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Genesis and development of Argillic Horizon in Ultisol Climosequence

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ABSTRACT

This soil research on 5 Ultisol pedons was aimed to investigate various processes and factors influencing the genesis and development of the argillic horizon. The results of the research showed that the Clay Iluviation Index (CII) and the depths of the E, Bt and Bt-E horizons relatively increased and the Argillic Development Index (ADI) relatively decreased with increasing rainfall. The total clay ratio of Bt/A or Bt/E horizons for the 5 pedons showed a value of >1.2. The fine clay to total clay (FC/TC) ratio in Bt horizon ofthe P1 and P2 pedons was higher than that in horizons above and below the Bt horizon, whereas the FC/TC ratios in the P3, P4, and P5 pedons were only higher than that in the A horizon, respectively. The difference of the highest with the lowest FC/TC ratio was in the P2 pedon (0.53), indicating that the ADIwas quite large. The P3 pedon showed the largest thickness of Bt, Bt-E and Bt / E ratio horizons. There were varying percentages of clay coating (3.61 - 28.18% vol.), showing evidence of the argillic formation.

Key words : *Argillic genesis, Climosequence, Clay coating*

Introduction

The difference in the amount of rainfall and temperature from one to another area can have different effects on the process of soil formation and development. As stated by Yaalon (1983), Brady (1990), Eswaran(1993), Alvarez and Lavado (1998), Hardjowigeno (2003), Quilchano *et al.* (2009), rainfall and temperature are important climatic factors influencing the process of soil formation and soil properties. The influence of climate on changes in soil properties is known as a climosequence, generally associated with the height of a place from the surface of the sea (altitudinal climate). The higher a placeis, the greater the rainfall (Hardjowigeno, 2003; Dai and Huang, 2006) will be, in which the height reaches a maximum between 1,000 and 1,500 m above sea level (Tan, 2008). Alvarez and Lavado (1998) showed a correlation between rainfall and depth of soil solum and clay content. Webb and Campbell (1986) and Jenny (1994) have also studied the relationship between rainfall and soil clay content.

Ultisol is a type of soil that shows advanced soil development (Hardjowigeno, 2003) and has an argillic horizon with a little weathered mineral (Foth, 1990; West *et al.*, 1998). This soil is dominant in East Kalimantan Province, Indonesia, with an area of 8,809,912 ha (Mulyani *et al.*, 2004). The process of forming and developing Ultisol in this humid tropical climate, according to Hardjowigeno (2003), is generally through extensive washing processes of bases, strong weathering due to fairly hot temperatures (> 8^0C) and translocation of clay (*lessivage*). According to Brady and Weil (2007), the main process in the formation of Ultisol is weathering clay minerals and clay translocation that accumulates in the argillic horizon. This soil is characterized by a relatively acidic B horizon with a Base Saturation (BS) of <35%.

The Argillic horizon is one of the characteristics of Ultisol, formed through the translocation process of clay from the eluvial horizon (generally close to the soil surface) to the subsoil layer where the clay accumulates on the argillic horizon. As a result, the argillic horizon contains higher phyllosilicate clay than the layer or layers of soil above it. The increase in phyllosilicate clay results from a process known as clay illuviation (Soil Survey Staff, 2013; 2014).

Some pedologists are interested in studying an argillic horizon because this horizon has specific characteristics formed by different mechanisms of clay illuviation. The Argillic horizon had been studied for decades. Some of them are Reynders (1972) examining an argillic horizon in Mediterranean soils in Morocco, Bronger (1991) examining loess soils that have the ustic moisture regime, and Khormali *et al.* (2003) investigating the development of argillic horizon in calcareous soils in arid and semiarid regions. Meanwhile, McKeague *et al.* (1981) evaluated the criteria for argillic (Bt) horizon soils in Canada using macro- and micromorphological methods, and Ibrahim (2011) examined the factors influencing the formation of argillic horizons and the direction of clay particle movement. According to Bronger (1991), there are differences in clay illuviation and the formation of argillic horizons due to lithogenic (pedoturbation) and climatogenic processes. This research aimed at investigating the various processes and factors influencing the genesis and development of the argillic horizon in Ultisol climosequence.

