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Characteristics of soil acidification of haplic Acrisols on ancient alluvial deposits under intensive cassava cultivation in Chau Thanh district, Tay Ninh province

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ABSTRACT

This paper clarified the characteristics of soil acidification of haplic Acrisols on ancient alluvial deposit under intensive cassava cultivation in Chau Thanh district, Tay Ninh province, Southeastern Vietnam. Soils were sampled at 3 intervals (0-20, 20-40, 40-60 cm in depth) in 12 sites of intensive cassava cultivation and geochemical parameters related to soil acidity were analysed. The haplic Acrisols under intensive cassava cultivation showed quite high levels of active and exchange acidity (pH_{H2O} 4.40±0.11, pH_{KCl} 3.98±0.07). The hydrolytic acidity and Al saturation level were also high (respectively 4.52±0.37 meq/100g and 57.64±6.41%) while the exchange alkali and alkaline earth cations were very low (Ca^{2+} 0.76±0.25 meq/100g, Mg^{2+} 0.88±0.85 meq/100g, K^{+} 0.16±0.06 meq/100g in the top layer). This exhibited a limit for mineral nutrients and risk of Al toxicity to cassava plants. If the area for intensive cassava cultivation is expanded and the high-yield cassava varieties are applied, the risk of soil acidification will be expected to be highly serious. It is needed to clarify the processes involved and to establish measures to reduce soil acidification and stabilize cassava production in the study area and Tay Ninh province.

Keywords: soil acidification, nutrient, haplic Acrisols, Tay Ninh, cassava.

1. Introduction

Soil acidification as a result of intensive cassava cultivation in upland areas is an issue of global concern. Intensive cassava cultivation has been proved to cause the depletion or nutrient imbalance in soils in Africa (Kenya, Uganda, Cameroon) and Southeast Asia (Thailand, Cambodia) (Araki, Sarr, 2013; CIAT, 2007; Francis et al., 2013; Noble et al., 2004; Sarr et al., 2013). The major causes of this are surface erosion and run-off, leaching, and harvest of biomass (Howeler, 1996; CIAT, 2007). Nutrients (particularly Ca and N) removed from soils are highly intensive if stems and leaves of cassava are also harvested (Howeler, 2001). The final consequence is the mass leaching of bases and accumulation of acidic components into the soils, leading to an overall soil acidification.

In Vietnam, cassava has largely been consumed in the domestic market and is one of the main crops for export (Pham Van Bien et al., 2002; Le Huy Ham et al., 2016). It pro-

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vides low yield in general, partly due to the fact that it is often planted on slope soils, which are heavily eroded and nutrient-depleted (Howeler, Phien, 2000). Nutrient imbalance and nutrient loss in upland soils under intensive cassava cultivation areas have been reported, for example, Nguyen Tu Siem, Thai Phien (1993) and Sat, Deturck (1998). This issue is very serious in the Southeast of Vietnam, even after 2 years of cultivation (Nguyen Tu Siem, Thai Phien, 1993).

Tay Ninh province is located in the Southeast of Vietnam and covers an area of 4.035,45 km^2, in which Acrisols accounts for 84,13%. This soil group in Tay Ninh composes of three soil units, consisting of Haplic Acrisols (230,323 ha), Stagni-Plinthic Acrisols (50,526 ha) and Gleyic Acrisols (49,184 ha) (Sub-NIAPP, 2004). Due to the natural conditions and market demand, the area for cassava cultivation has been on the increase in Tay Ninh province, particularly in Tan Bien, Tan Chau, Chau Thanh and Duong Minh Chau districts. According to the provincial planning for agriculture, the area for cassava cultivation in 2020 will rank 4th and occupy 29,000 ha, after sugarcane (30,000 ha), rubber (87,000 ha), and rice (125,000 ha) (Tay Ninh Provincial People's Committee, 2012).

