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Relationship between pH and base saturation associated with soil cation exchange capacity in soils of Mato Grosso do Sul, Brazil

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ABSTRACT: Soil pH and base saturation are important parameters for evaluating the effects of acidity on plant growth. However, the relationship between soil pH and base saturation (V%) has been poorly studied in Brazil. The aim of this study was to evaluate the influence on the cation exchange capacity (CEC) on this relationship for soils of Mato Grosso do Sul, Brazil, using a database consisting of 30,244 analyses of soils collected from 0–0.2- and 0.2–0.4-m depths. The CEC at pH 7 of analyzed soils varied from 3.4 to 40.5 $\text{cmol}_c \cdot \text{dm}^{-3}$ and were grouped into four classes (< 6, 6–10, 10–20, and > 20 $\text{cmol}_c \cdot \text{dm}^{-3}$) for each soil layer. The V% versus pH relationship was CEC dependent for both soil layers. For 0–0.2 m, V% was directly related to CEC (< 6, 6–10, 10–20, and > 20 $\text{cmol}_c \cdot \text{dm}^{-3}$) and reached 50, 55, 60, and 74% at pH 5 and 66, 73, 81, and 88% at pH 6, respectively. Predicting V% in relation to pH was also affected by CEC, with a decrease in the correlation of $p = 0.82$ for CEC < 6 $\text{cmol}_c \cdot \text{dm}^{-3}$ to $p = 0.64$ for CEC > 20 $\text{cmol}_c \cdot \text{dm}^{-3}$. The decrease in this correlation was related to low clay content (17%) of soils with CEC < 6 $\text{cmol}_c \cdot \text{dm}^{-3}$, which provided low buffering capacity. For soils with CEC > 20 $\text{cmol}_c \cdot \text{dm}^{-3}$ and higher clay content (45%), greater buffering capacity was observed associated with kaolinite. Findings suggest that CEC should be considered to understand the relationship between V% and pH $CaCl_2$.

Key words: acidic soils, liming, potential acidity.

INTRODUCTION

Most Brazilian soils exhibit tropical characteristics such as low pH and poor natural fertility. The first step to adapt soil conditions for agricultural cultivation is to partially neutralize soil acidity by liming (Ratke et al. 2018, Rheinheimer et al. 2018). As well as providing calcium (Ca^{2+}) and magnesium (Mg^{2+}), the practice of liming is very effective for neutralizing acidity originating from hydrogen (H^+) deprotonation of hydroxyls group from mineral and organic matter fractions and those hydrolyzed from exchangeable aluminum (Al^{3+}) (Bolan et al. 2023, Vargas et al. 2019). Among calculation methods for liming recommendation (LR), the most widely used method (Prado et al. 2020, Predebon et al. 2018) aims to increase soil base saturation (V%) (Quaggio et al. 1985) by elevating initial soil base saturation (V1) to levels required for producing a certain crop (V2). This method considers the cation exchange capacity at pH 7 ($\text{cmolc} \cdot \text{dm}^{-3}$) and the total neutralizing relative power of the soil corrective (Quaggio et al. 1985).

There is a high correlation between V% and soil pH (the higher the V%, the higher the soil pH) in this LR method (Catani and Gallo 1955, Raij et al. 1968, Castro et al. 1972, Raij 2011, Cornelissen et al. 2018). However, some studies show that the desired V% value is not attainable under some conditions (Araújo et al. 2009), even though high productivity is still achieved. For example, Palhano et al. (1984) obtained 70% base saturation for maximum soybean growth in soils of Paraná, Brazil, while Sousa et al. (1997) and Vieira et al. (2013) found a V of 50% necessary for the same crop in Cerrado and Guarapuava, Paraná, respectively. Depending on the region of Brazil, increasing soil V% can be more difficult, partly related to aspects of acidity correction, but mainly due to soil properties such as mineralogy, clay content (texture), amounts of organic matter (OM) (Motta and Mello 2009), and other attributes related to cationic soil exchange capacity (CEC).

In poorly weathered soils with predominance of 2:1 clay, most of the charges are permanent and, even at low pH, can retain bases and Al^{3+} (the main buffer of the system) (Motta and Melo 2009). In soils with predominance of 1:1 clay type and oxides, there is an abundance of variable charges of hydroxyl groups (R-OH) that undergo deprotonation and retain cations as pH increases (Motta and Melo 2009), but the presence of different R-OH groups and different pKa causes this dissociation to vary from soil to soil. In general, Fe and Al oxides exhibit predominant behavior as weak acid radicals decreasing to 1:1 and then 2:1 phyllosilicate (Costa et al. 2020, Silva et al. 2008, Sposito 2008). With deprotonation of R-OH radicals, retention of cations causes change in V% that depends on the mineral. Since CEC varies in this same sequence, a relationship between CEC × pH × V % can be expected.