Materials and Methods

ResearchLocation: This soil research on 5 Ultisol pedons was carried out in transects survey according to the sequence of rainfall from the East to West of East Kalimantan Province, from P1 pedon (zone I with rainfall of <2,000 mm / yr), P2 pedon (zone II with a rainfall of 2,000 - 2,500 mm / yr), P3 pedon (zone III with rainfall of 2,500-3,000 mm/yr), P4 pedon (zone IV withrainfall of 3,000-3,500 mm/yr) to P5 pedon (zone V with rainfall of 3,500-4,000 mm/yr). The five Ultisol pedons are in one land unit (Map on Figure 1), derived from Tertiary-Quaternary sedimentary rocks, with a slope of 16-25% and land cover in the form of shrubs mixed with secondary dry forests and smallholder fruit crops. The Soil Temperature Regime (STR) and the Soil Moisture Regime (SMR) of the research site were calculated using the Newhall Simulation Model based on 30 years of climate data (1982-2012 period) sourced from climate-data.org (https://id.climate-data.org/info/privacy), indicating successively Isohyper-thermic and udic/perudic.

Soil Sampling and Analysis: Soil observation and sampling in the land unit for each climate zone were taken per 10 cm layer to a depth of 150 cm orthe bedrock layer for each selected pedon. The pedon and its environment were described using references to the Soil Profile Description (Rayes, 2006), Guidelines for Soil Description (FAO, 2006), Field Book for Describing and Sampling Soils (USDA, 2012) and Keys of Soil Taxonomy (Soil Survey Staff, 2014).

Texture analysis of 10 fractions including 5 sand fractions (very coarse sand of >1,000 μm, coarse sand of 500-1,000 μm, medium sand of 200–500 μm, fine sand of 100–200 μm, and very fine sand of 50–100 μm), 3 silt fractions (coarse silt of 20–50 mm, medium silt of 10–20 mm and fine silt of 2–10 mm) and 2 clay fractions (coarse clay of 0.05-2 mm and fine clay of <0–0.05 mm) were carried out by the pipette method, wet sieving and precipitating (van Reeuwijk, 1993).

Identification of the presence of clay coating (argillan) and other materials contained in Ultisol samples was performed using a polarizing microscope. In prior, it was necessary to make a thin section from a soil sample of *kubeina* box with the following procedure:(a) impregnating undisturbed soil sample with artificial resins, (b) solidifying the soil samples, (c) laminating solidified soil samples, (d) polishing the laminated soil samples with silicone powder, and (e) cutting the sample into thin slices with a thickness of 25-30 μm (Kerr, 1959).

Data Analysis: Some soil morphological data and soil texture of 10 fractions were calculated and analyzed mathematically or statistically, as follows:

(a) The Clay Illuviation Index (CII) showing the Intensity of the Clay Translocation (ICT) was calculated using the equation proposed by Delgado *et al.* (1994), as follows:

$$CII = \frac{\%\ Clay\ Ar\ gillic\ Bt\ Horizon}{\%\ Clay\ Eluvial\ E\ Horizon}$$