The haplic Acrisols on ancient alluvial deposit in Tay Ninh province are light-textured, highly eroded, and acidic soils. The rapid development of intensive cassava production might increase the risk of acidification of these soils. Up to present, there has been no study dealing with factors and processes relating to soil acidification due to cassava cultivation in Tay Ninh province. To build up grounds for the deeper understanding on soil acidification, this paper aims to examine the characteristics of soil acidification of haplic Acrisols on ancient alluvial deposited under cassava cultivation areas in Chau Thanh district.

2. Materials and methods

2.1. Study area

Chau Thanh district (571.25km^2) is located at the South-West border of Tay Ninh province, sharing the 48 km borderline with Svay Rieng province of Cambodia. There is a source of all-year-round freshwater supply, making the area highly favorable for agricultural development. Haplic Acrisols in this area mainly distribute in mounds or in elevated foot slopes.

Cassava is cultivated on a wide range of topography of the district (Figure 1a). Land areas for cultivating cassava was previously used to grow other crops, such as rice, tobacco, cashew, or cassava intercropped with other vegetables. This conversion is taken place due to a higher economic return of cassava in comparison to the former crops. Following harvest, farmers often shred the stems and bury it with the leaves into the soil surface layers (Figure 1b).

(a) (b)

Figure 1. Intensive cassava cultivation in Chau Thanh district

2.2. Soil sampling and analysis

Soils were sampled at 12 sites (Figure 2) in August 2015 based on the soil map of Tay Ninh province, scale 1:100,000) (Sub-NIAPP, 2004). At each sampling site, samples were collected at 3 depth intervals (0-20 cm, 20-40 cm, and 40-60 cm in depth) after removing the topsoils generated by raised beds in 3 profiles within an area of about 400 m^2. Samples of the same depths in these 3 profiles were mixed to form a composite sample for analysis. In total, there were 36 soil samples to be analysed.

