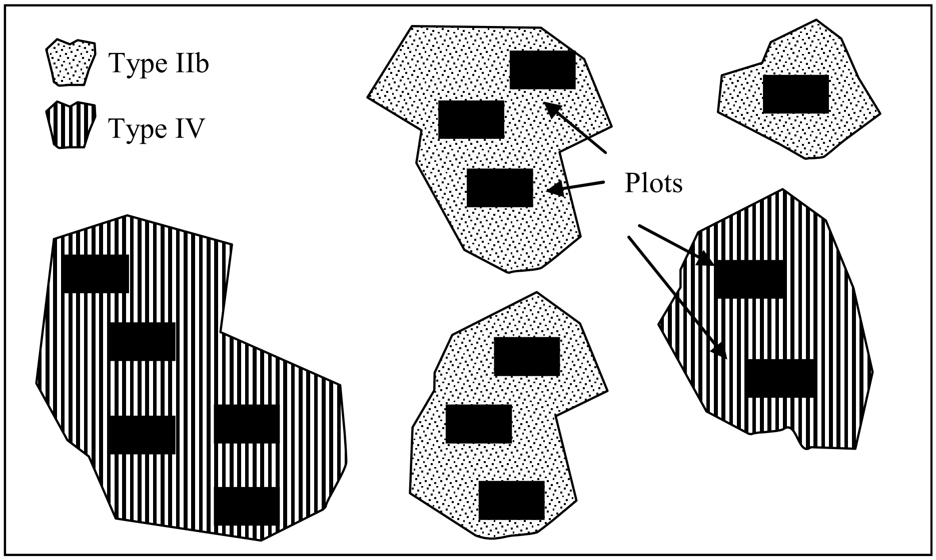


Fig.1. Plot system in the research area (Hung, 2016)

In each plot, soil samples in each depth (0 - 10, 10 - 20, 20 - 30, 30 - 50cm) were collected at 5 random spots at 4 corners and the plot centre by sampling tools and the samples at the same depths were bulked together to generate a composite sample.

2.2. Soil sample analysis methods in the laboratory

Collected samples were air-dried, homogenized. Litter and stone were removed and sieved by 2mm sieve mesh. All samples were analyzed and the rests were stored in labeled plastic bags.

Each parameter was analyzed with 3 replicates for some soil properties: pH, soil organic carbon content, total nitrogen, total phosphorus, total potassium and mobilized Fe ion.

pH_{KCl} were determined by automatic pH machine. The determination of organic carbon in soil was applied by Tiurin method. Total nitrogen (%) was determined by applying modified Kjeldahl method (TCVN 6498:1999). Total phosphorus (%) was determined by colorimetric method (TCVN 8940:2011). Total potassium (%) was analyzed by flame spectroscopy method (TCVN 8660:2011). Atomic absorption spectroscopy method was applied to determined mobilized Fe ion (meq/100g soil) (TCVN 8246 - 2009).

2.3. Data processing methods

Collected data were analyzed by using SPSS software version 20. Box plots were used to understand demonstration the differences of the parameters between two forest types and between soil depths.

Checking of differences in SOC contents, macronutrients, mobilized Fe ion between two forest types as well as between soil vertical depths used linear mixed effect model commands. The difference can be concluded by the Sig. value.

Test the correlation between the studied parameters was conducted by using path analysis and principal component analysis methods. The principal component analysis will be more visible to make conclusions about the relationship.

III. RESULTS AND DISCUSSIONS

3.1. Characteristics of soil chemical properties at different soil horizons under two forest types

Soil chemical properties of both old-growth and secondary forest are given in Fig.2.

