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Efficiency of the base saturation method in determining lime requirements for Dystrophic Yellow Latosol Soil in Eastern Amazon

Eficiência do método de saturação por bases para recomendação de calagem em um Latossolo Amarelo na Amazônia Oriental

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ABSTRACT

High soil acidity, low cation-exchange capacity, and low fertility are the major bottlenecks in the Amazon region's agricultural activities, making liming an essential technique for crop production. This study aimed to assess the efficiency of two liming methods, namely broadcasting and incorporation, in meeting base saturation (BS) requirements at different soil depths and time intervals in a Latossolo Amarelo in the eastern Amazon. The experiment was carried out using a randomized block design arranged in a 5 × 2 factorial, with five lime doses recommended for raising the BS to 0, 40, 80, 160, and 320% and two application methods (broadcasting and incorporation). After lime application, soil samples were collected at three depths (0.00-0.05, 0.05-0.10, and 0.10-0.20 m) and three periods (30, 60, and 90 days after application, DAA) for BS determination. The highest BS values were observed at 30 DAA with incorporation. The expected BS value was obtained by incorporating the 40% dose but was limited to the 0.00-0.05 and 0.05-0.10 m layers. Lime incorporation is the most efficient method for achieving the recommended BS levels at 30 DAA. At 90 DAA, most doses did not provide BS values equal to or greater than the calculated values. Therefore, regression analyses are recommended in field experiments respecting the threshold of 80% BS.

KEYWORDS: acidity; lime; lime requirement; fertility; Amazonian soils; Latossolo Amarelo; Oxisol.

RESUMO

Alta acidez do solo, baixa capacidade de troca catiônica e baixa fertilidade são os principais gargalos das atividades agrícolas na região amazônica, o que torna a calagem uma técnica essencial para a produção agrícola. Este estudo teve como objetivo avaliar a eficiência de dois métodos de calagem, a saber, a lanço e incorporado ao solo, para atender às exigências da saturação por bases (V%) em diferentes profundidades e intervalos de tempo em um Latossolo Amarelo na Amazônia oriental. O experimento foi realizado em delineamento de blocos casualizados em esquema fatorial 5 × 2, com cinco doses de calcário recomendadas para elevar o V a 0, 40, 80, 160 e 320% e dois métodos de aplicação (a lanço e incorporado). Após a aplicação do calcário, amostras de solo foram coletadas em três profundidades (0,00-0,05, 0,05-0,10 e 0,10-0,20 m) em três períodos (30, 60 e 90 dias após a aplicação, DAA) para determinação do V%. Os maiores valores de V% foram observados aos 30 DAA com incorporação. O valor de V% esperado foi obtido pela incorporação da dose de 40%, mas foi limitado às camadas de 0,00-0,05 e 0,05-0,10 m. A incorporação de cálcario é o método mais eficiente para atingir os níveis recomendados de V% aos 30 DAA. Aos 90 DAA, a maioria das doses não forneceu valores de V% iguais ou superiores aos valores calculados. Portanto, análises de regressão são recomendadas em experimentos de campo respeitando o limite de 80% V.

PALAVRAS-CHAVE: acidez; calcário; necessidade de calcário; fertilidade; solos Amazônicos.

INTRODUCTION

Most soils are highly weathered in the Amazon region and frequently have high acidity, low cation-exchange capacity, and low fertility. These soil properties constitute the region's main obstacles to agricultural production (SOMBROEK et al. 1993, GLASER & BIRK 2012, CRAVO et al. 2012, SOUSA et al. 2020). Therefore, liming is essential for various agricultural systems, as it creates a favorable environment for root development, thereby ensuring the availability of nutrients such as Ca^{2+} and Mg^{2+}. Furthermore, liming increases soil pH, resulting in Al^{3+} neutralization (CARMO & SILVA 2016, MARASCHIN et al. 2020), and positively influences soil microbial biomass, further enhancing nutrient availability soil structure (VASQUES et al. 2020).

In Brazil, several methods are used to determine the need for liming, including the Shoemaker-McLean-Pratt buffer test, carbonate or lime incubation, and base saturation (BS) assessment. The methods take into account factors such as Al^{3+} neutralization and increases in Ca^{2+} and Mg^{2+}. The BS method is interesting as it considers not only soil properties but also the nutritional requirements of crops. Nevertheless, it is common that the expected values are not reached after liming (NETO et al. 2000). For example, CAIRES & FONSECA (2000) applied lime by broadcasting and found that adequate BS levels were only reached at the 0.00-0.05 m depth. ROSA JUNIOR et al. (2006) aimed to increase BS to 60% and 100% in a distroferric Red Latosol, but the expected values were not reached by the end of a 45-day experimental period.

The efficiency of a lime treatment depends on the dose, particle size, application method, soil class, climatic conditions, cropping system, and reactivity time (QUARTEZANI et al. 2015). Therefore, it is essential to use the recommended values for Amazonian soils to obtain the adequate correction of soil acidity, thus increasing fertilizer efficiency. Generally, the recommended values for the region are 50 to 70% BS (BRASIL & CRAVO 2020). Therefore, this study aimed to evaluate the efficiency of the BS method in determining the limestone requirements applied by haul and incorporated into the substrate for different periods of time in Dystrophic Yellow Latosol in the Eastern Amazon.

MATERIAL AND METHODS

The experiment was conducted from December 27, 2019, to March 26, 2020, in a nursery under 50% shade located at the Federal University of Western Pará (UFOPA). The soil used as substrate was collected at the UFOPA Experimental Farm (2°41′02.7″S 54°31′55.0″W) in Santarém, Pará State, eastern Amazon, Brazil. The soil was classified as an “Latossolo Amarelo Distrófico argissólico” (Oxisol), according to ALMADA et al. (2021). The region has a humid tropical climate (Am type in the Köppen classification system), with average temperature and rainfall of 25.9 °C and 2150 mm, respectively (FISCH et al. 1998). Figure 1 shows the monthly rainfall and relative moisture throughout the experimental period. Soil samples were collected from the surface layer (0.00-0.20 m).