The large quantity of pH-dependent charges in OM promotes a high degree of soil buffering, which needs attaining higher pH values to achieve a particular saturation compared to similar soils with less OM (Silva et al. 2008). Acid groups from soil colloids present in 1:1 phyllosilicates, oxides, and OM make up pH-dependent CEC and provide negatively charged sites capable of retaining bases [potassium (K^+), sodium (Na^+), Ca^{+2} and Mg^{+2}] (Aprile and Lorandi 2012). Since soils with the same CEC have similar mineralogy, OM content, pH range, and potential acidity, LR based on CEC ranges can make the correction more efficient and even reduce costs of these practices since responses to increased pH and the resulting V% will depend on these parameters (Aprile and Lorandi 2012, Zgorelec et al. 2019).

For the state of Mato Grosso do Sul, Brazil, our study objective was to investigate the influence of soil CEC on the relationship of V% × pH in soils by evaluating linearities; assessing the correlation of V% with Al^{3+}, H + Al, pH $CaCl_2$, OM, and clay; and obtaining regressions with the most significant variables for V% within various CEC ranges. We hypothesized that, if CEC and appropriate variables were known, the base saturation that would result from liming could be predicted using the V% method for a wide variety of Brazilian soils.

MATERIALS AND METHODS

The study was developed using a database of 30,244 soil samples collected at depths of 0–0.2 m (78% of total) and 20–40 cm (22% of total) in different regions of Midwest Brazil (state of Mato Grosso do Sul). According to Fig. 1, the municipalities of Rio Brilhante (63.2%) and Nova Alvorada do Sul (22.7%) had greater representation within the database.

Rio Brilhante and Nova Alvorada do Sul are located in the Southwest region of the state, with the first one being situated in the Grande Dourados region and belonging to the Rio Brilhante hydrographic basin, while the second one is located in the Campo Grande region. Both municipalities are in the Cerrado biome and do not present sites with protected areas. According to the Köppen classification, Rio Brilhante has influences of two tropical climates: savanna (Aw) and humid subtropical (Cfa). Winter is dry and cold with the occurrence of frosts, and the summer is hot, humid, and rainy with an mean annual rainfall of 1,600 mm (Alvares et al. 2013). Nova Alvorada do Sul is influenced only by the savanna climate (Aw), and the only difference was no frost or low temperatures in winter (Alvares et al. 2013).

While soils in the region of Rio Brilhante are predominantly Latosols with a clay texture and variable natural fertility, margins of watercourses had Glei Humic and Little Humic Glei soils, which were usually of high fertility. The relief was characterized by tabular and flat forms, with gentle slopes, and associated with accumulation areas next to main drainages (Sebrae 2015b). In Nova Alvorada do Sul, soils were mostly Alic Dark Red Latosol and Dystrophic Purple Latosol with small areas of Alic Planosol, Alic Quartz Sands, and Eutrophic Little Humic Glei. The relief was mottled in dissected forms of tabular tops in the western part and presented flat areas that resulted from fluvial accumulation, which were subjected to periodic flooding (Sebrae 2015a).