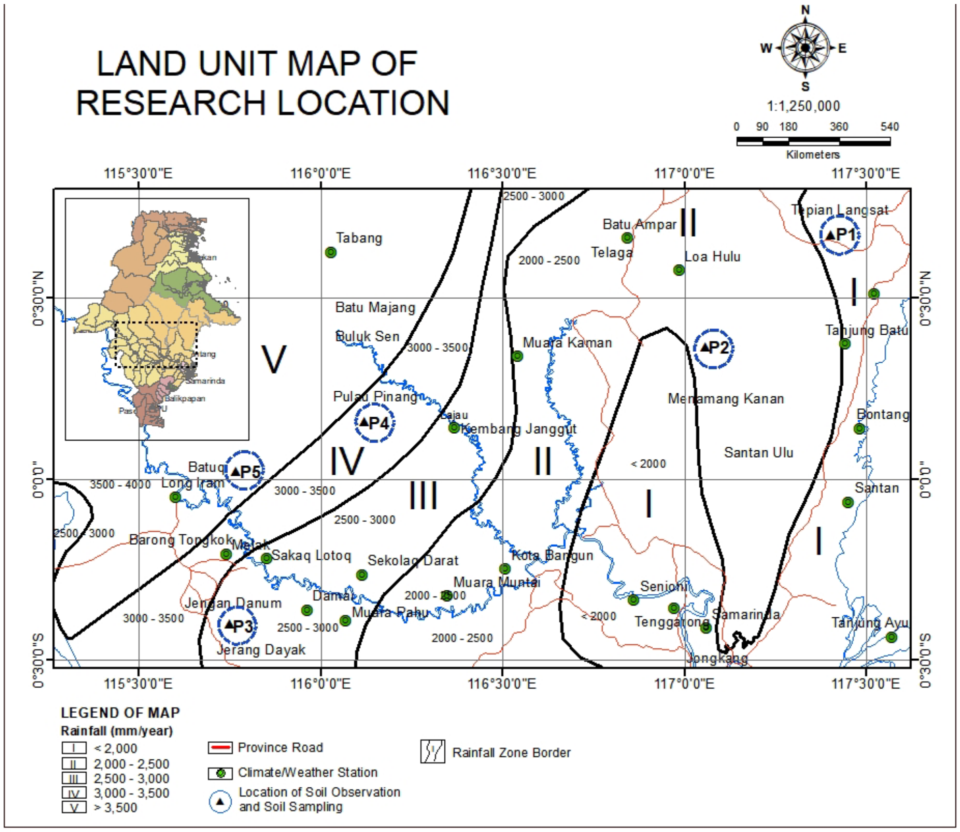

Fig. 1. Map of the research location showing the rainfall zone within the administrative area of East Kalimantan Province, Indonesia

(b) The clay content and clay ratio of illuvial to eluvial (Bt / E) horizons ratio;

(c) The ratio of fine clay to total clay (FC / TC ratio) in the illuvial (Bt) and eluvial (E) horizons;

(d) An index of clay illuviation/eluviation (I/E Index) showing the Argillic Development Index (ADI), with the equation proposed by Cremeens and Mokma (1986), as follows:

$$\frac{I}{E} Index = \frac{\left(\dfrac{\%\,Fine\ Clay\ of\ Bt\ Horizon}{\%\,Total\ Clay\ of\ Bt\ Horizon}\right)}{\dfrac{\%\,Fine\ Clay\ of\ E\ Horizon}{Total\ Clay\ of\ E\ Horizon}}$$

(e) The depth of the argillic horizon is determined based on the depth of the upper boundary of the argillic horizon from the soil surface;

(f) The ratio of the thickness of the illuvial and the eluvial (B / E or Bt / E) horizons is determined by comparing the thickness values of the two horizons. The thickness of the argillic horizon is determined based on the difference between the upper and the lower boundaries of the argillic horizon.

Results and Discussion

The Genesis of Argillic Horizon

The Intensity of Clay Translocation: As presented in Figure 2 and Table 1, the Intensity of Clay Translocation (ICT) is expressed in the form of a Clay Illuviation Index (CII), showing a relative risewith an

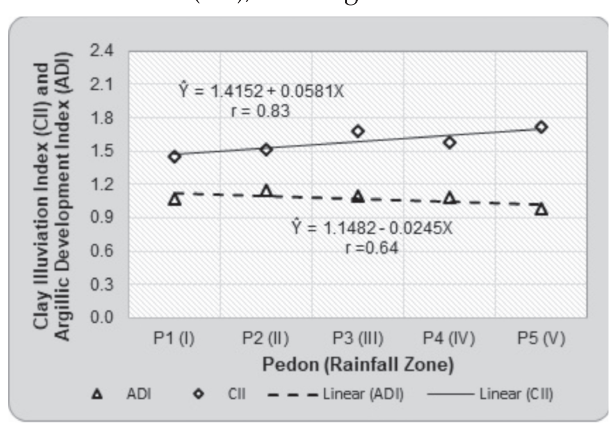

Fig. 2. Clay Illuviation Index (CII) and Argillic Development Index (ADI)

Table 1. Clay content, Bt/E thickness ratio, Argillic Development Index (ADI) and Clay Illuviation Index (CII) of the 5 selected pedons