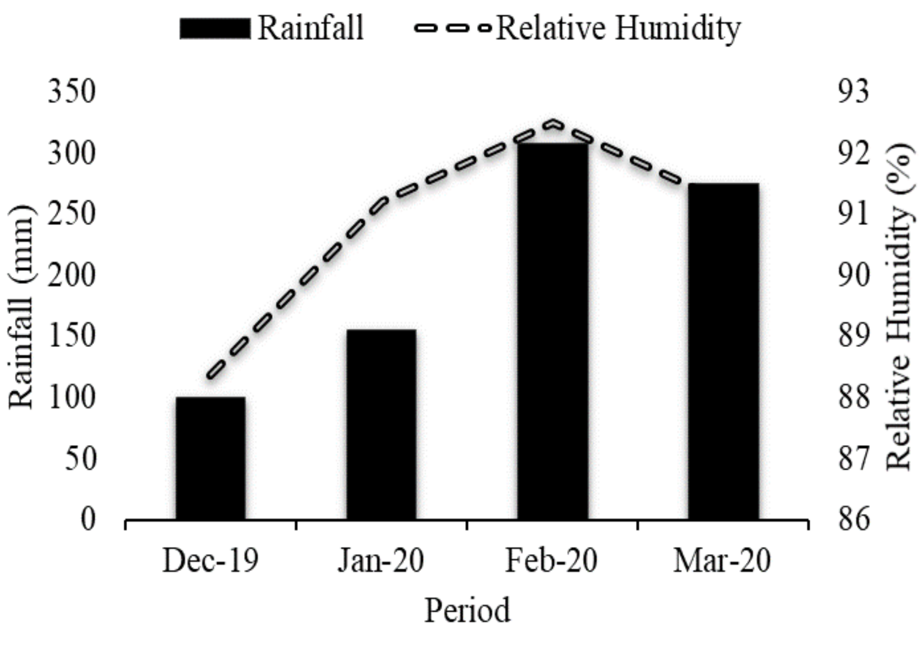

Figure 1. Mean monthly rainfall and relative humidity in Santarém city, Pará State, Brazil, during the experimental period. Source: INMET (2020).

After collection, the soil was air-dried and sieved through two mm mesh sieves to obtain air-dried fine earth, which was sent to the Soil Quality Laboratory at UFOPA for evaluation of chemical properties and texture according to the methods described by TEIXEIRA et al. (2017) (Table 1). For incubation, soil samples were air-dried, sieved through four mm mesh sieves, and stored in five L polyethylene pots filled to maximum capacity (5.4 kg of soil).

Table 1. Soil texture and chemical properties before liming in a greenhouse experiment conducted at the Federal University of Western Pará, Santarém city, Pará State, Brazil.

pH_{H2O}	pH KCl	Ca^{2+}	Mg^{2+}	Al^{3+}	K^+	Na^+	SB	$H^+ + Al^{3+}$	CEC	BS	P
				---------------------- $cmol_c\ dm^{-3}$ ----------------------						%	$mg\ dm^{-3}$
5.47	3.83	0.50	0.30	0.40	0.04	0.04	0.88	6.27	7.15	12	2.92

Sand	Silt	Clay
	------------------------------- $g\ kg^{-1}$ -------------------------------	
634.0	86.5	279.5

SB - sum of bases; CEC - cation-exchange capacity; BS - base saturation. P was extracted with Mehlich-1. Soil texture was determined by the pipette method.

The experiment was conducted using a randomized block design with a 2 × 5 factorial arrangement, consisting of two methods of lime application (broadcasting and incorporation in the soil), five lime doses (0, 2.22, 5.40, 11.76, and 24.47 Mg ha^{-1}, calculated to increase BS by 0, 40, 80, 160, and 320%, respectively), and five replications per treatment, totaling 50 plots. The lime used was dolomitic (32% CaO, 15% MgO, and 90% total neutralizing value (TNV)). Lime doses were determined on the basis of soil analysis by the BS method, as described by the following equation: $LR = CEC \times (BS_2 - BS_1) \div 100 \times f$, where LR is the lime dose required to achieve the desired BS (expressed in Mg ha^{-1} and corrected to TNV), CEC is the cation-exchange capacity of the soil, BS_1 is the current BS, BS_2 is the desired BS, and f is the lime correction factor (TNV).

Evaluations were performed at 30, 60, and 90 days after application (DAA). Using a mini-Auger, two simple samples were collected from each plot at three depths (0-0.05, 0.05-0.10, and 0.10-0.20 m) and combined to form a composite sample. Samples were sent to the Soil Quality Laboratory of UFOPA, air dried, and passed through a 2 mm mesh sieve to obtain air-dried fine earth for further analysis.

pH analysis was performed in H_2O (1:2.5 w/v). Ca^{2+}, Mg^{2+}, and Al^{3+} contents were extracted using a 1 mol L^{-1} KCl solution and quantified by titration with 0.0125 mol L^{-1} EDTA and 0.025 mol L^{-1} NaOH. Available Na^+ and K^+ contents were determined using Mehlich-1 solution and flame photometry. The extraction of H+ + Al3+ content was determined by a 0.5 mol L^{-1} calcium acetate solution and titration with 0.0125 mol L^{-1} NaOH. Subsequently, sum of bases, cation-exchange capacity, and BS were calculated. All analyses and calculations were performed following the guidelines described by TEIXEIRA et al. (2017).

Electrical conductivity was determined in deionized water (1:2.5 w/v). Briefly, 10 g of soil was added with 25 mL of water. The mixture was stirred and left to rest for one hour. Then, samples were homogenized and measured using a portable conductivity meter (CARMO & SILVA 2016).

Data were tested for normal distribution and homogeneity of variance and subjected to Pearson correlation analysis. Then, an analysis of variance was performed, and when differences were significant by the *F*-test, data were subjected to regression analysis at the 5% significance level. All statistical analyses were performed using Minitab beta version 18.