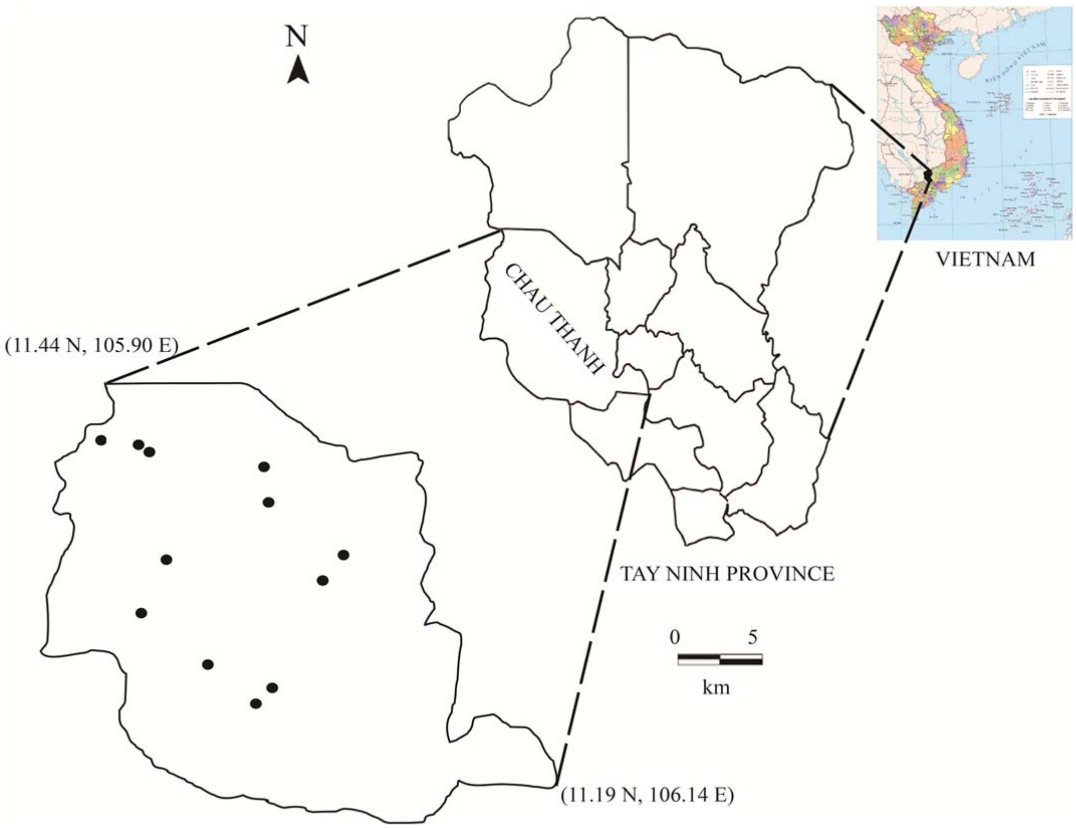


Figure 2. Chau Thanh district and the sampling sites

In the laboratory, samples were air-dried, ground and passed through a 2 mm sieve, then were analysed at Ho Chi Minh City Institute of Resources Geography and Ho Chi Minh City University of Science. The parameters, methods, and calculations are as follows (1) pH_{H2O}: by pH-meter after extracted with distilled water (1/2.5); (2) pH_{KCl}: by pH-meter after extracted with KCl 1N (1/5); (3) exchange acidity: extracted with KCl 1N, titrate the filtered solution by NaOH 0.02N with phenolphthalein as color indicator to light pink color; (4) exchange H^+ and Al^{3+}: titrate the filtered solution after extracted with KCl 1N with NaOH 0.02N (phenolphthalein as indicator) to light pink color (after precipitating Al^{3+} by NaF 3,5%) to calculate exchange H^+, then exchange Al^{3+} is calculated by subtracting exchange H^+ from the exchange acidity; (5) hydrolytic acidity: extracted with CH_3COONa 1M (pH 8) and titrated with NaOH 0.1N with phenolphthalein as color indicator to light pink color; (6) Exchange alkali and alkaline earth cations (Ca^{2+}, Mg^{2+}, K^{+}): extracted with CH_3COONH_4 1N (pH 7) and measured by Atomic Absorption Spectrometry; (7) effective CEC (eCEC) = sum of exchange base cations + exchange acidity; (8) Base saturation = (sum of exchange base cations × 100)/eCEC; (9) Al saturation = (exchange Al^{3+} × 100)/eCEC; and (10) $\Delta pH = pH_{KCl} - pH_{H2O}$ (Mekaru, Uehara, 1972; Rowell, 1994; Soils and Fertilizers Research Institute 1998).

2.3. Statistical analysis

Descriptive statistics, t-test (dependent samples) and Repeated Measured ANOVA were applied. The independent variable is "depth" with 3 levels (0-20cm, 20-40cm, 40-60cm). Dependent variables are geochemical parameters. A Pearson correlation matrix was calculated to examine the correlated levels among geochemical parameters. The 95% confidence interval of the dependent variables are set as Mean ± 1.96*SE (standard error). All of the statistical tests are performed on the Statistica package, version 7.0 (StatSoft, Inc., 2001).

3. Results

The haplic Acrisols in the study area were characterized by low pH, $\Delta pH<0$, elevated exchange acidity and Al^{3+}, and low eCEC (Table 1). While pH_{H2O} showed little variations with depths, pH_{KCl} at 40-60 cm was significantly lower ($p<0.05$) in comparison to the topsoil (Figure 3), being similar to the trend of exchange acidity, exchange Al^{3+} and sum of exchange base cations.