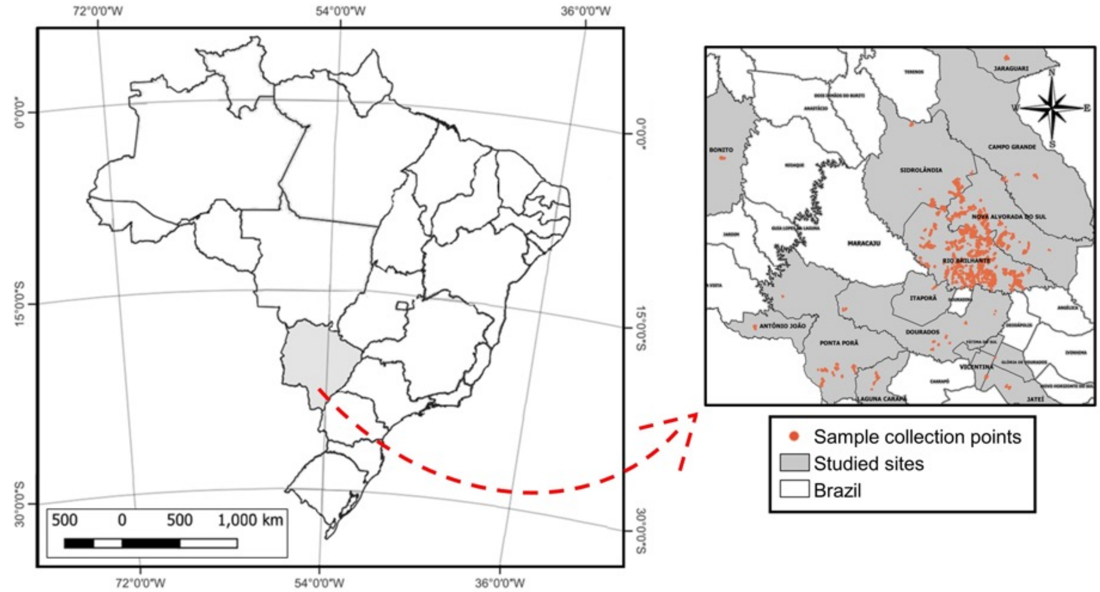

Figure 1. Location of Mato Grosso do Sul in midwest Brazil and sites in the state where the 30,244 samples were collected (in orange) that constituted the study database (23,551 in the 0–0.2-m layer and 6,693 in the 0.2–0.4-m layer).

Soil samples were dried, homogenized, and passed through a 2-mm sieve to obtain fine air-dried earth before chemical characterization according to the Manual of Soil Analysis Methods (Embrapa 2017). Soil chemical analyses consisted of evaluating pH in $CaCl_2$ (0.01 $mol{\cdot}L^{-1}$), soil/$CaCl_2$ ratio (1:2.5); pH SMP; Al^{3+}, Ca^{2+}, and Mg^{2+} extracted by KCl (1 $mol{\cdot}L^{-1}$); K^+ and phosphorus (P) (extracted by Mehlich 1943); and organic carbon analyzed by the Walkley Black method. The determination of Ca^{2+} and Mg^{2+} were by atomic absorption spectrometry, Al^{3+} by titrimetric analysis, K^+ by flame photometry, and P by colorimetry.

The physical analysis of soil texture consisted of determining sand, silt, and clay fractions by the pipette method (Embrapa 2017). This analysis was performed on 50% of samples in the database with the highest percentage being in the 0–0.2-m soil layer.

Data from the 0–0.2-m layer were subdivided according to CEC ($cmol_c{\cdot}dm^{-3}$): 0 to 6 (1,106 samples); 6 to 10 (8,341 samples); 10 to 20 (13,411 samples); and greater than 20 (693 samples). Subdivisions of 0.2–0.4-m layer samples according to CEC ($cmol_c{\cdot}dm^{-3}$) were: 0 to 6 (1,049 samples); 6 to 10 (3,593 samples); 10 to 20 (1,982 samples); and greater than 20 (69 samples). Descriptive data parameters (mean, standard deviation, median, maximum, and minimum) were calculated, in addition to analyzing the relationships between pH $CaCl_2$ and V% by linear regression and Spearman's correlation analysis between chemical attributes ($p < 0.05$).

The equations obtained between V% and pH for each CEC class (< 6, 12, 18 and 24 $cmol_c{\cdot}dm^{-3}$) and layers (0–0.2 and 0.2–0.4-m depths) were used to determine values of V% and CEC at fixed values of soil pH (5, 5.5, and 6). Statistical analyses were performed using R software, and the graphs were plotted using Excel and OriginLab software.

RESULTS AND DISCUSSION

Descriptive statistics of soils in the 0–0.2 m shown in Table 1 indicate that, regardless of CEC class, pH $CaCl_2$ mean values were greater than 5, resulting in Al being hydrolyzed, which reduced mean values close to 0. In a soil survey of a Cerrado area under native conditions, Lopes and Cox (1977) found a mean equivalent pH of 4.4 in $CaCl_2$ 0.01 M (pH 5 in water) and 0.56 $cmol_c{\cdot}dm^{-3}$ for Al. This difference was expected since liming is almost a mandatory practice in converting native regions for agricultural use (Prado et al. 2020).

Table 1. Descriptive statistics of soil samples collected in the state of Mato Grosso do Sul, Brazil, at a depth of 0–0.2 m subdivided according to their CEC pH 7.