Pedon (Zone)	Horizon	Horizonthickness (cm)	Clay content			FC/CC Ratio	FC/TC Ratio	TC Bt/A Ratio	TC Bt/E Ratio	Bt/E thickness Ratio	ADI	CII
			Coarse	Fine	Total							
P1 (I)	A (0-6.5)	6.5	4.92	16.12	21.04	3.28	0.77			1.4167	1.0723	1.4563
	E (6.5-18.5)	12.0	4.05	18.92	22.98	4.67	0.82					
	Bt (18.5-35.5)	17.0	3.91	29.55	33.46	7.57	0.88	1.59	1.46			
	BCt (35.5-76.0)	40.5	7.22	31.13	38.35	4.31	0.81					
	Ctv (76.0-96.5)	20.5	11.35	25.08	36.43	2.21	0.69					
	Cv (96.5-100)	3.5	11.87	29.11	40.98	2.45	0.71					
P2 (II)	A (0-5.0)	5.0	6.34	20.50	26.84	3.23	0.76			1.4762	1.1423	1.5130
	E (5.0-15.5)	10.5	5.70	22.49	28.19	3.95	0.80					
	EB (15.5-34.0)	18.5	4.15	28.78	32.93	6.93	0.87	1.59	1.51			
	Bt (34.0-49.5)	15.5	3.78	38.88	42.66	10.28	0.91					
	BCtv (49.5-112.5)	63.0	9.65	43.58	53.23	4.52	0.82					
	Cv (112.5-140.0)	27.5	14.01	53.80	67.81	3.84	0.79					
P3 (III)	A (0-12.0)	12.0	6.79	16.07	22.85	2.37	0.70			2.0794	1.1237	1.6859
	E (12.0-43.5)	31.5	4.88	19.49	24.38	3.99	0.80				1.0741	
	E/Bt (43.5-57.5)	14.0	2.19	21.03	23.22	9.60	0.91					
	Bt (57.5-78.0)	20.5	3.50	31.00	34.50	8.87	0.90	1.51	1.42			
	Btv (78.0-123.0)	45.0	7.13	43.43	50.56	6.09	0.86	2.21	2.07			
	Ctv (123.0-140.0)	17.0	7.94	44.83	52.77	5.65	0.85					
P4 (IV)	A (0-6.0)	6.0	4.25	12.80	17.05	3.01	0.75			1.0909	1.0865	1.5775
	E (6.0-39.0)	33.0	3.14	17.95	21.09	5.72	0.85					
	E/Bt (39.0-80.5)	41.5	2.50	24.61	27.11	9.83	0.91					
	Bt (80.5-116.5)	36.0	2.50	30.77	33.27	12.29	0.92	1.95	1.58			
	BCt (116.5-150.0)	33.5	2.83	35.23	38.05	12.47	0.93					
P5 (V)	A (0-5.0)	5.0	3.11	14.02	17.14	4.50	0.82			1.2439	0.9775	1.7144
	E (5.0-46.0)	41.0	2.22	12.92	15.13	5.83	0.85					
	EBt (46.0-87.0)	41.0	1.64	15.15	16.79	9.24	0.90					
	Bt (87.0-138.0)	51.0	4.30	21.65	25.94	5.04	0.83	1.51	1.71			
	Ctv (138.0-160.0)	22.0	4.45	27.16	31.62	6.10	0.86					

Note: Clay content data using 10 fraction analysis results
FC / CC Ratio = Fine Clay / Coarse Clay Ratio, FC / TC Ratio = Fine Clay / Total Clay Ratio,
TC Bt/A Ratio = Total Clay Ratio of Bt/A Horizons, TC Bt/E Ratio = Total Clay Ratio of Bt/E Horizons,
ADI = Argillic Development Index, CII = Clay Illuviation Index

increasing amount of rainfall (according to rainfall sequences, from zone I to zone V) and a high correlation coefficient (r = 0.83). Pal *et al.* (2003) and Bockheim *et al.* (2005) said that clay illuviation is one of the earliest known soil formation processes, which involves the genesis of many types of soil that develop in many types of climate.

According to Buurman *et al.* (1998), clay illuviation is a climate-dependent process that isrestricted to the vadose zone. Frederiksen (1981) said that in the process of clay illuviation, the clay fraction decreases in the eluvial horizon and increases in the illuvial horizon. Phillips (2004) and Sauzet *et al.* (2016) added that the intensity of illuviation is generally measured through the texture differentiation index between eluvial and illuvial horizons. Unfortunately, data related to this differentiation is difficult to interpret clearly because the differentiation can becaused by several different processes, such as *in-situ* weathering, bioturbation, and micro-division.

The real values of CII in the P3, P4 and P5 pedons indicated that the clay translocation process was quite intensive and continuous, causing the formation of deeper argillic Bt horizon in the soil.

The clay content and ratio of fine clay to total clay: As presented in Table 1, the ratio of total clay of the Bt to the A (Bt/A) horizons or the Bt to the E (Bt/E) horizons showed values of >1.2. Based on particle size distribution data, Gunal and Ransom (2006) confirmed that the Bt horizon has at least 1.2 times the total clay compared to the eluvial horizon. Increased total clay content is sufficient to classify soils having argillic horizons. Wang and Mckeague (1982) showed that there was a sharp increase in the fraction of total clay (<2 μm) and fine clay (0.2 μm) in the Bf horizon compared to the Ae and C or CB horizons for 3 pedons (no lithologic discontinuity) studied, which became clear evidence of clay illuviation.

The ratio of fine clay to total clay (FC/TC) in the Bt horizon of each P1 and P2 pedon was higher than that in the horizon above and below it. Hopkins and Franzen (2003) also found that the total clay distribution and FC / TC ratio increased in the argillic horizon compared to the surface horizon and parent material.