RESULTS

Lime broadcasting afforded the highest values of soil pH, electrical conductivity, Ca, Mg, and $H^+ + Al^{3+}$ at the 0.00-0.05 m depth (Figure 2). In 0.05-0.10 and 0.10-0.20 m layers, Al^{3+} and $H^+ + Al^{3+}$ increased gradually, even at higher lime doses and acidic pH values.

Lime incorporation resulted in a more homogeneous reactivity of attributes at all depths evaluated, with Al^{3+} contents equal to zero (Figure 3). Application of lime at the highest doses to achieve BS values of 160 and 320% resulted in soil pH values greater than seven at 30 and 60 DAA, an effect that may reduce the availability of certain elements. A reduction in $H^+ + Al^{3+}$ content (potential acidity) occurred at 30 DAA at all depths; potential acidity increased at 60 DAA and then decreased at 90 DAA.

Lime incorporation increased soil electrical conductivity in the 0.00-0.05 and 0.05-0.10 m layers at 90 DAA. With lime broadcasting, electrical conductivity was highest at 60 DAA in the 0.00-0.05 m layer, and low values were observed at 30 DAA.

As depicted in the correlation matrix (Figure 4), in 0.00-0.05 m depth soil treated with broadcast lime, there were positive correlations between pH, Ca^{2+}, Mg^{2+}, and electrical conductivity. Ca^{2+} and pH negatively influenced Al^{3+} and $H^+ + Al^{3+}$, as expected given the effects of lime application. However, in the other layers, the influence of these attributes on $H^+ + Al^{3+}$ and Al^{3+} decreased, with only pH exerting a significant negative effect on $H^+ + Al^{3+}$.

Correlation analysis showed a significant negative influence on $H^+ + Al^{3+}$ at 0.05-0.10 and 0.10-0.20 m depths for lime incorporation.

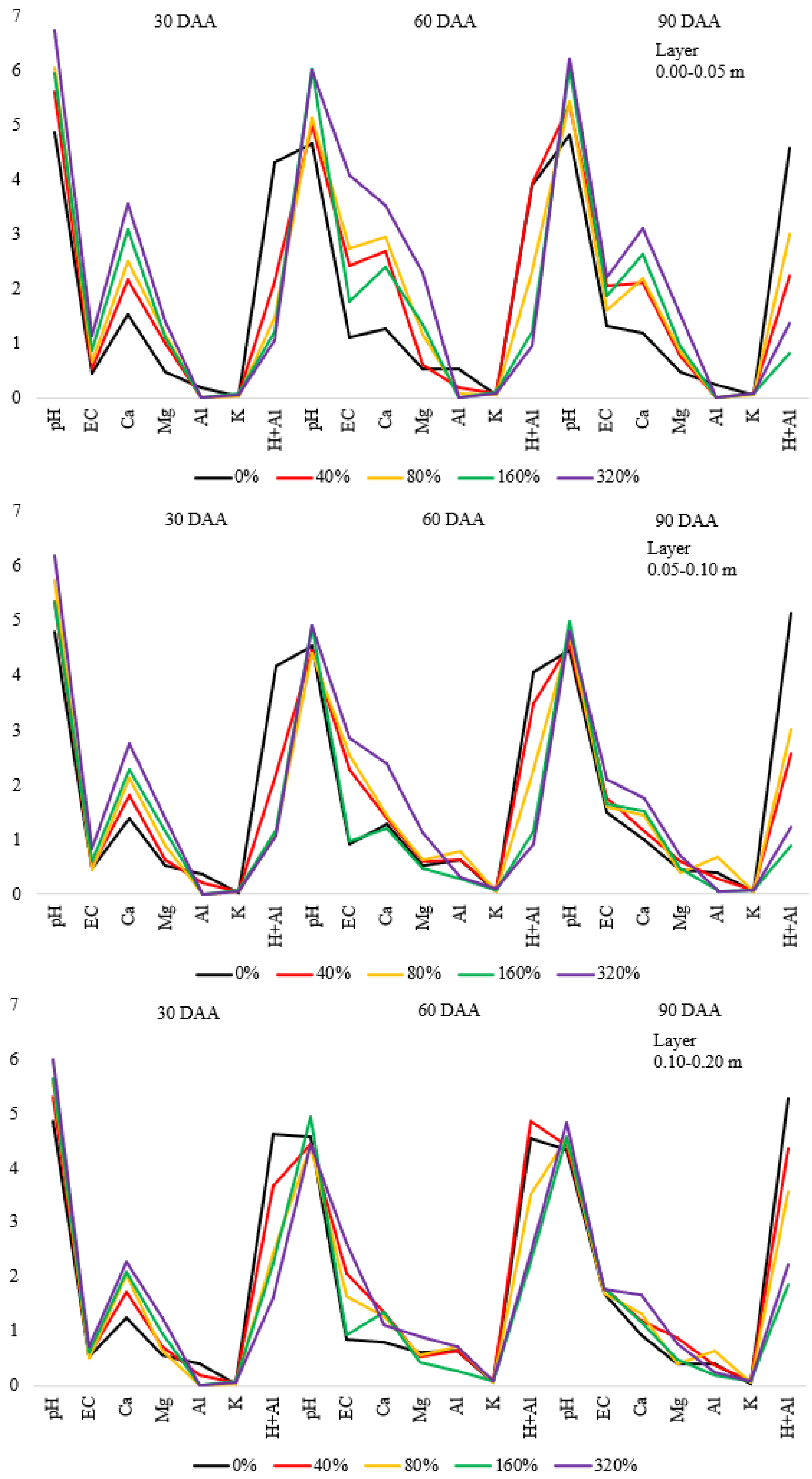

Figure 2. Chemical properties of Dystrophic Yellow Latosol in the (a) 0.00-0.05, (b) 0.05-0.10, and (c) 0.10-0.20 m layers at 30, 60, and 90 days after application (DAA) of different lime doses by broadcasting. Electrical conductivity (EC) is expressed in mS cm^{-1}. Ca^{2+}, Mg^{2+}, Al^{3+}, K^+, and $H^+ + Al^{3+}$ contents are expressed in $cmol_c\ kg^{-1}$. Federal University of Western Pará, Santarém, Pará State, Brazil