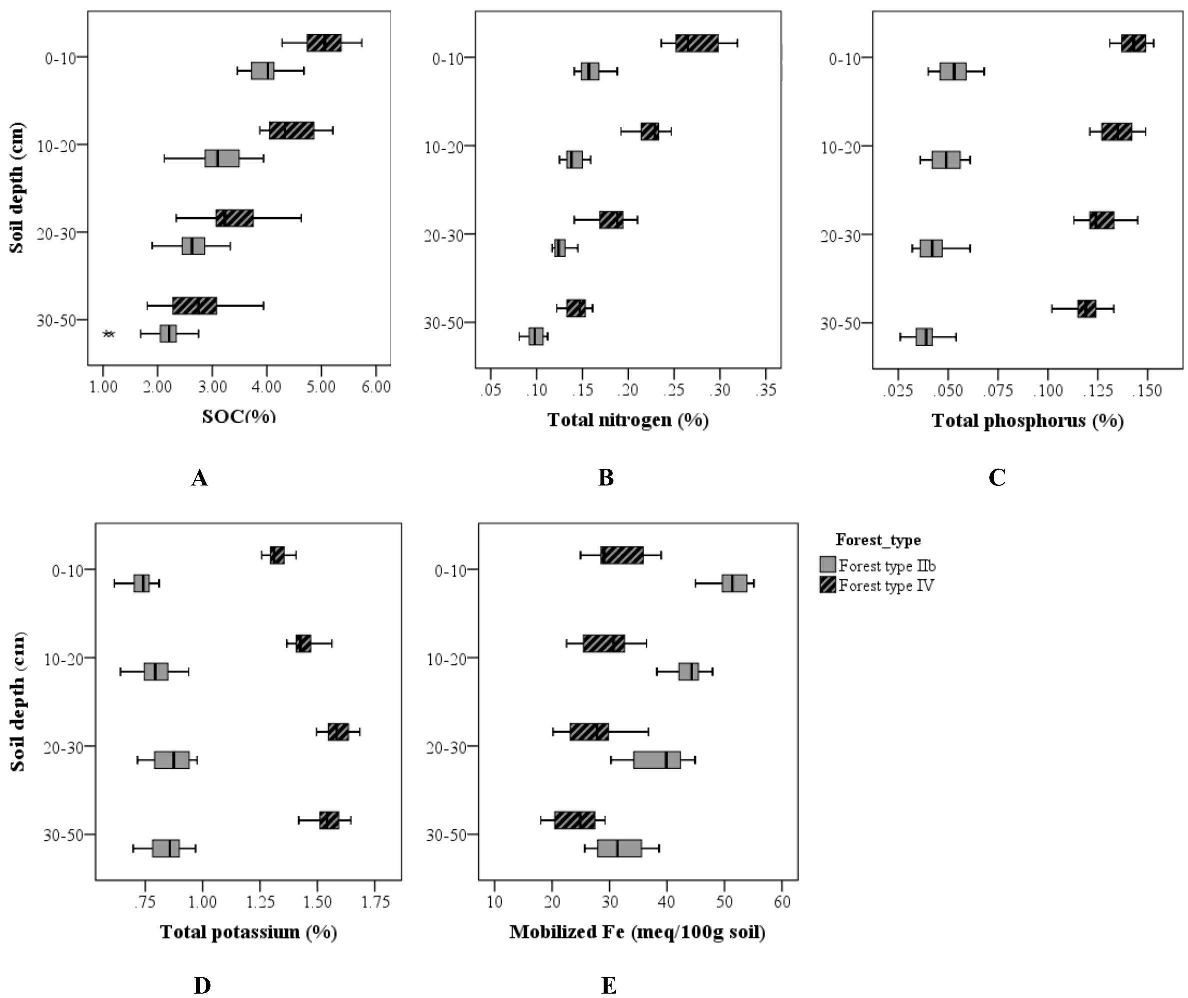


Fig.2. Vertical distribution of SOC, macronutrients and mobilized Fe ion under forest type IIb and IV

SOC content under old-growth forest are higher than secondary forest and decreases with depths. Topsoil layers at depth of 0 - 10cm accumulate the highest SOC ranged between 4.28% and 5.74% in the old-growth forest and from 3.46% to 4.68% in the secondary forest. Besides, SOC content strongly decreases in the subsoils in forest type IIb (from 1.06% to 3.33%) and IV (1.81 - 4.63%), see Fig.2A.