CEC		pH $CaCl_2$	V	Clay	Al^{3+}	H + Al	OM
$cmol_c \cdot dm^{-3}$			-------% -------		------ $cmol_c \cdot dm^{-3}$ -------		$g \cdot dm^{-3}$
< 6	Mean	5.04	50	17.4	0.11	2.65	18.32
	SD	0.51	11	4.1	0.15	0.61	4.15
	Median	5.01	51	16.0	0.00	2.58	18.05
	Minimum	3.95	18	16.0	0.00	1.32	8.42
	Maximum	6.51	75	30.0	0.57	4.44	28.51
6 to 10	Mean	5.10	56	37.6	0.08	3.61	21.32
	SD	0.46	12	18.3	0.14	1.01	4.91
	Median	5.10	57	35.0	0.00	3.55	20.80
	Minimum	3.87	24	6.0	0.00	1.21	7.73
	Maximum	6.35	87	81.0	0.55	6.43	35.25
10 to 20	Mean	5.16	64	54.9	0.07	4.59	24.01
	SD	0.39	11	12.3	0.12	1.28	4.81
	Median	5.14	64	58.0	0.00	4.48	23.69
	Minimum	4.20	33	21.0	0.00	1.25	10.07
	Maximum	6.29	90	80.0	0.45	8.21	38.14
> 20	Mean	5.43	82	45.1	0.00	4.10	25.44
	SD(4)	0.32	5	15.2	0.00	1.02	4.90
	Median	5.43	83	45.0	0.00	3.95	25.76
	Minimum	4.47	64	16.0	0.00	1.52	12.13
	Maximum	6.42	94	72.0	0.00	7.23	38.69

CEC: Cation exchange capacity at pH 7; V: base saturation; OM: organic matter; SD: standard deviation.

Although lime is normally incorporated to ~20 cm or soil surface applied, pH and Al for the 0.2–0.4-m depth (Table 2) was similar to 0-0.2-m observations (Table 1) (Prado et al. 2020). However, soil acidity under native conditions is generally similar throughout the profile of highly weathered soils (Motta and Melo 2009). This confirms Melinski's (2020) observations suggesting that the influence of liming can expand to deeper soil layers over time. Soils in the 0.2–0.4-m layer also presented pH values greater than 5, except for soils with CEC < 6 $cmol_c \cdot dm^{-3}$.

Despite similar soil pH among CEC classes, H + Al rose with increasing class. This could be related to increases in clay content and/or OM (Table 1), which drives soil buffering capacity (Motta and Melo 2009).

Soils with CEC smaller than 6 $cmol_c \cdot dm^{-3}$ were sandy soils with low clay concentrations and low OM contents. Sandy soils are more susceptible to nutritional imbalance and maintain low base reservoirs and buffering capacity due to low CEC (Resende et al. 2016). This imbalance was observed by Volf et al. (2022), who found K application reduced foliar Ca, Mg, Fe, and B in soybean. The CEC of sandy soils under tropical conditions are more pH-dependent (Aprile and Lorandi 2012, Obalum et al. 2013).

CEC class had a large impact on the relationship between pH and V% at the 0–0.2 (Fig. 2) and 0.2–0.4-m depths (Fig. 3). For evaluated depths, all adjustments were obtained with quadratic equations. Greater adjustments to quadratic models (higher R^2) describing V% and pH relationships were observed among CEC classes in the 0–0.2 m soil layer (Fig. 2) relative to the 0.2–0.4-m layer (Fig. 3); these observations corroborate Beery and Wilding's finding (1971) for soils in Ohio, United States of America. Quadratic models of pH $CaCl_2$ and V% showed nonlinear characteristics for the 0–0.2-m soil layer and exhibited a concave curve shape; this was mainly observed for soils having CEC greater than 10 $cmol_c \cdot dm^{-3}$ (Figs. 2 and 3).

Table 2. Descriptive statistics of soil samples collected in the state of Mato Grosso do Sul, Brazil, at a depth of 0.2-0.4 m subdivided according to their CEC pH 7.0.