Table 1. The geochemical parameters related to soil acidity of Haplic Acrisols on ancient alluvial deposit in the study area

Parameter	Unit	Mean	Minimum	Maximum	1.96*SE
pH_{H2O}	-	4.40	3.97	5.24	0.11
pH_{KCl}	-	3.98	3.68	4.64	0.07
ΔpH	-	-0.42	-1.13	-0.05	0.08
Exchange acidity	meq/100g	1.7	0.68	3.33	0.21
Exchange H^{+}	meq/100g	0.08	0.05	0.09	0.01
Exchange Al^{3+}	meq/100g	1.63	0.63	3.24	0.2
Exchange Ca^{2+}	meq/100g	0.65	0.13	1.7	0.12
Exchange Mg^{2+}	meq/100g	0.58	0.02	5.11	0.34
Exchange K^{+}	meq/100g	0.14	0.05	0.61	0.04
Sum of exchange base cations	meq/100g	1.36	0.23	6.66	0.44
eCEC	meq/100g	3.07	1.54	7.54	0.4
Base saturation (BS)	%	39.55	13.48	88.24	6.69
Al in exchange acidity	%	95.22	90.82	97.81	0.51
Al saturation	%	57.64	11.09	82.21	6.41
Hydrolytic acidity	meq/100g	4.52	2.38	6.58	0.37

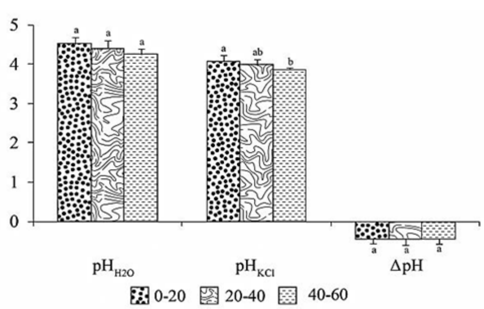


Figure 3. Variations of pH_{H2O}, pH_{KCl}, and ΔpH with depths

The mean pH_{H2O} was 4.40±0.11, being higher than pH_{KCl} (mean 3.98±0.07) for all depth intervals ($p<0.001$). On average, ΔpH was -0.42±0.08 pH unit (Figure 3). The relationship between pH_{H2O} and ΔpH was negative, by which soils reached to the point of zero charge when ΔpH = 0, corresponding to a pH_{H2O} of 3.96 (Figure 4). The exchange acidity and Al^{3+} tend to increase with depths, while the sum of exchange base cations showed an opposite trend (Figure 5).

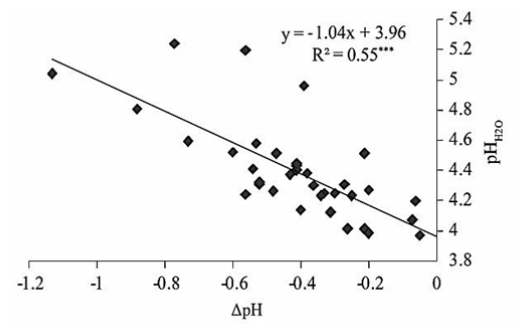


Figure 4. Relationship between pH_{H2O} and ΔpH

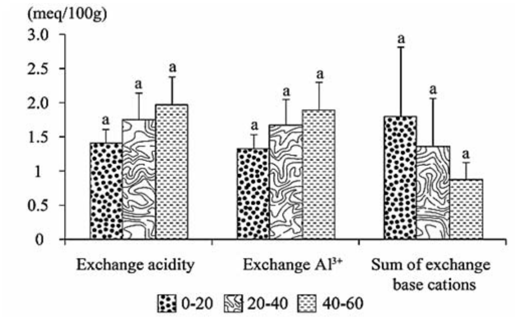


Figure 5. Mean±1.96SE of exchange acidity, exchange Al^{3+} and sum of exchange base cations of each soil layer

The hydrolytic acidity was high, ranging from 2.38-6.58 meq/100g with an overall mean of 4.52±0.37 meq/100g (Table 1). The hydrolytic acidity slightly varied with depth (Figure 6a) and positively correlated with exchange acidity (Figure 6b). On average, values of hydrolytic acidity are 2.82±0.28 meq/100g higher than that of exchange acidity.

