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ADJUSTMENT OF THE LIME RATE RECOMMENDATION FOR THE SOYBEAN-MAIZE SYSTEM IN THE CERRADO-AMAZON TRANSITION REGION

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ABSTRACT – Liming is an essential practice for high productivity systems, but the recommended rates are often not enough to increase base saturation (V%) and to guarantee an extended residual effect. Thus, we aimed to evaluate, across three crops, soybean and maize productivity as well as chemical changes in the soil after lime rates above the recommended, in Querência, Mato Grosso, Brazil. Eight treatments were tested, combining dolomitic lime, calcitic lime and two ways of application (superficial or incorporated), in addition to a control group, in a randomized block design, with four replications. Lime rates were calculated through the base saturation method (aiming for V = 75%, 100% and 150%) or through increase of Ca and Mg percentages in the CEC_{pH7} (60/20% and 75/25%). Liming significantly improved soil pH, Ca and Mg concentration, base saturation and participation of these cations in the CEC_{pH7}, reflecting in higher productivity of soybean and maize. The treatment with half of the rate incorporated and half superficial achieved better results. Therefore, lime rates above the traditionally recommended are viable, especially when part of it is incorporated, promoting lasting changes in soil fertility and increase of crop productivity.

Keywords: calcitic lime, dolomitic lime, application depth, base saturation.

Soybean production in Brazil in the 2024/25 harvest was 168 million tons and the state of Mato Grosso (MT) contributed with 49,7 million tons, 30% of the total. Oilseeds productivity in the state until the 2015/16 harvest had never surpassed 3,200 kg ha^{-1}, but from the 2016/17 harvest the growth has been linear, going from 3,294 kg ha^{-1} to 3.903 kg ha^{-1} in the 2024/25 harvest (Acompanhamento da Safra Brasileira de Grãos, 2025), with reports of areas producing more than 4.800 kg ha^{-1}.

For the second-crop maize, productivity gains are even more expressive. Until the 1990s, yield did not surpass 2,000 kg ha^{-1}, being cultivated for straw formation and soil coverage purposes, with low investments and low expectancy of economical returns. On the other hand, the soybean varieties available in the market presented long production cycle, narrowing the ideal sowing window of maize. Currently, maize performs a key role in the state's economy, generating substantial income for the farmer, countless jobs in the processing facilities, farms, livestock raising, and specially on ethanol plants, 11 of which are located in the state, being responsible for 80% of ethanol production from maize in Brazil (Petroli, 2023). In this scenario, productivity was 3,900 kg ha^{-1} in the 2005/06 harvest, surpassed 6,000 kg ha^{-1} in the 2016/2017 harvest and reached an average of 6,900 kg ha^{-1} in the 2023/24 harvest.

Soil management also evolved during this period, and starting in the 1990s, conventional tillage gave way to the No-Till Farming System (NTFS). However, methods for determining lime application rates have changed little. In an attempt to reduce problems with excessive surface liming, which caused micronutrient deficiencies in plants, Sá (1999) in the state of Paraná proposed for clay soils 1/2 to 1/3 of the rate recommended by the base saturation (V) method, with a limit of 2.5 t ha^{-1}, and for clay-sandy and sandy soils, 1/2 of the recommended rate, with a limit of 1.5–2.0 t ha^{-1}, corroborating Lopes (1999), who recommends the use of small annual rates of fine-grained limestone, rather than high rates every 3 to 4 years, as was the practice in conventional soil preparation. Thus, this recommendation regarding lime rates has been widely used for Cerrado (Brazilian tropical savanna) soil conditions, aiming to avoid nutritional imbalances in the soils when using rates higher than the proposed limits.

Regarding the official recommendations for the Cerrado region and surrounding areas, Sousa and Lobato (2004) consider Ca levels between 1.5 and 7.0 $cmol_c$ dm^{-3} and Mg levels between 0.5 and 2.0 $cmol_c$ dm^{-3} to be adequate, and a base saturation (V) of 50% for soybeans and maize grown under rainfed conditions. For soybean cultivation on soils with CEC_{pH7} ~8.0 $cmol_c$ dm^{-3}, Embrapa mentions ideal values of Ca and Mg between 2 and 4 or >4.0 $cmol_c$ dm^{-3} and 0.4 to 0.8 or >0.8 $cmol_c$ dm^{-3}, respectively, and an increase in V to 50% to 75%, considered medium and high, respectively (Tecnologias […], 2013). More recently, Quaggio and Raij (2022) recommend raising the V value to 70% for soybean and maize crops.