CEC		pH $CaCl_2$	V	Al^{3+}	H + Al	OM
$cmol_c \cdot dm^{-3}$			%	------ $cmol_c \cdot dm^{-3}$ -------		$g \cdot dm^{-3}$
< 6	Mean	4.61	38	0.41	3.13	10.19
	SD	0.41	10	0.31	0.66	2.87
	Median	4.59	38	0.31	3.09	9.79
	Minimum	3.61	11	0.00	1.57	2.64
	Maximum	5.77	67	1.42	4.99	18.05
6 to 10	Mean	5.23	54	0.02	3.57	12.11
	SD	0.18	7	0.07	0.63	3.54
	Median	5.18	54	0.00	3.59	11.86
	Minimum	5.01	37	0.00	1.88	4.29
	Maximum	5.75	72	1.50	5.37	23.14
10 to 20	Mean	5.26	67	0.01	4.17	11.96
	SD	0.21	9	0.05	0.89	3.15
	Median	5.20	67	0.00	4.16	11.86
	Minimum	5.01	44	0.00	2.00	4.29
	Maximum	5.84	90	0.51	6.50	19.42
> 20	Mean	5.02	73	0.16	6.83	11.57
	SD	0.67	20	0.36	5.25	3.27
	Median	5.26	82	0.00	4.21	11.17
	Minimum	3.75	20	0.00	2.04	5.66
	Maximum	6.29	93	1.61	24.53	19.42

CEC: Cation exchange capacity at pH 7; V: base saturation; OM: organic matter; SD: standard deviation.

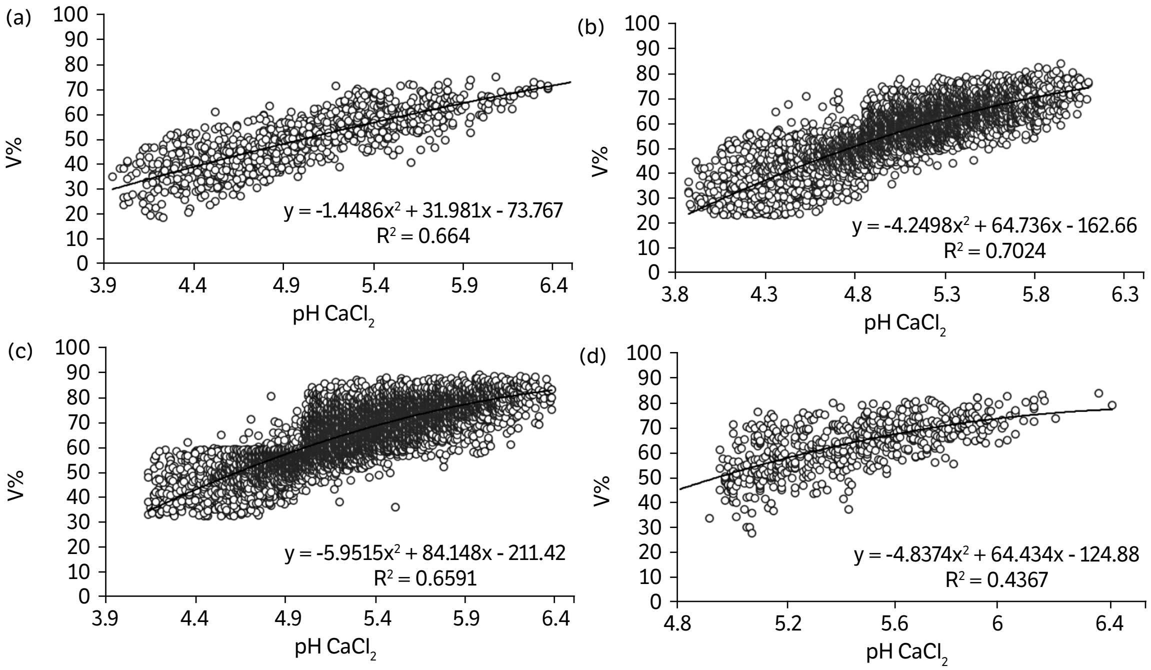

Figure 2. Relationship between soil base saturation (V%) and pH $CaCl_2$ as a function of soil cation exchange capacity at pH 7: (a) between 0 and 6, (b) 6 and 10, (c) 10 and 20, and (d) > 20 $cmol_c \cdot dm^{-3}$. Samples from the 0–0.2-m soil layer collected in the state of Mato Grosso do Sul, Brazil.