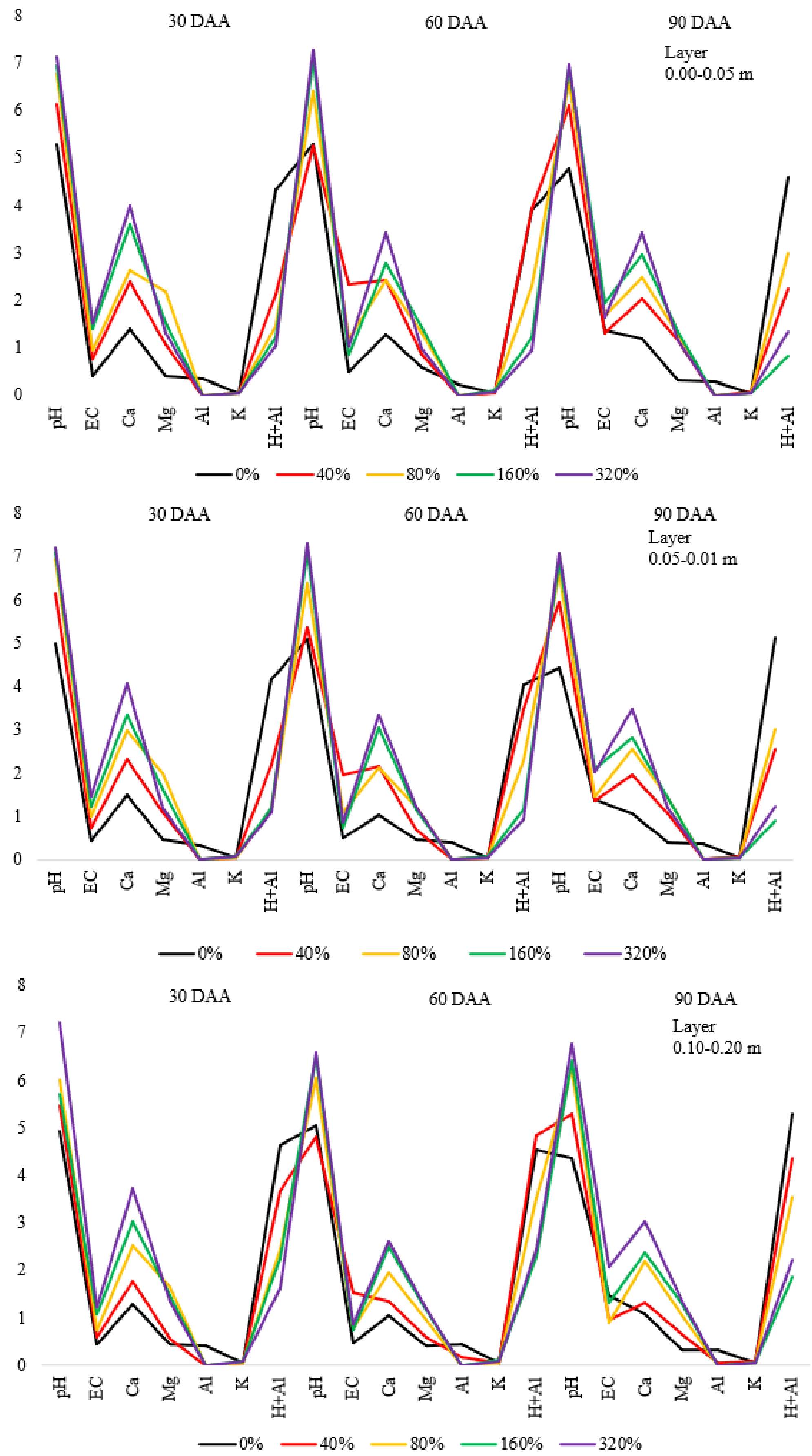

Figure 3. Chemical properties of Dystrophic Yellow Latosol in the (a) 0.00-0.05, (b) 0.05-0.10, and (c) 0.10-0.20 m layers at 30, 60, and 90 days after application (DAA) of different lime doses by incorporation. Electrical conductivity (EC) is expressed in mS cm^{-1}. Ca^{2+}, Mg^{2+}, Al^{3+}, K^{+}, and $H^{+} + Al^{3+}$ contents are expressed in $cmol_c\ kg^{-1}$. Federal University of Western Pará, Santarém, Pará State, Brazil.