Total nitrogen contents are significantly different between forest type IIb and IV. Topsoil layers from 0 to10 cm have the highest total nitrogen concentration with the range between 0.244 - 0.319% in the old-growth forest and 0.146 - 0.188% in the secondary forest. However, this nutrient fell exponentially as soil depth increased (20 - 50cm) in forest type IIb ranged from 0.081% to 0.145% and from 0.103 to 0.210% in forest type IV, see Fig.2B.

Total phosphorus contents of the old-growth forest range from 0.136% to 0.153% which are about 2.2 times higher than secondary forest in ranged of 0.047% to 0.068%. The differences between the old-growth and the secondary forest are extremely significant, see Fig.2C.

Total potassium contents in the old-growth forest type (ranged from 1.541% to 1.685%) are significantly higher than those of secondary forests (values from 0.728% to 0.976%). The range of this nutrient at depth of 20 - 50cm in forest type IIb are from 0.697% to 0.969% and from 1.564 to 1.685% in forest type IV, see Fig.2D.

Mobilized Fe ion concentration in secondary forest type ranged from 25.69 to 55.11 meq/100g soil are higher compared to old-growth forest type which have values ranged from 18.01 to 38.98 meq/100g soil. From 20 - 50cm of soil depths, mobilized Fe ion reaches 25.69 - 44.88 meq/100g soil in forest type IIb which are higher than in forest type IV ranged 18.01 - 36.78 meq/100g soil, see Fig.2E.

3.2. Differences and trends of soil chemical properties at different horizons

Most of soil chemical properties of old-growth forest are higher than secondary forest, except for mobilized Fe ion. The differences of soil chemical properties in different forest types are indicated at Table 1.

Table 1. T and Sig. values of dependent variables of two forest types

Parameters \ Variables	SOC		Total nitrogen		Total phosphorus		Total potassium		Mobilized Fe ion	
	t	Sig.	t	Sig.	t	Sig.	t	Sig.	t	Sig.
Intercept	38.499	.000	44.797	.000	76.216	.000	127.632	.000	38.522	.000
[Forest_type = IIb]	-6.536	.000	-11.496	.000	-33.638	.000	-40.975	.000	12.989	.000
[Forest_type = IV]	.	.	.	.	.	.	.	.	.	.
a. Dependent Variable: SOC, total nitrogen, total phosphorus, total potassium, mobilized Fe ion.										

Most of soil chemical properties of both old-growth and secondary forest are highest at the topsoil layers and decreased to the subsoil layers, except to total potassium. It tends to be higher at the subsoil horizons. The differences of soil chemical properties at different soil depths are given at Table 2.

Table 2. T and Sig. values of dependent variables of different soil depths under two forest types

Forest types	Depths \ Variables	SOC		Total nitrogen		Total phosphorus		Total potassium		Mobilized Fe ion	
		t	Sig.	t	Sig.	t	Sig.	t	Sig.	t	Sig.
IIb	Intercept	22.922	.000	40.440	.000	10.464	.000	49.776	.000	39.236	.000
	0 - 10cm	13.896	.000	17.256	.000	2.511	.014	-4.762	.000	16.871	.000
	10 - 20cm	7.604	.000	12.081	.000	1.691	.095	-2.035	.045	10.580	.000
	20 - 30cm	3.540	.001	7.276	.000	.795	.429	.645	.521	5.921	.000
	30 - 50cm	.	.	.	.	.	.	.	.	.	.
IV	Intercept	24.021	.000	28.877	.000	67.928	.000	120.134	.000	26.691	.000
	0 - 10cm	14.420	.000	18.738	.000	9.282	.000	-12.052	.000	6.075	.000
	10 - 20cm	10.762	.000	12.533	.000	5.921	.000	-5.572	.000	4.137	.000
	20 - 30cm	4.169	.000	5.553	.000	2.693	.009	2.757	.007	2.371	.020
	30 - 50cm	.	.	.	.	.	.	.	.	.	.
a. Dependent Variable: SOC, total nitrogen, total phosphorus, total potassium, mobilized Fe ion.											