The FC / TC ratios of the Bt horizon in each P3, P4, and P5 pedon were only higher than the that on the surface horizon (horizon A) (Table 1). This also strongly indicates the formation of the argillic horizon of the three pedons. Osman and Eswaran (1973), Bullock and Thompson (1985), Breeman and Buurman (1998), Khormali *et al.* (2003), and Gunal and Ransom (2006) stated that the ratio of fine clay to total clay in argillic horizons is higher than thatin surface horizons. The results of Gunal and Ransom's study (2006) show that all pedons givea higher proportion of fine clay to total clay in the Bt horizon than that in the surface horizon.

The FC / TC ratio of the Bt horizon in the P3 pedon was slightly lower than that in the E / Bt transition horizon above it, while thatin the P4 pedon was slightly lower than the BCt transition horizon below it, and that in the P5 pedon was lower than the EBt transition horizon above it and the Ctv transition horizon below it. It was caused by the still active process of eluviation and illuviation

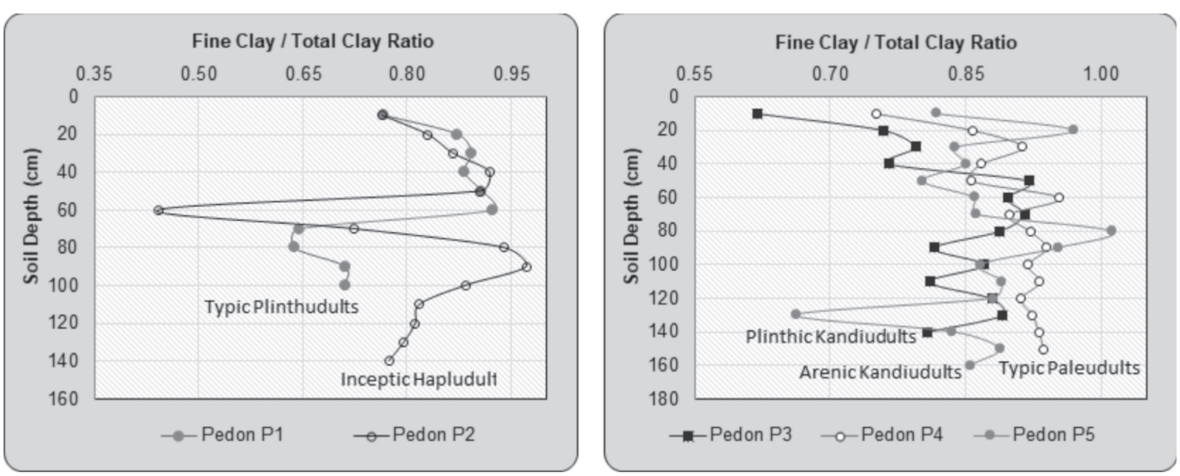

Fig. 3. Fine clay to total clay ratio of P1 dan P2 pedons [a] and P3, P4andP5 pedons [b]

in these three pedons (rainfall 2,500 - 4,000 mm), driving the accumulation of clay content in the Bt horizon continue to change. Besides, there was no sharpening of the boundary of the Bt horizon with the horizon above and below it, similarly, due to the still-active eluviation process.

Figure 3[a] shows the FC / TC ratio in the P1 and P2 pedons located in the East and Central part of the research location, and Figure 3[b] shows the FC / TC ratio in the P3, P4 and P5 pedons located in the Western part of the research site.

Clay Micromorphology of Ultisol

As presented in Table 2, on average, the 5 selected pedons representing 5 rainfall zones (zones I to V) contains a variable amount of clay coating (3.61 - 28.18% vol.). Clay coating or argillan is one of the instructions for the process of lessivage and formation of argillic horizons in the soil. McCarthy *et al.* (1999) and Ufnar (2007) suggested that lessivage is a determining factor in the formation of argillan. According to Quenard *et al.* (2011), lessivage is generally identified in soils in the presence of argillan or clay coating and filling at the macroscopic or microscopic scale. According to Bronger and Bruhn (1990), the presence of argillan can beused to show the clay illuviation process, at least in soils with low tomoderate COLE values. Bullock and Thompson (1985) and Pal *et al.* (2003) stated that detailed micromorphology of soil features