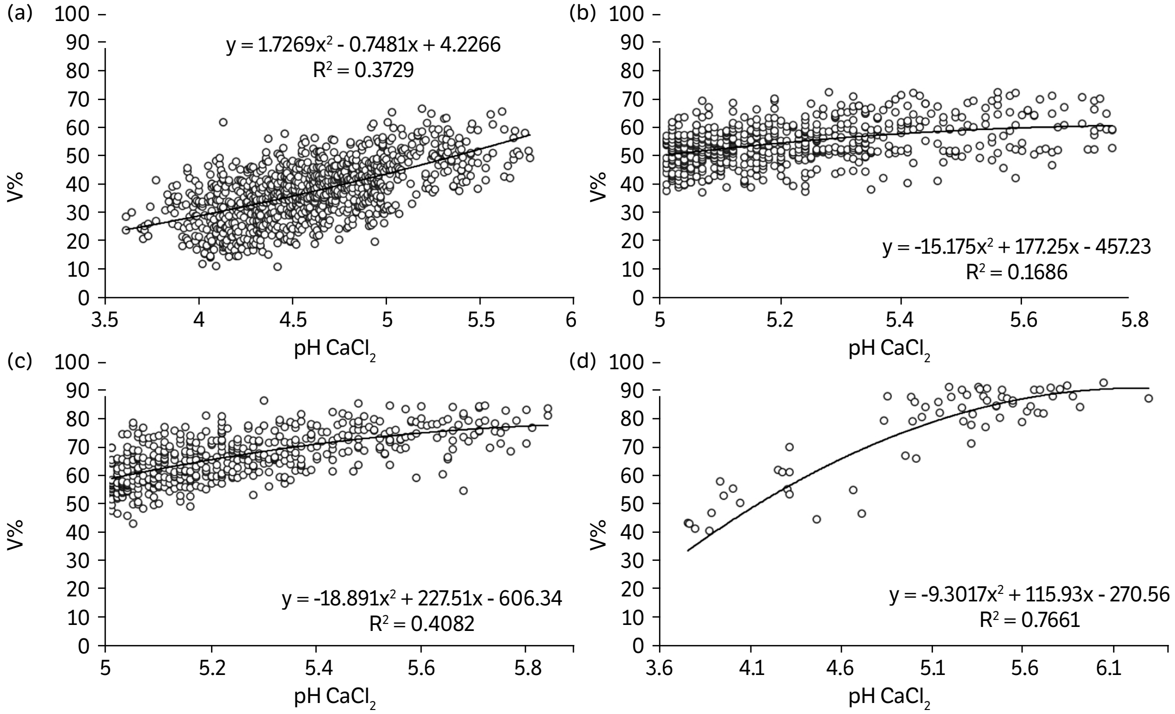

Figure 3. Relationship between soil base saturation (V%) and pH $CaCl_2$ as a function of soil cation exchange capacity (CEC) at pH 7: (a) between 0 and 6, (b) 6 and 10, (c) 10 and 20, and (d) > 20 $cmol_c{\cdot}dm^{-3}$. Samples from the 0.2–0.4-m soil layer collected in the state of Mato Grosso do Sul, Brazil.

Results confirm variation among different clay type with differing CEC (Mehlich 1943). Silva et al. (2008) found relationships between pH and V% to be nonlinear among different soil types and attributed the concave shape of curves to kaolinite soils. Similar behavior between pH and V% was observed in soils with CEC greater than 10 $cmol_c{\cdot}dm^{-3}$ in this study (regardless of depth from which soil was collected), particularly when soil pH was greater than 5.

The relationship between V% and CEC under three fixed pH values (5, 5.5, and 6) is shown in Fig. 4. For the 0–0.2-m layer at pH 5, V% attained would be ~50, 55, 60, and 74% for the four CEC ranges, respectively (Fig. 4a). At pH 5.5, V% would be 58, 64, 71, and 82%, respectively (Fig. 4a), and respective values at pH 6 were 66, 73, 81 and 88% (Fig. 4a); this indicates that increases in V% at the same pH is dependent on soil CEC. For the 0.2–0.4-m layer, V% values were very close to values found for the 0–0.2-m soil layer using quadratic models (Fig. 4b). Increasing values of V% obtained at pH 5, 5.5, and 6 from quadratic models of pH $CaCl_2$ and V% indicate that increases in base saturation (according to pH) is delimited by soil CEC (regardless of depth). In other words, the higher the soil CEC, the lower the pH required to achieve a target V% (Figs. 4a and 4b). Soil CEC regulates the retention of basic cations and is therefore an indicator of the magnitude of parameter V% (Ramos et al. 2018).