Significant effects on soil and crops resulting from increased lime application rates compared to traditional recommendations have been observed in newly cleared areas (Bortoluzzi et al., 2014; Santos et al., 2018; Moraes et al., 2023). In established no-till areas, the feasibility of surface liming with recommended or higher rates has yielded benefits by improving the chemical properties of the soil profile, with positive effects on crop nutrition and productivity (Rodrighero et al., 2015; Costa et al., 2016; Crusciol et al., 2016; Joris et al., 2016; Chapla, 2017; Silva, 2023).

In the state of Mato Grosso, farmers have been increasing their use of lime in soybean/maize and soybean/cotton fields in recent years, rising from an average of 0.5 Mg ha^{-1} in 2016 to 1.2 Mg ha^{-1} in 2022 (Lange et al., 2023). Given this information, in areas where base saturation (V) is below adequate levels, it is possible to apply higher-than-recommended rates of lime to achieve a faster increase in V% and a more prolonged residual effect.

The objective of this study was to evaluate the response of soybean and maize crops and the effects on the soil resulting from liming with rates higher than those recommended, using two methods to calculate the application rate.

Material and Methods

The experiment was conducted from 2018 to 2022 in an area planted with soybeans and second-crop maize at Fazenda Concórdia, located in the municipality of Querência, at coordinates Latitude: 12°44’43.3” S and Longitude: 52°11’06.6” W, at an altitude of ~360 m, in the northeastern region of the state of Mato Grosso (Araguaia Valley), Brazil. The local climate is classified as Aw according to the Köppen classification, with an average annual precipitation of 1,696 mm and a average monthly temperature range of 24°C to 27°C. The average monthly precipitation for the period during which the experiments were conducted (2018 to 2022) is shown in Figure 1. The soil in the experimental area is classified as dystrophic Red-Yellow Latosol (Oxisol) of medium texture.

Prior to the setup of the experiment (Sept. 2018), soil samples were collected from the 0–20 cm layer; the analytical results showed the following values for chemical and physical properties: pH_{H_2O} = 5.8; P-Mehlich1 = 65.3 mg dm^{-3}; K = 25.8 mg dm^{-3}; Ca = 2.34 $cmol_c$ dm^{-3}; Mg = 0.6 $cmol_c$ dm^{-3}; Al = 0.0 $cmol_c$ dm^{-3} of soil; and OM = 21.5 g dm^{-3}; V = 41.8%; $CEC_{pH\ 7}$ = 7.2 $cmol_c$ dm^{-3}; ratios: Ca/Mg = 3.9; Ca/CEC_{pH7} = 32%; Mg/CEC_{pH7} = 8% and K/CEC_{pH7} = 1%; Clay = 274 g dm^{-3}; Silt = 76 g dm^{-3}; Total sand = 650 g dm^{-3}.

A randomized block design was used, with four replicates and eight treatments, involving different rates, types of lime and methods of application. Two methodologies were used to determine the rates: (a) the base saturation (V) method and (b) a method proposed to increase the percentages of Ca and Mg in the potential CEC (Table 1). To increase the saturation of Ca and Mg, in %, in the soil’s CEC_{pH7}, based on the characteristics of the correctives and the soil prior to liming, we first calculated how many $cmol_c$ dm^{-3} of Mg were needed to reach the desired value, which corresponds to the desired