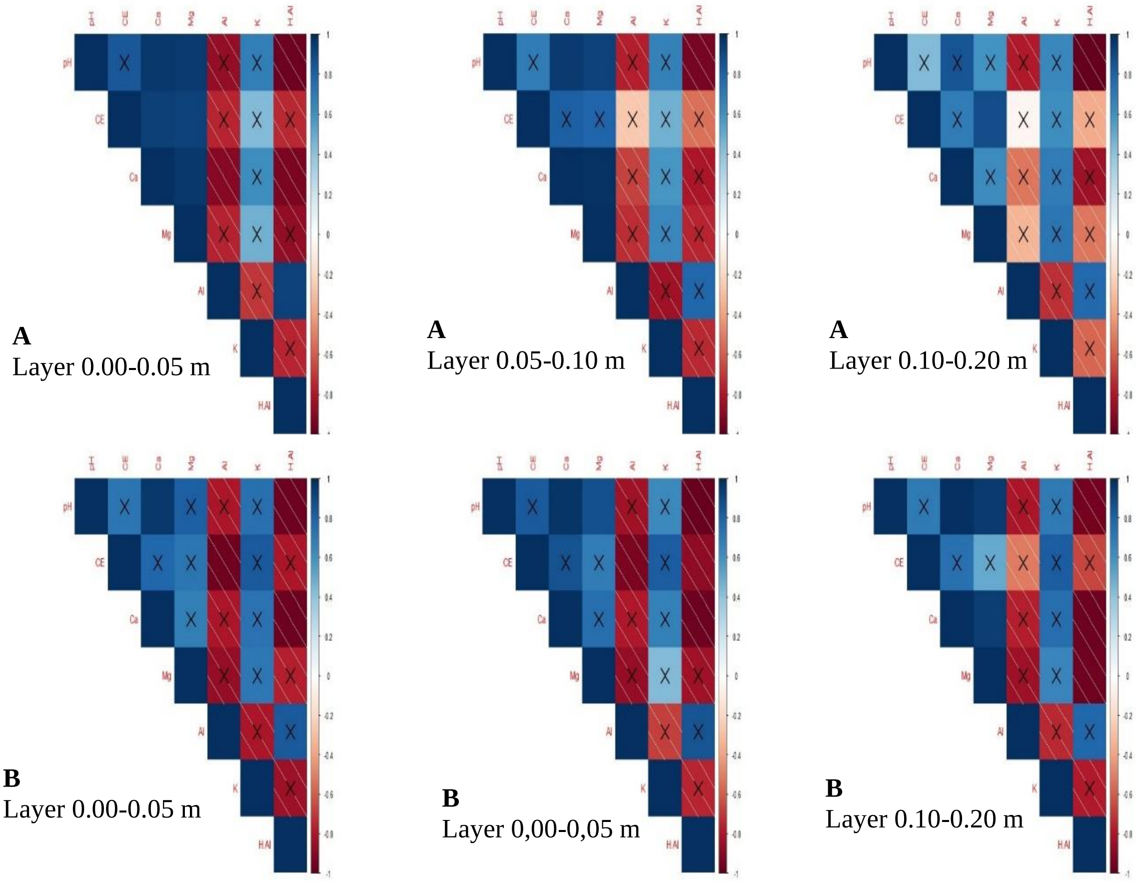

Figure 4. Pearson correlation matrix for the total mean values of soil chemical properties after application of different lime doses by (a) broadcasting and (b) incorporation. An X indicates a lack of significance at the 5% level.

Figure 5 shows the regression curves of applied BS as a function of calculated BS for each soil layer at 30 DAA. Broadcasting resulted in a linear relationship between BS and dose, with greater reactivity in the 0.00-0.05 m layer (Figure 5A), although the calculated BS was not reached with any lime dose. For lime incorporation (Figure 5B), a quadratic model showed the best fit to the data. A decreasing trend was observed for application doses greater than 160%. For example, 40 and 80% doses showed overlapping lines for 0.00-0.05 and 0.05-0.10 m layers, with higher BS values at 80%.

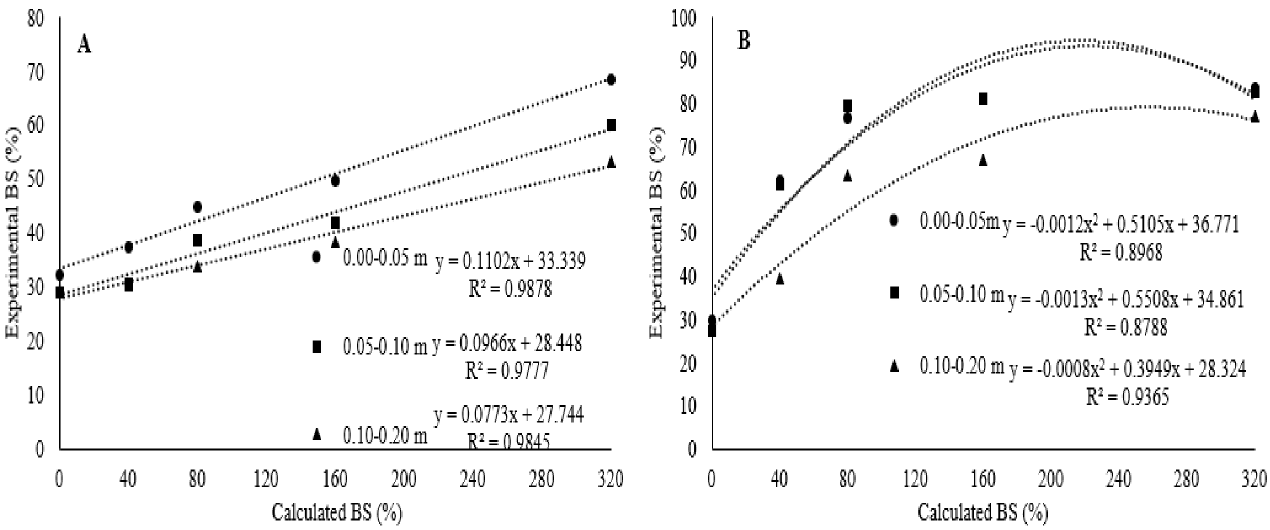

Figure 5. Regression models for base saturation (BS) in different layers of Dystrophic Yellow Latosol at 30 days after application of different lime doses by (A) broadcasting and (B) incorporation. *Significant at 5% probability of error, by the F test.

A quadratic model best explained the relationship between dose and calculated BS in the 0.00-0.05 m layer at 60 DAA (Figure 6A); BS tended toward stabilization at application doses greater than 226,7%. For the 0.05-0.10 m layer, a linear model provided the best fit to data, and for the 0.10-0.20 m layer, no model showed a significant fit. Lime incorporation data were best explained by a quadratic equation for all depths (Figure 6B). An application dose of 40% resulted in BS values higher than the calculated values at depths of 0.00-0.05 and 0.05-0.10 m, although BS values were lower than those at 30 DAA (Figure 5B), as was observed for the other doses.