**** Soil organic carbon content***

The SOC content in the old-growth and secondary forests is significantly different (Sig. = 0.000) (see Table 1). In the old-growth forests, the soil surface layer holds much of the degraded detritus or litter fall and partly decomposed by soil microorganisms compared to secondary forests. Moreover, differences in plant composition, plant age and forest cover (Lal, 2005) in two forest types are factors affecting the accumulation and decomposition of organic matter.

In two forest types, SOC content is dramatically decreased in soil depth from 0cm to 50cm (Sig. = 0.000) (see Table 2), in which, topsoil layers 0 - 10 cm accumulate the highest SOC. Besides, SOC content strongly decreases in the subsoils in forest type IIb and IV. Gillabel *et al.*, 2010 indicates that at different depths the distribution of SOC content varies, on the other hand, the C accumulation and degradation process is very different between the topsoil layer and the subsoil layers (Fontaine *et al.*, 2007; Salomé *et al.*, 2010). In other words, organic matter input is mainly concentrated in topsoil layer compared to the subsoil layers (Liu *et al.*, 2012).

**** Total nitrogen content***

The total nitrogen content in old-growth and secondary forests is significantly different (Sig. = 0.000), see Table 1. The accumulation of organic material in soil surface under forest type IV much higher than forest type IIb leading to nitrogen mineralization process more strongly. This is because as soils have sufficient moisture, soil microorganisms decompose organic matter for releasing nitrogen in soil environment and contributing to the soil nitrogen supply. Moreover, organic C have a positive relationship with total nitrogen in soils (Liu *et al.*, 2012) because most N exists in organic compounds from the consumption of SOC.

In both old-growth and secondary forest types, the total nitrogen content decreased markedly from 0 - 10cm to 30 - 50cm soil depths (Sig. = 0.000). In particular, the variation in total nitrogen content in the old-growth forest type went down significantly and more obvious than in the secondary forest, see Table 2. This result also supports for the conclusion of Liu *et al.* 2012, the distribution of total nitrogen was concentrated mainly in the surface soil layer due to the high input of organic matter more than the subsoil layer.

**** Total phosphorus content***

The significant differences in total phosphorus in the two forest types are showed clearly (Sig. = 0.000), see Table 1. In the secondary forest, the total phosphorus content is lower than the old-growth forest because phosphorus can be fixed by mobilized iron and aluminum in the acidic pH (pH_{KCl} ranges from 3.69 to 4.47 in the secondary forest) (Mohd-Aizat *et al.*, 2014). Besides, the concentration of mobilized iron is much higher in the secondary forests than in the old-growth forests, see Fig. 2C.

Total phosphorus at topsoil layers in forest type IIb, IV are higher than subsoil layer (Sig. = 0.014; 0.000 respectively), see Table 2. In forest soil, topsoil layers contain the source of phosphorus releasing from vegetation residue matter by microorganism activities. Hue N.V., 1991 showed that total P content released through surface mineralization is quite stable even the litter layer thickens.

Total phosphorus in the subsoil layers is not high because of the various factors: mechanical composition (sand texture and high porosity), surface water permeate to lower layers in the season rain. However, the P content in the subsoil layers from 20cm to 50cm in forest type IIb, IV was not significantly different (Sig. = 0.095; 0.087 respectively), see Table 2. The thicker root system distribution in the subsoil layers may be the main cause of the organic anion or phosphorus of fungus which are phosphorus sorption sources (Hue N.V., 1991).

**** Total potassium content***

It is different with vertical distribution of nitrogen and phosphorus in soil layers, potassium content in both forest types trends to increase and less change from the depth of 20 cm, see Table 1. In two forest types, potassium content in topsoil layer 0 - 10cm and 10 - 20cm had a significantly different compared to subsoil layers (Sig. = 0.000). However, from the depths of 20 - 50cm, potassium content was not significantly different (Sig. = 0.521 with forest type IIb; Sig. = 0.431 with forest type IV), see Table 2.

Because potassium persists primarily due to its association with the silica, mica and illites, the amount of potassium in the soil depends a great deal on the mineral composition of the soil. Moreover, the potassium rarely exists in organic matter and humic substances even do not contain potassium (Blume *et al.*, 2016). Therefore, although the amount of organic matter accumulating in topsoil in both forest types is high, the potassium content is low and increases at different depths mainly due to increased mineral composition in the soil layers.

