Effect of P and Si amendment on the charge characteristics and management of a geric soil

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Abstract
Improving surface charge characteristics of geric Ferralsols may increase nutrient retention in highly weathered tropical soils of Vietnam. Application of increasing amounts of fused magnesium phosphate (FMP) increased soil pH by one unit and cation exchange capacity (CEC) 6-fold following 7 days incubation near field capacity at 40°C. Similarly, calcium and magnesium silicate amendments at rates designed to apply the same amount of silicon as a high FMP application also increased pH and CEC. In contrast pHo remained relatively unchanged except following high silicon application. It is recommended that strategies that increase pH are more likely to increase CEC in geric soils than amendments that aim to lower the pHo.

Key Words
Soil charge, geric property, pH_0, CEC, silicate, fused magnesium phosphate, phosphorus buffer index, charge fingerprint.

Introduction
In Vietnam, upland soils such as Acrisols and Ferralsols cover about 72 percent of the total surface (Nguyen and Thai 1999; Ton *et al.* 1996). These highly weathered tropical soils are characterised by high desilication, soil acidity and phosphorus fixation and are intensively cultivated with minimal fertiliser input(Nguyen and Thai (1999). Soil surface charge is often characterized by net positive charge, a geric property, especially in the subsoil layer of Ferralsols (Moody and Phan 2008), where the soil pH in water is close to or lower than that in 1 M KCl (Phan *et al.* 2005). Therefore, cations are easily leached and soil fertility conditions deteriorate. Theoretically, cation loss can be prevented by developing negative surface charge and thus creating additional cation exchange capacity (CEC) (Uehara and Gillman 1981). This can be obtained either by raising soil pH, increasing the electrolyte concentration in the soil solution or lowering the pH_0. Soil amendments that may affect these soil properties include lime, phosphate, silicate and organic matter application. This paper presents the effect of P and Si amendment application on the charge characteristics of a Ferralsol from north Queensland having similar charge characteristics to Ferralsols in the uplands of Vietnam.

Materials and methods
Soil collection
Soil was collected at a depth of 20-40cm (to remove interference from organic matter in determining charge characteristics) from a Pingin series Red Ferrosol under sugarcane cultivation in north Queensland This soil has similar geric properties to many upland soils in Vietnam. The sample was air-dried and passed through a 2mm-sieve before taking a representative sample for incubation and analysis. Soil properties and soil charge characteristics are presented in Table 1.

Table 1. Soil and soil charge properties of a Pingin subsoil (20-40cm)

Si (%)	Si salt ext.[1] (µM)	P sorbed[2] (mg/kg)	Soil pH[3]	pH_0	CEC_b[4]	CEC_t[5]	AEC[6]	PZNC[7]
					(cmol$_c$/kg)			
6.48	78	985	4.27	4.67	0.22	0.24	0.62	4.79

[1] 0.01M $CaCl_2$ (1:1000 ratio of soil:solution); [2] P sorbed from added 1000 mg P/kg;[3] Soil pH in 0.002 M $CaCl_2$ (1:10 ratio of soil:solution); [4]CEC_b – Base cation exchange capacity; [5]CEC_t – Total cation exchange capacity; [6]AEC – Anion exchange capacity; [7]PZNC – Point of zero net charge

Soil incubation and analysis
A 100 g soil sample with 20% moisture content, *i.e.* 100 g soil + 20 mL water, was incubated in a pot placed

in the oven at 40^{0}C. Water was added daily to replace evaporative losses and to maintain moisture content at 20%. Eight treatments were involved in this study. Fused magnesium phosphate (FMP) was applied at the rates of 0, 75, 150 and 300 mg P/kg. The silicate materials, wollastonite (Ca-Si) and olivine (Mg-Si) were added at rates equal to the Si content in FMP at 300 mg P/kg *i.e.* 320 mg Si/kg. Similarly, two other silicate materials, acidulated wollastonite (Ac-Ca-Si) and acidulated olivine (Ac-Mg-Si), were added to be equivalent in applied Si to that of the 150 mg P/kg application of FMP, *i.e.* 160 mg Si/kg. Chemical components of amendments are presented in Table 2.