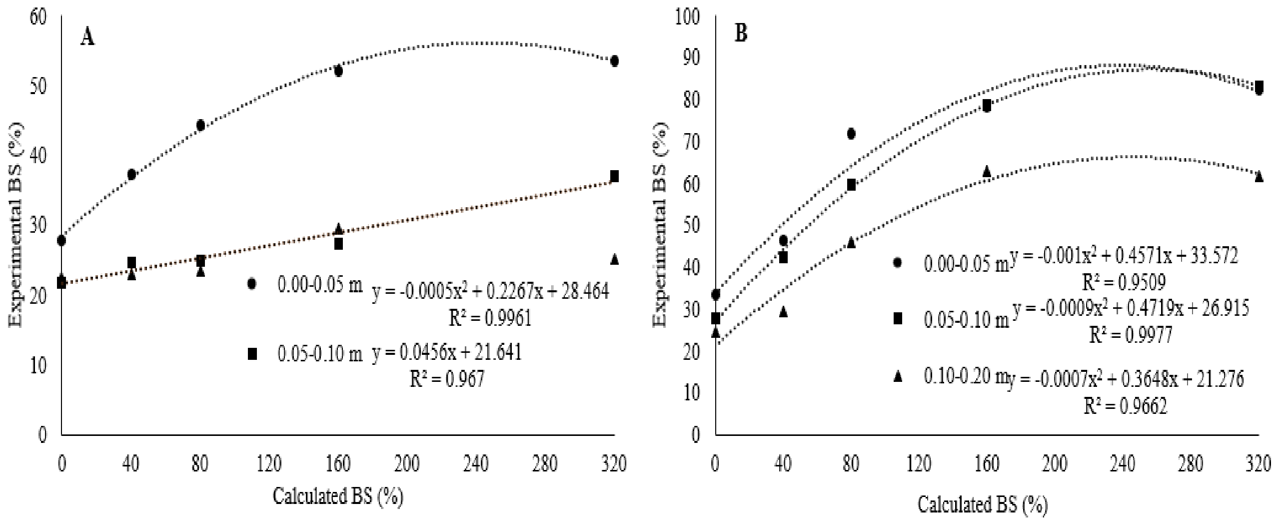

Figure 6. Regression models for base saturation (BS) in different layers of Dystrophic Yellow Latosol at 60 days after application of different lime doses by (A) broadcasting and (B) incorporation. *Significant at 5% probability of error, by the F test.

A quadratic regression equation (Figure 7A) showed that, at 90 DAA, a liming to haul led to the elevation of the BS in the 0.00-0.05 m layer, as also observed at 60 DAA. As a result, calculated BS was only achieved by applying 40% via broadcasting. At depths of 0.05-0.10 and 0.10-0.20 m, a linear relationship was observed between applied doses and calculated BS values, but with the dose of BS 320% reaching values above 30%.

For lime incorporation (Figure 7B), a quadratic relationship was observed; BS continued to increase with lime doses. Incorporation of lime at 40% continued to result in BS values greater than 40% at 0.00-0.05 and 0.05-0.10 m depths and close to 30% at 0.10-0.20 m depth.

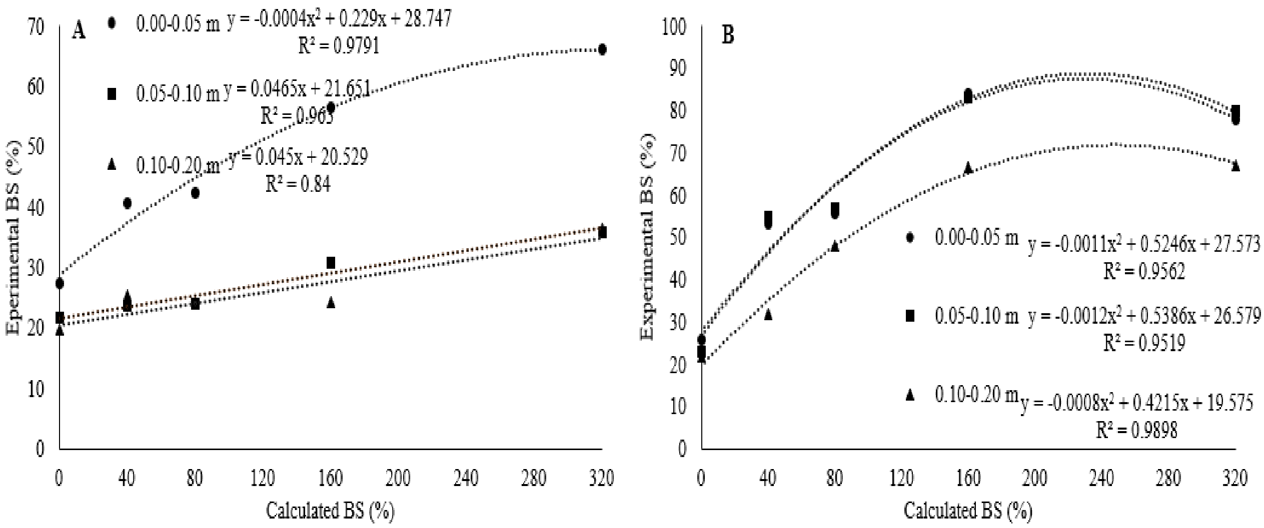

Figure 7. Regression models for base saturation (BS) in different layers of a Dystrophic Yellow Latosol at 90 days after application of different lime doses by (A) broadcasting and (B) incorporation. *Significant at 5% probability of error by the F test.

Lime broadcasting to achieve 40% BS resulted in a greater reactivity at 0.00-0.05 m; the expected BS was reached at 90 DAA. The other application doses did not afford the expected BS. Broadcasting did not lead to an increase in BS in deeper layers (0.10-0.20 m).