This result is also consistent with the study by Ngo Dinh Que *et al.*, 2009, the variation of readily potassium increased in depths in 19 year-old pine forest in Trieu Phong-Quang Tri: 45.68ppm/100g soil on topsoil layer 0 - 10cm and 48.97ppm/100g soil on the 20 - 30cm layer.

**** Mobilized iron ion***

Mobilized iron (Fe) ion concentration in the secondary forest type are higher compared to the old-growth forest type (Sig. = 0.000), see Table 1. SOM accumulation under secondary forests in a short-term leads to higher in soil mineral phase and lower in SOM than old-growth forest type. Because mobilized Fe exists in soils that are primarily derived from the solid phase of soils. In addition, the existence of Fe^{3+} in the soil solution and the combination of Fe^{3+}-SOM determine the stability and duration of organic matter (Blume *et al.*, 2016). In other ways, composition of fresh organic matter with Fe oxides might constitute a major mechanism for OM stabilization (Eusterhues *et al.* 2005), forming aggregates protected from microbial degradation.

Total mobilized Fe concentration tends to decrease with depth of soil in both forest types (Sig. = 0.000), see Table 2. Kogel-Knabner, 2008 found that Fe ion types include dithionite-Fe, oxalate-extractable Fe increase with soil depths, but pyrophosphate-extractable Fe which belongs to organo-Fe complexes mainly concentrates on topsoil layer and decreases with soil depths. Therefore, in both forest types, non-impacted litter fall layer is an important condition for the formation of iron-SOM compounds. On the other hands, the mobilized Fe can still occur in the subsoil layers due to the movement of water on the soil surface (Blume *et al.*, 2016).

3.3. Relationships between studied parameters

The relationship between SOC and other soil properties under two forest types was analyzed by path analysis and given at Table 3:

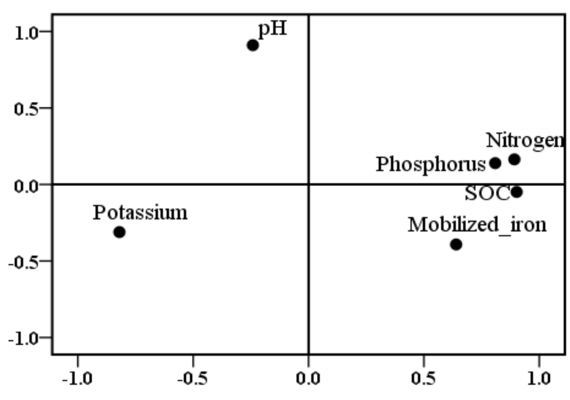
Table 3. Relationship between soil properties under two forest types

Forest type	Nitrogen	Phosphorus	Potassium	Mobilized Fe ion	pH	Direct effect	Indirect effect
Type IIb	.103	.113	-.065	.626	-.167	.447	.258
Type IV	.575	.373	.065	.066	-.153	.501	.262

The results indicate that the analytical indicators have different relationship in the two forest types. In forest type IIb, SOC has a positive relationship with total N, total P, mobilized Fe ion with beta values of 0.103, 0.113 and 0.626. The causes of these relationships are clearly explained in Section 3.2. Total K content and pH were negatively correlated with SOC content (β =-0.065,-0.167 respectively). In forest type IV, SOC has a positive relationship with most of soil properties: total N (β = 0.575), total P (β = 0.373), total K (β = 0.065), mobilized Fe ion (β = 0.066), except for pH (β =-0.153).

Unlike forest type IIb with direct effect = 0.447, forest type IV was more stable in terms of forest structure, litter and organic decomposition so that the relationship between SOC and nutrient elements is relatively high (Direct effect = 0.501). Indirect effect factors such as altitude, slope, canopy cover, litter amount impact on changes in soil properties under two forest types with values of 0.258 in forest type IIb and 0.262 in forest type IV.

All the studied parameters have a positive or negative correlation in soils. In particular, the content of SOM has a great influence on the others. An visible overview of the natural relationship between these parameters in the two forest types is shown in Fig.3.