Soil base saturation and mineral nutrients for cassava (alkali and alkaline earth cations) were very poor (Table 1). In the top layer, contents of exchange Ca^{2+}, Mg^{2+} and K^+ were very low, 0.76±0.25 meq/100g, 0.88±0.85 meq/100g and 0.16±0.06 meq/100g, respectively. Ca^{2+} and Mg^{2+} concentrations tend to reduce with depth (Figure 7).

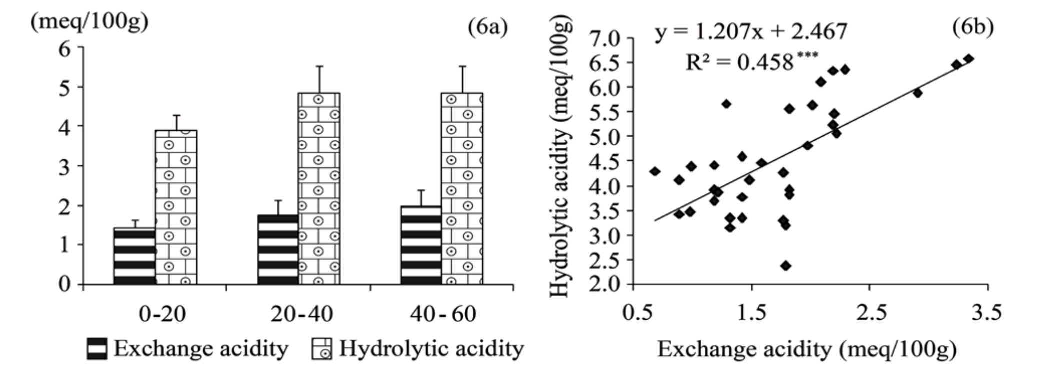
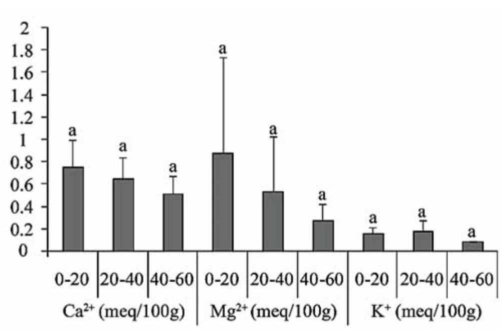


Figure 6. Mean±1.96SE of exchange acidity and hydrolytic acidity of each soil layer and relationship between exchange acidity and hydrolytic acidity



←**Figure 7.** Mean±1.96SE of alkali and alkaline earth cations of each soil layer

4. Discussion

4.1. Active and exchange acidity

According to the classification of soil acidity based on pH_{H2O} (Rengel, 2005), haplic Acrisols in the study area are categorized from moderately acidic (pH_{H2O} 4.5-5.5) to very acidic (pH_{H2O} 3.5-4.5), similar to Acrisols in

Tay Ninh province (Sub-NIAPP, 2004; Le Cong Nong, 2010).

ΔpH<0 (Figure 3) indicated that the exchange surface of soil particles (mostly from organic matter and clay minerals) contained a net negative charge, leading to a tendency to adsorb cations from the soil solution. According to Zołotajkin et al. (2011), ΔpH is dependent on the amount of soil organic matter. When pH_{H2O} dropped to values lower than 3.96 (soils having ΔpH> 0), an inverse trend can be expected (Figure 4).

Over the whole profile, pH_{H2O} and pH_{KCl} were linearly and positively correlated ($p<0.001$) (Figure 8a). This correlation was quite strong in the top layer ($R^2=0.556$, $p<0.01$) (Figure 8b) but became weaker at deeper layers (Figure 8c, 8d), probably due to the accumulation of Al^{3+} on the exchange surface of soil particles (Figure 5).