The incorporation of lime resulted in high reactivity for all application doses. The largest increase in BS was observed at 30 DAA, with a dose of 40% affording BS values greater than 40%, although such an effect was limited to 0.00-0.05 and 0.05-0.10 m layers. Doses above 40% were more reactive in the 0.10-0.20 m layer up to 90 DAA. Doses greater than the economic level (160 and 320%) did not result in BS values higher than 90%.

DISCUSSION

Analysis of the cation-exchange complex reflects the concentrations of dominant cations present in soil solution, demonstrating the influence of lime or fertilizer application, which affects soil electrical conductivity (AMARAL & ANGHINONI 2001). An increase in electrical conductivity with the lime application was also observed by CARMO & SILVA (2016).

Broadcasting of lime increased Ca^{2+} + Mg^{2+} contents from low to medium, according to the classification of BRASIL & CRAVO (2020) for Pará State. The highest values were observed at 30 DAA at all depths. However, at 90 DAA, Ca^{2+} + Mg^{2+} content in the 0.10-0.20 m layer was low, demonstrating low availability in soil. On the other hand, lime incorporation resulted in medium to high Ca^{2+} + Mg^{2+} contents, with the highest values observed at 30 DAA and intermediate values at other periods in all layers.

Although liming enhanced Ca^{2+} and Mg^{2+} contents, this practice may negatively affect K^+, leading to potassium deficiency in plants (NOLLA et al. 2020). Excess potassium fertilization may lead to reduced Mg^{2+} absorption and, consequently, yield losses, as observed in maize by VELOSO et al. (2001). Thus, it is recommended to use the proportions proposed by BEAR & TOTH (1948) for soil cation-exchange capacity to mitigate yield losses: 65% Ca^{2+}, 10% Mg^{2+}, 5% K^+, and 20% H^+. However, as highlighted by OLIVEIRA & PARRA (2003), the results of these relationships are contradictory and not applicable to all crops.

Al^{3+} content was more strongly influenced at increasing depths, demonstrating the higher efficiency of lime incorporation as compared with broadcasting on neutralization of Al^{3+} and active and potential acidity. These findings are in agreement with those of BAMBOLIM et al. (2015).

As revealed by the correlation matrix, the greatest reactivity of broadcast lime was observed in the 0.00-0.05 m layer, largely due to the low mobility of lime in the soil. Such an effect extended to the other layers when lime was incorporated in soil, in agreement with the results of CAIRES et al. (2004). According to CAIRES et al. (1999), the Al^{3+} neutralizing effect of broadcast lime is not long-lasting, limiting BS values.

Although lime incorporation increased BS to the expected value, such effects were limited to the 0.10 m layer, being also due to the low solubility of lime and also due to the increase in the buffering power of the soil at depth. CORÁ & BERALDO (2006) applied liming and phosphating treatments to sugarcane crops and found that lime dose did not increase BS to the calculated value of 70%, not even when lime was incorporated in the soil; the final BS values were about 60%. ALLEONI et al. (2005) also did not observe an increase in BS to the calculated value in the 0-0.20 m layer after lime incorporation.

The reactivity of lime in subsurface layers is a challenge. As observed in the current study, the effects of liming decrease with time when applied at doses of 40 and 80% BS; at 90 DAA, BS values at the 0.10-0.20 m depth are even lower. CAIRES et al. (2003) underscored that the downward displacement of lime particles broadcast onto the soil surface is influenced by vegetation cover and channels made by plant roots and soil macro-, micro-, and mesofauna. Moreover, soluble organic complexes are formed, promoting lime reactivity in subsurface soil. However, it should be noted that the experimental site was not planted with crops; results were determined by incubation of soil samples.

Considering the low mobility of lime, generally limited to the 0.00-0.05 m layer when broadcast on soil, FRANCHINI et al. (2001) studied the application of water-soluble organic compounds from oat and turnip to increase the effects of lime at greater depths. The authors observed that the combined treatment increased pH, Ca^{2+}, and Mg^{2+} and reduced Al^{3+} at the 0.25 m depth. Such a strategy seems to improve the efficiency and reactivity of broadcast lime at depths >0.20 m.

Reactivity is influenced not only by form of application but also by the reaction speed of lime, as discussed by NATALE et al. (2007). The authors argued that reactivity indices are overestimated to fit the Brazilian legislation, which is of 90 days, and that buffer power and rainfall also influence reactivity.

According to CAVALCANTE et al. (2018), although lime exerts a positive influence on soil properties, an excessively high dose can compromise crop yield, as it disrupts the balance of K^+, Ca^{2+}, and Mg^{2+}. SILVA CARNEIRO et al. (2018) highlighted that high lime doses increase soil pH to values that do not favor nutrient availability for plants, particularly that of micronutrients such as Mn and Zn (FILHO & SILVA 2000). Thus, doses of 80% BS should be avoided because they increase soil pH to values above 6.5.

SILVA et al. (1995) found that cotton plants have a better response to liming when potassium fertilization is performed concomitantly, using values similar to those of BS (40-60%). CAVALCANTE et al. (2018) obtained high passion fruit yields (37.75 Mg ha^{-1}) when potassium fertilization was carried out with lime application. Therefore, balanced potassium fertilization may contribute to increasing BS.

Field tests, combined with regression analysis of experimental data, are needed to determine the required lime doses to maintain Ca^{2+} and Mg^{2+} contents above 1 and 0.5 cmol$_c$ kg^{-1}, respectively, for 90 days within the 80% BS threshold.

CONCLUSION

Lime incorporation was the most effective, with the highest BS values being observed at 30 DAA at all depths evaluated. However, at 90 DAA, most doses failed to maintain BS at the expected values. Only application of lime at 40% BS resulted in soil BS values above the calculated; and this effect was limited to the 0.00-0.10 m layer. Therefore, regression analyses are recommended in field experiments respecting the threshold of 80% BS.

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REFERENCES

ALLEONI LRF et al. 2005 Atributos químicos de um latossolo de cerrado sob plantio direto, de acordo com doses e formas de aplicação de calcário. Revista Brasileira de Ciência do Solo 29: 923-934.