Table 2. Results of Micromorphologyofthe 5 selected Pedons

Pedon (zone)	Horizon	Texture	Diagnostic Horizon Endopedon	Composition in % vol.				
				Matrix	Clay coating (Argillan)	Fe Oxide	Fragment Quartz	Lithic / Rock Fragment
P1 (I)	A (0-6.5)	L						
	E (6.5-18.5)	L						
	Bt (18.5-35.5)	CL	Argillic					
	BCt (35.5-76.0)	CL						
	Ctv (76.0-96.5)	CL		65.38	15.00	6.92	12.69	
	Cv (96.5-100)	C						
P2 (II)	A (0-5.0)	SiL						
	E (5.0-15.5)	SiL						
	EB (15.5-34.0)	SiCL						
	Bt (34.0-49.5)	SiC	Argillic					
	BCtv (49.5-112.5)	C		50.99	14.07	30.77	4.18	
	Cv (112.5-140.0)	C						
P3 (III)	A (0-12.0)	L						
	E (12.0-43.5)	L						
	E/Bt (43.5-57.5)	L						
	Bt (57.5-78.0)	CL	Kandic					
	Btv (78.0-123.0)	C		32.73	28.18	30.23	6.59	2.27
	Ctv (123.0-140.0)	C						
P4 (IV)	A (0-6.0)	L						
	E (6.0-39.0)	L						
	E/Bt (39.0-80.5)	L						
	Bt (80.5-116.5)	CL	Argillic					
	BCt (116.5-150.0)	CL		47.35	3.61	4.46	44.59	
P5 (V)	A (0-5.0)	SL						
	E (5.0-46.0)	SL						
	EBt (46.0-87.0)	SL						
	Bt (87.0-138.0)	CL	Kandic					
	Ctv (138.0-160.0)	CL		56.54	7.65	2.47	33.33	

Note: Clay illuviation level; negligible = <0.3% Vol., weak = 0.3-1.0% Vol., Medium = 1.0 - 4.0% Vol., strong = 4.0-7.0% Vol., very strong ≥ 7.0% Vol. (Miedema and Slager, 1972) (pedofeature) is seen as the best method for identifying illuvial clay.

The clay coating in the P1 pedon (shown in figure 4) is broken, stringy, spreads in the matrix, surrounds the iron oxide or quartz and is on the crack. According to Beinroth (1982) and Schaetzl and Anderson (2005), argillan is almost impossible to identify in the field with kaolinite and oxic mineralogy. If observed in a thin section, they tend to be also thin and degraded. Furthermore, Schaetzl and Anderson (2005) suggested that at the stage of continued degradation, all residual argillan and Bt horizons would normally be destroyed.

In addition to clay coating, all the pedons studied also contain iron oxide and quartz with a considerably large variation, namely: iron oxide ranging from 2.46 to 30.77% vol. and quartz ranging from 4.18 to 44.59% vol. (Table 2). Large amounts of iron oxide were found in the BCtv and Btv horizons of the P2 pedon. Jakobsen (1989) and Schaetzl and Anderson (2005) suggest that Al and Fe-rich clay skin (clay coating) isabove Fe-rich clay skin in horizon B. As further said by Schaetzl and Anderson (2005), ferri-argillan is one of the cutaneous or clay coating which contains a mixture of clay minerals and iron oxide and hydroxide.

Specifically, in the horizon Btv of P3 pedon, there are lithic/rock fragments rich in micro—crystalline