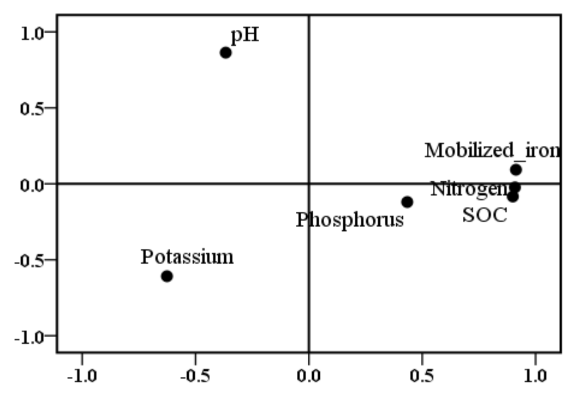


Fig.3. Principal component in rotated space of two forest types
Forest type IIb: A; Forest type IV: B

Above principal component analysis graphs show that SOC contents positively related with total N, total P and total K. In which, SOC contents have a close relationship with total N in forest type IV and IIb (R^2 = 0.640 and 0.567 respectively). SOC have a strong relationship with total P in forest type IV (R^2 = 0.727) and relatively close relation in forest type IIb (R^2 = 0.531). Because the SOM decomposition closely related to release macronutrients to the soils by soil microorganism activities (Mohd-Aizat *et al.*, 2014), especially total N and P in soils, SOC have a weak relationship with total K in forest type IV and IIb (R^2 = 0.365 and 0.198 respectively). Clearly, total K in soils is primarily derived from mineral compositions that are not contained in SOM (Blume *et al.*, 2016) so there is no close relationship with SOC.

Otherwise, SOC content have a negative relationship with mobilized Fe ion and pH. According to Kogel-Knabner 2008, Fe ion which derived mainly from mineral composition poorly absorbed into organic matter leads to this relationship. Moreover, mobilized Fe ion is mainly derived from the mineral composition soil in subsoil layers.

Generally, soil pH directly and indirectly effects on most soil physical and chemical processes (Brady and Weil, 2002). The reduction of soil pH led to the formation and increase of concentrations of Fe, biologically toxic aluminum ions (Flis *et al.*, 1993) and reduced activity of soil microorganisms, which is a major contributor to SOM decomposition which is the main source of food and energy for soil microorganisms (Edward *et al.*, 1999). Therefore, soil pH is inversely proportional to the content of macronutrients and is directly proportional to the soil mobilized Fe ion content.

IV. CONCLUSIONS

SOC content at topsoil layer 0 - 10cm accumulate the highest SOC ranged between 4.28% and 5.74% in the old-growth forest and from 3.46% to 4.68% in the secondary forest. SOC content strongly decreases in the subsoil horizons in forest type IIb (from 1.06% to 3.33%) and IV (1.81 - 4.63%).

Similarly, topsoil layer at depth of 0 - 10cm has the highest total nitrogen concentration with the range between 0.244 - 0.319% in the old-growth forest and 0.146 - 0.188% in the secondary forest. This nutrient fell exponentially as soil depth increased (20 - 50cm) in forest type IIb ranged from 0.081% to 0.145% and from 0.103 to 0.210% in forest type IV.

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Total potassium contents in the old-growth forest type (ranged from 1.541% to 1.685%) are significantly higher than those of secondary forests (values from 0.728% to 0.976%). The ranges of this nutrient at 20 - 50cm in forest type IIb were from 0.697% to 0.969% and from 1.564 to 1.685% in forest type IV.

Mobilized Fe ion concentration in the secondary forest type ranged from 25.69 to 55.11 meq/100g soil are higher compared to the old-growth forest type which have values ranged from 18.01 to 38.98 meq/100g soil. From 20 - 50cm of soil depths, mobilized Fe ion reaches 25.69 - 44.88 meq/100g soil in forest type IIb which are higher than in forest type IV ranged 18.01 - 36.78 meq/100g soil.

SOC contents positively related with total N, total P and total K while it had a negative relationship with mobilized Fe ion and pH in soil.

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