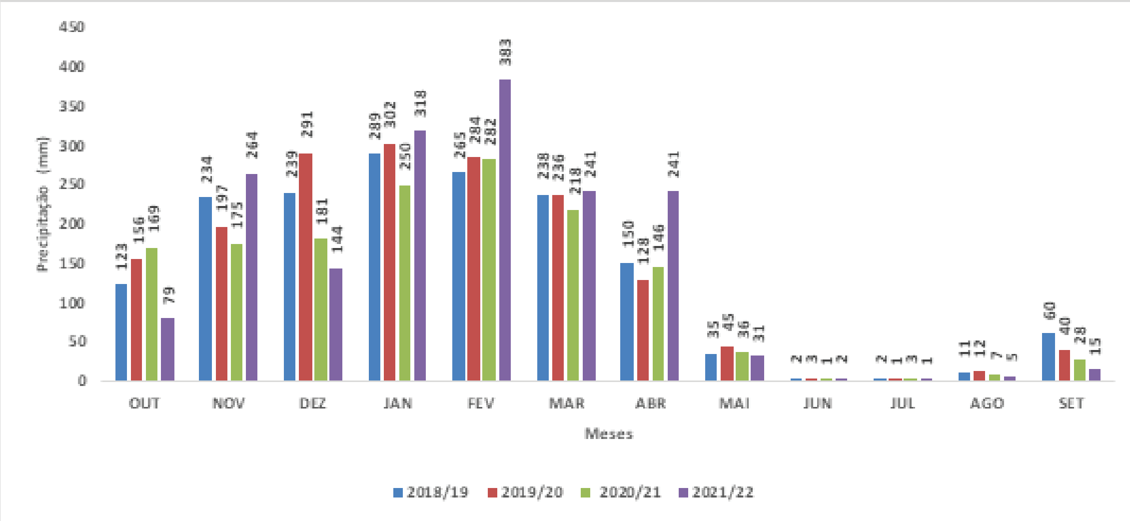

Figure 1 – Monthly rainfall and annual totals in Querência (MT) from October 2018 to September 2022. Data collected from the study site and neighboring farms

%, and for this purpose, we applied the rate of dolomitic lime, already corrected for the Relative Power of Total Neutralization (PRNT). After this procedure, it was determined how many $cmol_c$ dm^{-3} of Ca were applied in this first application, and, by difference, a new application of calcitic lime was made to supply the remaining Ca deficiency ($cmol_c$ dm^{-3}). In the end, it is found that, in theory, the % of Ca in CEC_{pH7} is adjusted to the desired value and that the % of Mg in CEC_{pH7} is slightly higher than desired, since calcitic lime typically contains 2–3% MgO. The liming materials used were dolomitic lime (CaO = 30.6%; MgO = 18.1%; PRNT = 89.1%) and calcitic lime (CaO = 47%; MgO = 0.3%; PRNT = 73.8%).

The reference lime rate was determined based on the results obtained by Joris et al. (2016) and Chapla (2017), setting the increase in soil base saturation (V) to 75% (Table 1). The remaining rates, calculated using the base saturation method, were intended to hypothetically achieve V values of 100% and 150%, thereby enabling the derivation of multiplication factors for adjusting the lime rates (Table 1).

In the treatment where the lime rates (5.6 t ha^{-1} of calcitic lime and 4.4 t ha^{-1} of dolomitic lime) were applied in split applications, 50% of the total rate was applied to the soil surface on October 9th, 2018, the same date as the other applications, before soybean sowing, and 50% on June 27th, 2019, after the maize harvest, for this treatment (Table 1). In the treatment involving the incorporation of calcitic lime, 5.3 t ha^{-1} was incorporated into the 0–0.20 m layer using a plow harrow, followed by a leveling harrow, and subsequently, dolomitic lime was applied to the soil surface at a rate of 4.4 t ha^{-1} (Table 1). The plots for the lime treatments were 10 m long and 8 m wide and were established in the field on October 9th, 2018.

For soybean crops in all the seasons evaluated

Table 1. List of treatments, including rates, application methods, and the types of lime used.

Treat.	Application	Calculation method	Target V%	Rate (t ha^{-1})
T1	-	-		-
T2	Sup.	V% 75	75	2,7Dol
T3	Sup.	1,75*T2	100	4,7Dol
T4	Sup.	3,27*T2	150	8,7Dol
T5	Sup.	Ca-60%, Mg-20%	% de Ca e Mg na CEC	2,3Calc+1,9Dol
T6	Sup.	Ca-75%, Mg-25%	% de Ca e Mg na CEC	3,4Calc+2,7Dol
T7*	Sup-Calc+Dol	3,6*T2	150	5,3Calc+4,4Dol
T8	Inc-Calc+Sup-Dol	3,6*T2	150	5,3Calc+4,4Dol

(Dol- dolomitic): 30,6% CaO; 18,1% MgO; PRNT 89,1%; (Calc- calcitic): 47% CaO; 0,3% MgO; PRNT 73,8%; Sup- surface-applied, Inc-incorporated to the soil (0-20 cm). T7*: Sup-Calc (09/10/2018|)+Dol (27/06/2019).