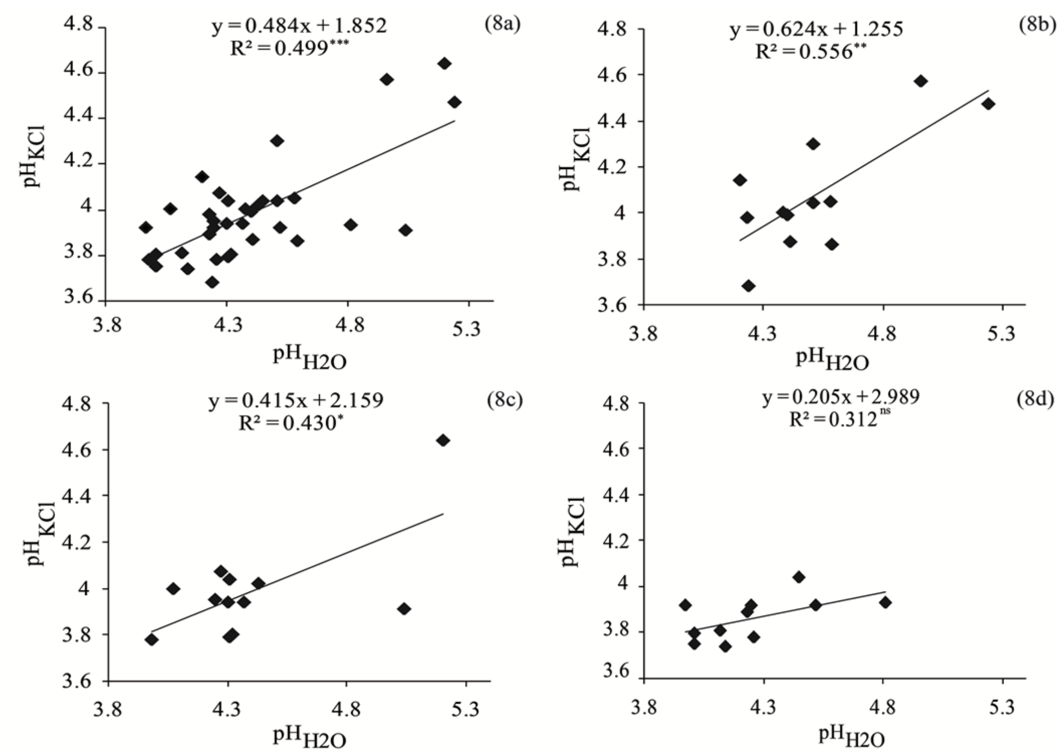


Figure 8. Relationship between pH_{H2O} and pH_{KCl} over the whole soil profile (8a), the 0-20 cm layer (8b), the 20-40 cm layer (8c), and the 40-60 cm layer (8d)

Exchange Al^{3+} accounted for the majority of exchange acidity (95.22±0.51%). This is due to the elevated Al content in Acrisols on ancient alluvial deposit, which was mostly in soluble forms at soil $pH_{H2O}<5$ (Rengel, 2005). When extracted with KCl, several forms of Al were released into the soil solution, including $Al(OH)_3$ (amorphous or precipitated), dispersed alum inosilicates, networks of hydroxy-Al ($AlOH^{2+}$, $Al(OH)_2^+$) or Al-organic matter complexes (Rengel, 2005). Al saturation was quite high in the soils (57.64±6.41%).

The pH_{H2O} and pH_{KCl} of haplic Acrisols in the study area (Table 1) varied in a large range in comparison to those of the similar soil in Don Thuan commune, Trang Bang district, Tay Ninh province (respectively 4.57-

4.90 and 3.98-4.18) (Le Cong Nong, 2010). Exchange acidity of haplic Acrisols in the study area ranged from 0.68-3.33 meq/100g (1.70±0.21 meq/100g), being significantly higher in comparison to Alfisols in Bihar and West Bengal of India (0.07-0.43 meq/100g) (Dolui, Mehta, 2001) and Acrisols (Rhodic Acrisols, Haplic Acrisols) in the coast of Ghana (≤0.43 meq/100g) (Dowuona et al., 2012).

The 40-60 cm soil layer was not affected by root metabolism and land preparation because cassava roots reached to a shallow depth. The lower pH_{KCl} at 40-60 cm layer as compared to that of the topsoil inferred that human impacts on the soil surface may not be a main driver for soil acidification in the study area.