V% values for the 0–0.2-m soil layer showed a high negative correlation with the sum of H and Al (H + Al) and a high positive correlation with pH $CaCl_2$ ($p < 0.01$) (Table 3). On the other hand, soils from the 0.2–0.4-m layer showed a lower negative correlation with H + Al values, as well as a lower correlation with pH $CaCl_2$ compared to the 0–0.2-m layer, except when the CEC > 20 $cmol_c{\cdot}dm^{-3}$. Other chemical parameters did not significantly correlate with V% at any depth ($p > 0.05$). The high negative correlations of V% with H + Al indicate the relationship of potential acidity in the maintenance of V% in acidic soils. A large part of CEC exchange sites in tropical soils is occupied by Al^{3+} or H+, and these soils have mineralogy composed of kaolinite, gibbsites and hematite, and an absence of 2:1 minerals (Pincus et al. 2017). With increased pH, H and Al are dissociated from the exchange complex at the same time that available negative charges are capable of retaining basic cations (Ca^{2+}, Mg^{2+}, K+), which increases V% (Motta and Melo 2009).

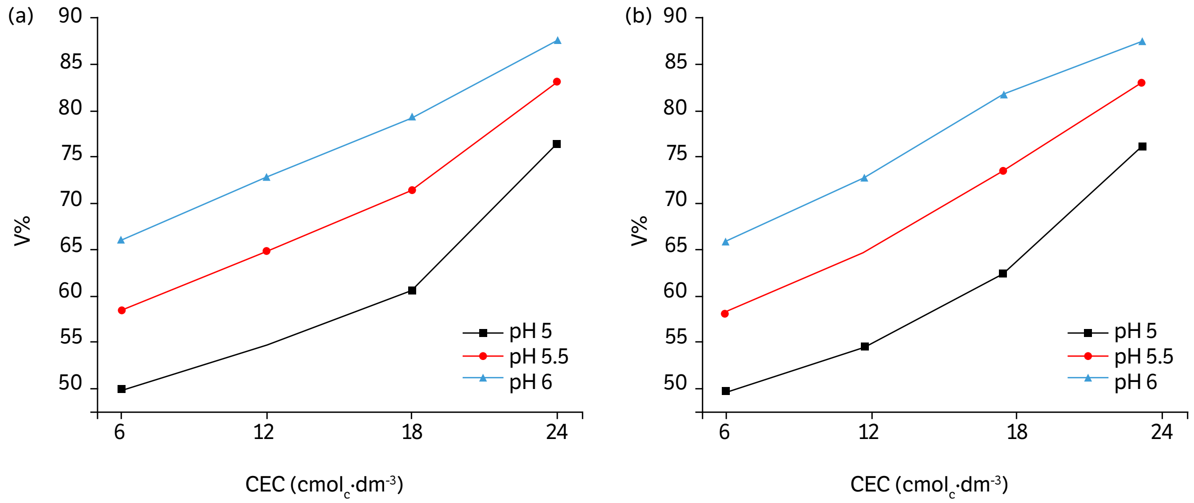

Figure 4. Base saturation (V%) obtained in soils at pH 5, 5.5, and 6 in the (a) 0–0.2- and (b) 0.2–0.4-m layers based on soil cation exchange capacity (CEC) at pH 7 of 6, 12, 18, and 24 cmol$_c$·dm^{-3} for samples collected in the state of Mato Grosso do Sul, Brazil.

Table 3. Spearman's correlation coefficients (ρ) between V% and H + Al and V% and pH CaCl$_2$ as a function of CEC values at pH 7 of soil samples collected in the state of Mato Grosso do Sul, Brazil, at the depths of 0–0.2 and 0.2–0.4 m*.

Depths (cm)		------- 0–20 -------		------- 20–40 -------	
CEC cmol$_c$·dm^{-3}		H + Al	pH CaCl$_2$	H + Al	pH CaCl$_2$
< 6	V%	-0.91	0.82	-0.69	0.56
6 to 10		-0.86	0.84	-0.59	0.39
10 to 20		-0.85	0.81	-0.78	0.63
> 20		-0.89	0.64	-0.92	0.77

*$p < 0.01$ for all values of ρ; V%: base saturation; CEC: Cation exchange capacity at pH 7.