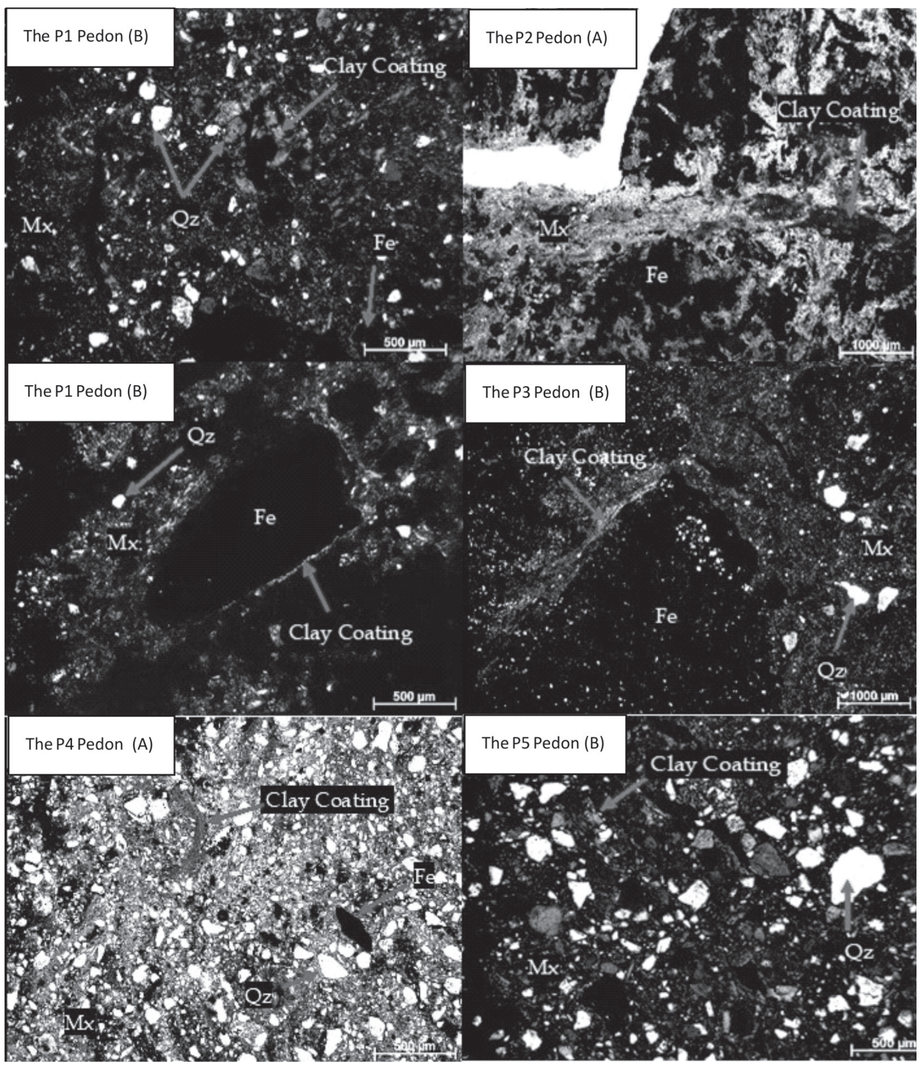

Fig. 4. Photomicrograph of a thin section from *a kubiena-box* soil sample of the 5th layer of 5 pedons studied; the plane-polarized light [A], the cross-polarized light [B].
Note: Mx= matrix, Fe= Fe oxide, Qz= quartz, Lit= lithic/fragment

quartz of 2.27% vol. A large amount of quartz is found in the P4 and P5 pedons.

By using the 5th layer of selected pedons, the number of clay coatings increased when the rainfall was 2,500 - 3,000 mm / year (zone III), then decreased when the rainfall was >3,000 mm / year (zones IV and V), as presented in Figure 5. The number of clay coatings was relatively increased in line with the increasing amount of iron oxide inthe rainfall zones I to III, then decreased in the rainfall zones IV and V.

As presented in Table 2, iron oxides in the P1, P2 and P3 pedons were shallower and closer to the surface, whereas the P4 and P5 pedons were relatively in the deeper soil layers. Of course, this is closely related to the higher amount of annual rainfall in the P4 and P5 pedons, enabling the process of leaching (nutrient leaching), including iron element, more intensively towards deeper layers of soil.

Argillic Development

Clay illuviation/eluviation index: The Argillic development index (ADI) expressed in the form of clay illuviation/eluviation index (I/E index) showed a relative decrease with an increasing rainfall (according to the sequence of rainfall from zone I to zone V), as shown in Figure 2. This is likely due to the higher rainfall, the less chance of the formation of clay coating (one indication of the argillic formation). In such conditions, the formed clay coating becomes diffused or broken, covering iron oxide or quartz.

Based on the calculation of clay content data per 10 cm soil layer, the difference between the highest FC/TC ratio, Rt and the lowest FC/TC ratio, Rr (Rt-Rr) on the P2 pedon was 0.53, indicating that the ADI was quite large. This is especially true when rainfall is low or during the dry season.

The depth and thickness of the eluvial and the argillic horizons: As presented in Table 1 and Figure 6, the depth of the argillic (Bt) horizon was directly proportional to the depth of the soil, with a linear equation, v´ = 10.9 + 27.2 X and a correlation coefficient (r) of 0.92. The depths of the E and Bt horizons was quite shallow in the P1 pedon (located in the rainfall zone area I, <2,000 mm / yr), compared to other pedons located in the area in the Middle and West of the research sites.

The depth of the argillic (Bt) horizon increased with an increasing rainfall (rainfall sequence I to V), *ie* in the P1 pedon at a depth of 18.5–35.5 cm, in the P2 pedon at a depth of 34.0–49.5 cm, in the P3 pedon at a depth of 57.5 –123.0 cm, in the P4 pedon at a depth of 80.5–116.5 cm, and in the P5 pedon at a depth of 87.0–138.0 cm. From this data, it appears that a considerable increase in argillic horizon depths occurred in the P3 pedon (rainfall zone III, 2,500 - 3,000 mm / yr) and the P5 pedon (rainfall zone V, 3,500 - 4,000 mm / yr). The depth of the eluvial (E) horizon was also relatively increased with increasing rainfall. The increasing depth of the eluvial (E) and argillic (Bt) horizons indicates that the eluviation and illuviation processes increased with an increasing amount of rainfall.