Table 2. Chemical components of amendments

Amendments	P (%)	Si (%)	[1]Si salt extractable (μM)	Neutralising value (%)
FMP	7.11	7.47	139	47.7
Ca-Si	-	25.65	167	48.1
Ac-Ca-Si	-	20.00	nd	0
Mg-Si	-	11.02	103	53.3
Ac-Ca-Si	-	7.23	525	0

[1] 0.01M $CaCl_2$ (1:1000 ratio of soil:solution)

After seven days of incubation, soils were analysed for pH, pH_0, basic cation exchange capacity (CEC_b), total cation exchange capacity (CEC_t), anion exchange capacity (AEC) and point of zero net charge (PZNC) by using the charge fingerprint procedure (Gillman, 2007); Colwell extractable P (Colwell, 1963) and phosphorus buffering index (PBI) (Burkitt *et al.* 2002) were also determined.

Results

After seven days of incubation at high temperature (40^{o}C), soil pH (in 0.002 M $CaCl_2$, 1:10) increased with increasing levels of applied FMP, about one unit pH increment after treatment with 300 mg P/kg (Figure 1). FMP applications also shifted pH_0 and PZNC to lower values than that of the incubated control; the more P applied, the lower the values of pH_0 and PZNC. In comparison with the non-incubated baseline soil (Table 1), soil pH and pH_0 were higher in all incubated treatments, while PZNC was lower (Figure 1).

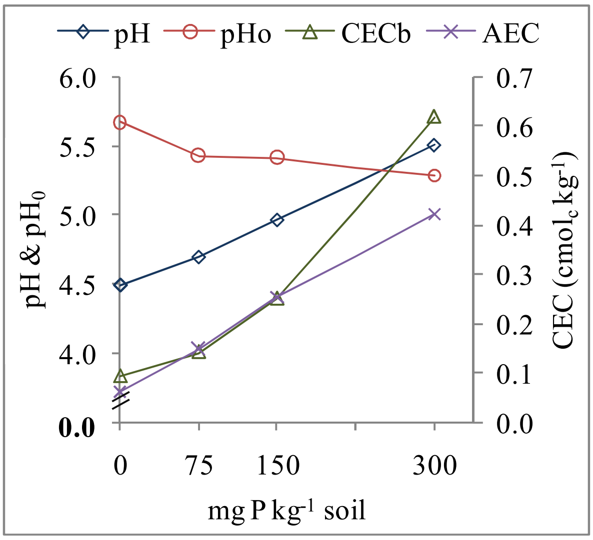

Figure 1. Change in soil pH and charge characteristics of a Pingin series subsoil as a function of P application as fused magnesium phosphate following incubation for 7 days at 40^{o}C near field capacity.

Phosphorus affected both CEC and AEC of the soil, the higher P application, the greater the increase in CEC and AEC (Figure 1). However, the increase in AEC was smaller than CEC following application of 300 mg P/kg. Phosphorus availability measured by Colwell (1963) extraction increased linearly from 34 to 100 mg/kg with increasing P application as FMP. A corresponding decrease in PBI from 840 to 700 was also observed.

Where Pingin soil was treated with unacidulated silicate amendments, soil pH increased and pH_0 decreased

(Table 3). In contrast, PZNC was higher in silicate treated soils compared to the incubated control, except the soil with Ac-Mg-Si. CEC and AEC also increased with silicate applications, but AEC decreased in the Ac-Ca-Si treatment. Similar to the effects with P application, silicate addition resulted in higher pH_0 and lower PZNC than those of the non-incubated baseline soil, but CEC and AEC of the soil treated with silicates was reduced in comparison to the non-incubated initial values. The exception was the Ac-Mg-Si treatment where both CEC_b and CEC_t were kept at the same values as the non-incubated baseline soil (Table 1 and 3).

Although Colwell P was not responsive to applied silicates, PBI decreased (Table 3). Hence soil P sorption capacity may be reduced by applying silicate.