ALMADA AP et al. 2021. Characterization and classification of soils from an Amazonic Biome in western Pará. Revista Brasileira de Ciências Agrárias 16: e8458.

AMARAL AS & ANGHINONI I. 2001. Alteração de parâmetros químicos do solo pela reaplicação superficial de calcário no sistema plantio direto. Pesquisa Agropecuária Brasileira 36: 695-702.

BAMBOLIM A et al. 2015. Calcário líquido e calcário convencional na correção da acidez do solo. Revista de Agricultura Neotropical 2: 34-38

BEAR FE & TOTH SJ. 1948. Influence of calcium on availability of other soil cations. Soil Science 65: 69-74.

BRASIL EC & CRAVO MS. 2020. Interpretação dos resultados da análise do solo. In: BRASIL EC et al. Recomendações de adubação para o estado do Pará. 2.ed. Brasília: Embrapa. p.61-66.

CAIRES EF et al. 2003. Alterações químicas do solo e resposta da soja ao calcário e gesso aplicados na implantação do sistema plantio direto. Revista Brasileira de Ciência do Solo 27: 275-286.

CAIRES EF & FONSECA AF. 2000. Absorção de nutrientes pela soja cultivada no sistema de plantio direto em função da calagem na superfície. Bragantia 59: 213-220.

CAIRES EF et al. 1999. Produção de milho, trigo e soja em função das alterações das características químicas do solo pela aplicação de calcário e gesso na superfície, em sistema de plantio direto. Revista Brasileira de Ciência do Solo 23: 315-327.

CAIRES EF et al. 2004. Alterações químicas do solo e resposta do milho à calagem e aplicação de gesso. Revista Brasileira de Ciência do Solo 28: 125-136.

CARMO DL & SILVA CA. 2016. Condutividade elétrica e crescimento do milho em solos contrastantes sob aplicação de diversos níveis de calagem. Pesquisa Agropecuária Brasileira 51: 1762-1772.

CORÁ JE & BERALDO JMG. 2006. Variabilidade espacial de atributos do solo antes e após calagem e fosfatagem em doses variadas na cultura de cana-de-açúcar. Revista de Engenharia Agrícola 26: 374-387.

CRAVO MS et al. 2012. Calagem em Latossolo Amarelo distrófico da Amazônia e sua influência em atributos químicos do solo e produtividade de culturas anuais. Revista Brasileira de Ciência do Solo 36: 895-905.

CAVALCANTE LF et al. 2018. Produção de maracujazeiro amarelo no solo com calcário e potássio sob irrigação com água salina. Revista Irriga 23: 727-740.

FILHO MPB & SILVA OF. 2000. Adubação e calagem para o feijoeiro irrigado em solo de cerrado. Pesquisa Agropecuária Brasileira 35: 1317-1324.

FISCH G et al. 1998. Uma revisão geral sobre o clima da Amazônia. Acta Amazonica 28: 101-126.

FRANCHINI JC et al. 2001. Potencial de extratos de resíduos vegetais na mobilização do calcário no solo por método biológico. Scientia Agricola 58: 357-360.

GLASER B & BIRK JJ. 2012. State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). Geochimica et Cosmochimica Acta 82: 39-51.

INMET. 2020. Instituto Nacional de Meteorologia. Disponível em: <http://www.inmet.gov.br/portal/index.php?r=home/page&page=rede_estacoes_conv_graf>. Acesso em: 04 set. 2020.

MARASCHIN L et al. 2020. Incubação do calcário e as características químicas de solos com texturas diferentes. Revista Nativa 8: 43-51.

NATALE W et al. 2007. Efeitos da calagem na fertilidade do solo e na nutrição e produtividade da goiabeira. Revista Brasileira de Ciência do Solo 31: 1475-1485.

NETO PHW et al. 2000. Correção da acidez do solo em função de modos de incorporação de calcário. Ciência Rural 30: 257-261.

NOLLA A et al. 2020. Correção da acidez e disponibilização de fósforo e potássio em latossolo vermelho distrófico típico submetido à calagem incorporada e superficial. Brazilian Journal of Animal and Environmental Research 3: 2478-2487.

OLIVEIRA EL & PARRA MS. 2003. Resposta do feijoeiro a relações variáveis entre cálcio e magnésio na capacidade de troca de cátions de latossolos. Revista Brasileira de Ciência do Solo 27: 859-866.

QUARTEZANI WZ et al. 2015. Efeito residual de corretivo líquido na acidez do solo na cultura do café. Revista Energia na Agricultura 30: 150-154.

ROSA JUNIOR EJR et al. 2006. Calcário e gesso como condicionantes físico e químico de um solo de cerrado sob três sistemas de manejo. Pesquisa Agropecuária Tropical 36: 37-44.

SILVA NM et al. 1995. Ensaio de longa duração com calcário e cloreto de potássio na cultura do algodoeiro. Bragantia 54: 353-360.

SILVA CARNEIRO JS et al. 2018. Supercalagem: alterações em atributos químicos de um latossolo vermelho-amarelo distrófico. Revista de Ciências Agroambientais 16: 32-38.

SOMBROEK WG et al. 1993. Amount, dinamics and sequestering of carbon in tropical and subtropical soils. Ambio 22: 417-426.

SOUSA MA et al. 2020. Atributos químicos e frações da matéria orgânica em solos antrópicos na Amazônia Oriental. Brazilian Journal of Development 6: 29623-29643.

TEIXEIRA PC et al. 2017. Manual de Métodos de Análise de Solo. 3.ed. Rio de Janeiro: Embrapa Solos. 573p.

VASQUES NC et al. 2020. Resposta da biomassa microbiana a diferentes corretivos de solo. Revista Ibero Americana de Ciências Ambientais 11: 161-169.

VELOSO CAS et al. 2001. Relações Cálcio, Magnésio e Potássio sobre a produtividade de matéria seca de milho. Acta Amazônica 31: 193-204.