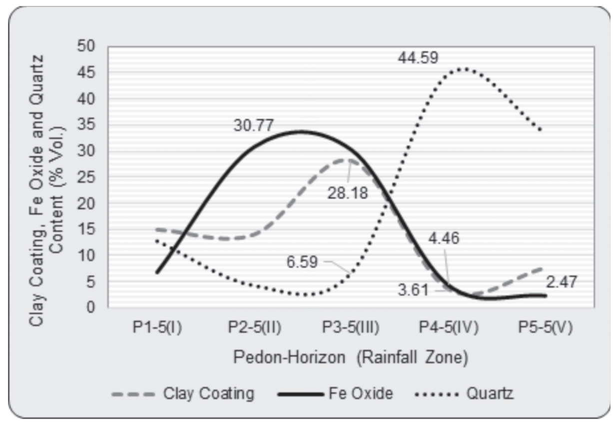

Fig. 5. The content of clay coating, iron oxide and quartz resulting from a thin section of samples from the 5 selected pedons

The difference in the depth of the argillic (Bt) and eluvial (E)horizons relatively rose with increasing rainfall. In the P1 pedon, there was relatively no significant difference between the eluviation and illuviation processes, both of which were slow in this pedon.

The thickness of the argillic (Bt) horizon was in line with the thickness of the eluvial (E) horizon, as shown in Figure 7. The P3 pedon showed the largest argillic horizon thickness, which was 65.50 cm and the largest Bt-E thickness, which was 34.0 cm. Phillips (2007) noted that the depth to the peak of the argillic horizon (thickness of the surface horizon) has a greater influence on the thickness of the argillic horizon and the proportion of thickness of the solum than the thickness of the Bt horizon itself. The largest thickness ratio of the illuvial/eluvial (Bt / E) horizons occurred in the zone III site represented by the P3 pedon, which was 2.08 (Table 1).

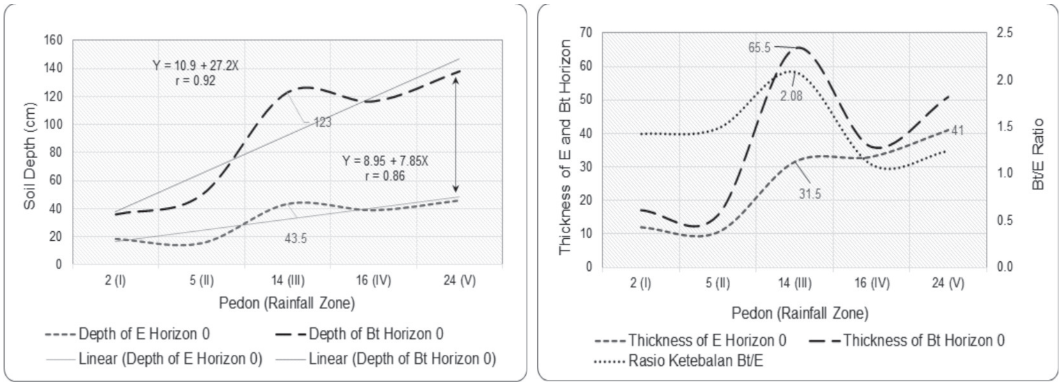

Fig. 7. The thickness of E and Bt horizons, and thickness ratio of Bt/E horizons from the 5 selected pedons

Conclusion

(1) Clay Illuviation Index (CII), the depth of the eluvial (E) and argillic (Bt), and Bt-E horizons relatively increase with increasing rainfall.

(2) The presence of clay illuviation processes and argillic horizons formation in the 5 selected pedons is proven by (a) the ratio of total clay of the Bt/A and the Bt/E horizons with a value of>1.2, (b) the higher ratio of fine clay to total clay (FC/TC) of the horizon (Bt) on the P1and P2 pedons than that in the horizon above and below the Bt horizon, and the higher ratios of FC/TC of the Bt horizon in the P3, P4, and P5pedons than that in surface horizons (A horizon), respectively, (c) Difference between the highest ratio of FC/TC and the lowest ratio of FC/TC on P2 pedons reaching 0.53, and (d) the presence of some of the clay coatings in the 5 pedons studied reaching 2.30-28.18 % vol.

(3) The Argillic Development Index (ADI) decreases with increasing rainfall, the depth of the argillic (Bt) horizon is directly proportional to the depth of the soil, and the thickness of the argillic (Bt) horizon is in line with the thickness of the eluvial (E) horizon. The P3 pedon shows the largest argillic horizon thickness, which was 65.50 cm and the largest Bt-E thickness, which was 34.0 cm.

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