Table 3. Effect of Si application on the charge characteristics, P availability and PBI of a Pingin series subsoil incubated for 7 days at 40°C near field capacity

Amendements	Si added (kg ha^{-1})	$pH_{(CaCl2)}$ (1:10)	pH_0	PZNC	CEC_b	CEC_t	AEC	Colwell P	PBI
					(cmol$_c$/kg)				
Control	0	4.49	5.63	4.28	0.09	0.11	0.06	33.5	838
Ca-Si	420	4.88	5.41	4.43	0.19	0.21	0.10	35.8	798
Ac-Ca-Si	210	4.54	5.41	4.35	0.11	0.14	0.01	33.1	812
Mg-Si	420	4.81	5.43	4.42	0.17	0.18	0.11	33.6	816
Ac-Mg-Si	210	4.61	5.32	4.14	0.21	0.23	0.11	31.5	784

Discussion

The application of FMP and raw silicate materials (Ca-Si and Mg-Si) increased soil pH accounting for the majority of change in soil CEC_b (Figure 1; Table 3). Increased soil pH following application of phosphate or silicate ions to ferric soils is most likely associated with release of hydroxide ions following specific adsorption reactions (Smyth and Sanchez, 1980). Hence the most effective way to increase charge in geric soils is to increase soil pH rather than adjust pH_0.

The exception to this trend occurred following application of acidulated Mg-Si where minimal change in pH was observed, yet CEC_b more than doubled (Table 3). The majority of the change in CEC_b for this amendment may be associated with lowering of the pH_0. The pH_0 of treated soils shifted to lower values compared to the incubated control; this can be attributed to the specifically adsorbed anions HPO_4^{2-} and SiO_4^{2-} that are released from FMP and silicate amendments (Qafoku *et al.* 2004; Uehara and Gillman 1981; Zhang and Zhao 1997). However, the pH_0 of all incubated soils, including the control, were higher than the pH_0 value of the non-incubated baseline soil. A number of factors may be involved with shift in pH_0 following incubation. First, the presence of Ca in the amended treatments may result in charge reversal due to Ca adsorption into the Stern layer (Uehara and Gillman 1981). Wann and Uehara (1978) observed similar results following Ca-Si amendments on Oxisols. Second, organic carbon coating Fe and Al oxides might have oxidised/mineralised during incubation at 40°C, thus exposing surfaces with a relatively higher pH_0. This explanation seems less likely because the test soil is a subsoil, but organic C analyses to compare incubated with non-incubated soils remain to be undertaken.

The interesting result of this study is that only the pH_0 value of FMP applied at 300 mg P/kg was lower than soil pH. This might be caused by the dual effects of P and Si anions that were released from FMP fertiliser. The relationship between soil pH and pH_0 determines the magnitude of net charge; therefore, on one hand the CEC in this treatment was greatly increased, and on the other hand PZNC was greatly decreased compared to the other treatments. In addition, FMP application brought about an increase in Colwell P and reduced PBI of the soil. This is a logical effect of the P content in FMP and also the competitive effect of Si content in FMP with P on the adsorptive sites.

Among silicate sources, although Ac-Mg-Si did not increase soil pH as much as Ca-Si and Mg-Si, it was the most responsive amendment in terms of reducing pH_0 and increasing CEC_b of the soil. Also, Ac-Mg-Si did not increase Colwell P, but it decreased PBI to the lowest value compared to the other silicate sources (Table 3). These effects can be explained by more available Si being released to the soil from this product than the others, as salt extractable Si of Ac-Mg-Si was much higher than that in the other silicate amendments (Table 2).

Conclusion

The Pingin series subsoil has similar charge characteristics to those of the geric Ferralsols of the uplands of Vietnam in terms of very low CEC and high pH_0. The application of FMP fertiliser not only overcomes a potential phosphorus deficiency, but through increasing pH may also increase soil charge and increase nutrient retention. Applying Ca-Si and Mg-Si materials can also rectify the problem of the geric property in highly weathered tropical soils by increasing the nutrient holding capacity of the soil and increasing P availability to the plant by the adsorptive competition of Si with P for sorption sites.

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