The high correlations of V% with pH (Table 3) are due to the generation of charges from pH-dependent minerals such as found in kaolin soils. At pH above 5, the displacement of H from hydroxyls increases the negative sites in soil clay fractions with pH-dependent loads, mainly due to functional groups with strong acidic characteristics such as silanol (Si-OH) of kaolinite (Almeida et al. 1999, Obalum et al. 2013). The increase in negative sites allows for greater base retention, which increases CEC and V% (Khawmee et al. 2013, Nakao et al. 2017). On the other hand, soils collected from the 0–0.2-m layer with CEC greater than 20 cmol$_c$·dm^{-3} had the lowest correlations between V% and pH CaCl$_2$ (Table 3). This was possibly due to the homogeneity of pH among samples since pH was above 5 for 89% of these soils. As seen in the 0–0.2-m layer, correlations between V% and H + Al, and V% and pH in the 0.2–0.4-m layer were the most important variables in explaining variation in base saturation. However, the curve of the relationship between pH CaCl$_2$ and V% was slightly convex for soils with CEC up to 6 cmol$_c$·dm^{-3}. Similar observations were reported by Silva et al. (2008) for soils rich in iron and aluminum oxides (oxidic), in which concave curves noticed for soils with CEC greater than 6 cmol$_c$·dm^{-3} were attributed to kaolinite soils.

The hydroxylated groups of oxidic soils are the weak acids ferrol (Fe-OH) and aluminol (Al-OH) that do not easily release H$^+$ (Kostenko 2015). The high pH of the point of zero charge (PZC) (pH$_{PZC}$ > 7) of Fe-OH and Al-OH groups (pH above which H$^+$ ion dissociation occurs) makes adding more negative charges sites difficult and limits the CEC of oxidic soils (Arai and Sparks 2007, Cornell and Schwertmann 2003, Gérard 2016). However, kaolinitic soils rich in Si-OH groups (pH$_{PZC}$ < 2.5) readily dissociate H$^+$, which provides greater cation retention and therefore higher V% (Fontes et al. 2001).

CONCLUSION

Considering V% a widely used liming recomendation method in Brazil, soil CEC proved to be of great importance in assessing the relationship between V% and pH. The relationship between V% and pH was also affected by CEC, in which the higher the soil CEC, the lower the pH required to achieve a target V%. The V% and pH $CaCl_2$ relationship was nonlinear, and the curve was slightly concave for soils with CEC values greater than 6 $cmol_c \cdot dm^{-3}$, which is characteristic of kaolinitic soils. For soils with CEC up to 6 $cmol_c \cdot dm^{-3}$, the curve of the pH $CaCl_2$ × V% relationship was slightly convex, which is characteristic of oxidic soils in which V% is limited under increasing pH due to low amounts of negative pH-dependent charges. Thus, soil CEC, texture, and buffering capacity should be evaluated in isolation to better understand the relationship between V% and pH $CaCl_2$. With better understanding of this dynamic, liming method can be more efficient by not compromising availability of other nutrients or losing bases by leaching.

CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTION

Conceptualization: Albuquerque, C. G., Gavelaki, F., Matera, H. B., Motta, A. C. V. and Araújo, E. M.; **Data Curation:** Albuquerque, C. G., Gavelaki, F., Matera, H. B., Motta, A. C. V. and Araújo, E. M.; **Formal Analysis:** Albuquerque, C. G., Gavelaki, F., Matera, H. B., Motta, A. C. V. and Araújo, E. M.; **Funding:** Motta, A. C. V.; **Investigation:** Albuquerque, C. G., Gavelaki, F., Matera, H. B., Motta, A. C. V. and Araújo, E. M.; **Methodology:** Albuquerque, C. G., Gavelaki, F., Matera, H. B., Motta, A. C. V., Araújo, E. M. and Prior, S. A.; **Project Administration:** Motta, A. C. V.; **Resources:** Motta, A. C. V.; **Supervision:** Motta, A. C. V.; **Validation:** Albuquerque, C. G., Gavelaki, F., Matera, H. B., Motta, A. C. V. and Araújo, E. M.; **Visualization:** Albuquerque, C. G., Gavelaki, F., Araújo, E. M.; Ercole, T. M. and Prior, S. A.; **Writing – Original Draft:** Albuquerque, C. G., Gavelaki, F., Matera, H. B., Motta, A. C. V., Ercole, T. M. and Prior, S. A.; **Writing – Review & Editing:** Albuquerque, C. G., Gavelaki, F., Motta, A. C. V., Ercole, T. M. and Prior, S. A.

DATA AVAILABILITY STATEMENT

All datasets were generated and analysed in the current study. Data will be available upon request.

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