4.2. Hydrolytic acidity

In haplic Acrisols in the study area, the hydrolytic acidity was higher and positively correlated with exchange acidity (Figure 6). The difference between these two kinds of acidity depends on the clay ratio and total Al content in the soils (Soils and Fertilizers Research Institute, 1998).

Hydrolytic acidity of Acrisols in the study area was much higher than that of haplic Luvisol in Slovakia (1.17 meq/100g) (Šimanský, 2011), haplic Cambisol in Rzeszów of Poland (≤2meq/100g) (Gasior, Puchalski, 2010), Alfisols in Bihar and West Bengal of India (0.96-3.65 meq/100g) (Dolui, Mehta, 2001) and other soils (Vertisols, Alfisols and Ultisols) in East Kalimantan of Indonesia (1.56±0.37 meq/100g) (Supriyo et al., 1992). This pattern showed a high risk of acidification of haplic Acrisols under intensive casava cultivation in the study area.

4.3. Alkali and alkaline earth cations, eCEC and base saturation

The basic cations in soils under research were very low (Table 1). Exchange Ca^{2+} and Mg^{2+} in the topsoils of haplic Acrisols in the study area were higher than those of the similar soil in Don Thuan commune, Trang Bang district, TayNinh province (respectively 0.15-0.55 meq/100g and 0.12-0.23 meq/100g) (Le Cong Nong 2010). The eCEC values was low (3.07±0.40 meq/100g), in which exchange Al^{3+} accounted for the majority (57.64±6.41%). Base saturation varied in a large range (13.48-88.24%) with a mean of 39.55±6.69% and has the tendency to decline with depth ($p>0.05$) (Figure 9), in accordance with that of exchange Al^{3+} and exchange acidity (Figure 5).

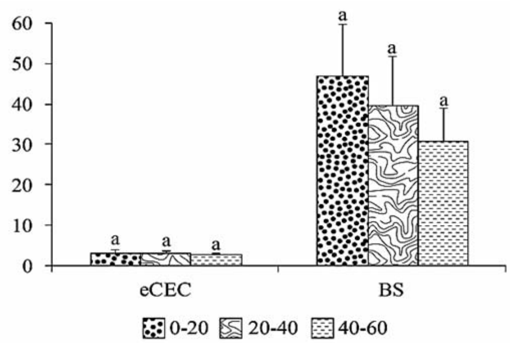


Figure 9. Depth variations of eCEC and BS

4.4. Effects of soil acidity to cassava yield in the study area

The pH_{H2O} of haplic Acrisols in the study area was lower in comparison to the optimal pH range for cassava (pH_{H2O} 5-5.5) (Araki, Sarr, 2013). Limited contents of basic cations (Figure 7) is one of the major factors to reduce the cassava yield as demand for mineral nutrition of cassava, particularly K, is large (Suyamto, 1998; Juo, Franzluebbers, 2003; CIAT, 2007; Sanginga, Woomer, 2009).

Al saturation levels were as high as 57.64%. Although cassava can grow in soils with a Al saturation range from 75-80% (CIAT, 1979, 2007), cassava yield reaches to only 90% of the maxima when Al saturation level exceeds 40% (Kamprath, 1980). Results demonstrated that the current soil acidity has, at least in part, posed negative impacts to the cassava yield in the study area. This assumption has been confirmed via discussion with local agricultural officials and farmers during field research.

5. Conclusions

The haplic Acrisols on ancient alluvial deposit under intensive cassava cultivation in the study area were acidic. Al saturation level was high whereas the exchange alkali and alkaline earth cations (Ca, Mg, K) were very low. This was one of the major factors to limit cassava growth and yield. If the cassava cultivation is expanded and the high-yield cassava varieties are applied, the acidification effect would be expected to be more serious. Studying the factors and processes involved and establishing measures are urgent to mitigate soil acidification in the study area.

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