(2019/20, 2020/21, and 2021/22), sowing took place in the second half of October, with row spacing of 0.50 m and seed rates of 260, 220, and 400 thousand seeds ha^{-1} for the respective seasons. All crops were inoculated with *Bradyrhizobium*. For seedbed fertilization, 180 kg ha^{-1} of MAP (11% N, 52% P_2O_5) was applied to the seed furrow, and ten days after sowing, 150 kg ha^{-1} of KCl (60% K_2O) was broadcast-applied to the soil surface. Pest, disease, and weed control were carried out as needed, using herbicides, fungicides, and insecticides recommended for the crop in the region.

Soybean harvest always took place in early February of each year. To assess yield, four five-meter rows were harvested within each plot; the number of plants was counted to determine the final plant density, and the number of seeds per plant and the thousand-seed weight were also assessed on 10 plants (3 samples of 100 grains dried at 105 °C and adjusted to 130 g kg^{-1} standard moisture content). The plants were then threshed to assess grain weight and moisture content, with grain weight adjusted to standard moisture content and yield estimated in kg ha^{-1}.

Maize was sown in the 2019, 2020, and 2021 growing seasons immediately after the soybean harvest (February), with a row spacing of 0.50 m and a seeding rate of 60,000 seeds ha^{-1}. At the time of planting, a basal fertilizer application of 90 kg ha^{-1} of MAP was applied to the seed row. For topdressing, 120 kg ha^{-1} of KCl was applied 12 days after emergence, and 150 kg ha^{-1} of urea (45% N) was applied 35 days after emergence. Pest, disease, and weed control were carried out as needed and according to the levels of damage observed, using insecticides, fungicides, and herbicides recommended for the crop.

Maize harvesting always took place during the last week of June. To determine grain yield, ears were harvested from four central rows, each five meters long; they were threshed, weighed, and moisture content was corrected to 130 g kg^{-1}. The number of plants in the harvested area was also assessed to determine the final plant density. To evaluate yield components, 10 ears were selected, and the number of kernels per ear and the thousand-kernel weight were determined.

After the maize harvest in the 2019, 2020, and 2021 growing seasons, soil samples were collected from the 0–20 cm layer in each plot, with 10 individual samples taken to form a composite sample. Since the area was fertilized in the seed furrow, it was decided to collect 1/3 of the samples along the row and 2/3 between rows, using a soil probe.

Upon completion of the field experiment, soil samples were collected after the harvest of the 2021/22 soybean crop (February 2022), thus marking 41 months since the application of the lime. On this occasion, trenches 50 cm wide by 25 cm deep were dug in the center of each plot, over the soybean seeding furrow, and soil was sampled from the 0–10 cm and 10–20 cm layers using knives, plastic trays, and buckets. The reason for stratified sampling at the end of the study is to verify the possible vertical movement of the soil corrective, since if such movement occurred, this would be the most appropriate time to observe it. The soil samples were sent to the laboratory for analysis of soil fertility parameters according to the methodologies proposed by Teixeira et al. (2017).

Statistical analysis was performed using the Sisvar software (Ferreira, 2011). Data were subjected to the Shapiro-Wilk normality test ($p < 0.05$). When the results of the analysis of variance indicated, via the F-test, significant effects ($P \leq 0.10$) of the treatments on the analyzed parameters, the comparison between means was evaluated using the Scott-Knott method at a 10% probability level. Pearson's correlation was used to verify the degree of association between soil variables and the average yields of soybeans and maize.

Results and Discusion

Effects of liming on soil parameters

Liming altered the values of pH, Ca, Mg, potential acidity (H+Al), base saturation (V), % Ca and Mg in CEC_{pH7}, and the Ca/Mg ratio at nine months, with these changes persisting over time (Tables 2 and 3), which was also observed in similar studies (Rodrighero et al., 2015; Costa et al., 2016; Crusciol et al., 2016; Esper Neto et al., 2019; Moraes et al., 2023; Silva, 2023). P and K levels were not altered by the applied treatments.

Soil pH in the 0–20 cm layer was lower in the absence of liming (≤6.0), dropping to 5.5 at 41 months after liming in the control treatment. Soil correction raised the pH to 6.5, particularly in the treatment that received 9.7 t ha^{-1} of lime, consisting of 4.4 t ha^{-1} of calcitic lime incorporated into the soil and 5.3 t ha^{-1} of dolomitic lime applied to the surface. Incorporation accelerates the reaction (Santos et al., 2018; Silva, 2023), intensified by high rainfall (~1,640 mm) each agricultural season (October to September) (Figure 1). In addition to the factors mentioned above, calcitic lime, which reacts more rapidly (Barber, 1984; Rodrighero et al., 2015), promoted earlier responses in the treatments in which it was applied.

In 2022, the pH reached 6.8 and 6.2 in the 0–10 cm and 10–20 cm layers, respectively. However, it did not exceed 7.0 in the treatment that received 9.7 t ha^{-1} of lime (4.4 t ha^{-1} of calcitic lime incorporated and 5.3 t ha^{-1} of dolomitic lime applied to the surface). Other treatments that received surface-applied lime had pH values close to 5.9 in the 10–20 cm layer, indicating soil profile correction even with surface lime application. Studies by Rodrighero et al. (2015) and Moraes et al. (2023), conducted under field conditions, as well as the study by Santos et al. (2024) and Lange et al. (2025), conducted under controlled conditions, demonstrated that at rates exceeding the recommended amount, the soil pH rarely exceeded 7.0. The behavior of H+Al followed the variations in pH was always higher in the absence of liming (3.1 to 5.0 $cmol_c$ dm^{-3}) for the 0–20 cm layer.

Ca concentrations and saturation in CEC_{pH7} were higher when the soil received 9.7 t ha^{-1} of limestone (4.4 t ha^{-1} of calcitic lime incorporated into the soil and 5.3 t ha^{-1} of dolomitic lime always applied to the surface). There was no difference compared to other treatments that received only surface liming, with Ca concentrations reaching 5.1 $cmol_c$ dm^{-3} in the 0–20 cm layer in 2021. In the absence of liming, the soil Ca concentration was close to 3.0 $cmol_c$ dm^{-3} (Tables 2 and 3).

At a depth of 10–20 cm, the vertical movement of Ca in the soil is notable, as the concentration was 2.1 $cmol_c$ dm^{-3} in the absence of liming, reaching 3.4 $cmol_c$ dm^{-3} when 9.7 t ha^{-1} of lime was applied to the soil surface. Ca saturation in CEC_{pH7} reached values of up to 72% in 2022 at a depth of 0–20 cm; we attribute this result to the use of calcitic lime.

The highest Mg concentrations in the 0–20 cm soil layer were observed in the treatments that received high rates of dolomitic lime. In 2022, Mg concentrations of 1.6 $cmol_c$ dm^{-3} were found in the 0–10 cm layer. Thus, the movement within the profile was evident, since in the control treatment, soil Mg levels of 0.5 $cmol_c$ dm^{-3} were measured in the 10–20 cm layer, while the application of 8.7 t ha^{-1} of dolomitic lime resulted in Mg levels of 1.1 $cmol_c$ dm^{-3} in the same layer. Mg saturation in CEC_{pH7} reached 20% in the 0–20 cm layer. Rates higher than traditional recommendations yielded Ca values exceeding 3.0 $cmol_c$ dm^{-3} and Mg values exceeding 1.0 $cmol_c$ dm^{-3} for the 0–20 cm layer, certainly contributing to the nutritional balance of crops (Sousa & Lobato, 2004; Tecnologias [...], 2013; Moraes et al., 2023) and increased crop productivity.

The highest V% values were observed when half the rate of the corrective agent was incorporated, with values ranging from 69% to 78% between 2019 and 2022 for the 0–20 cm layer, reflecting the greater reaction of the corrective agent and its higher efficiency when incorporated compared to surface application (Rodrighero et al., 2015; Costa et al., 2016; Rheinheimer et al., 2018; Santos et al., 2024). V% was close to 45% in the control group throughout the study period. In 2021, almost all liming treatments showed V% values above 65%, which is consistent with other studies that observed greater reaction 2 or 3 years after liming (Crusciol et al., 2016; Chapla, 2017;

Table 2. Effect of liming on pH, phosphorus (P); potassium (K); calcium (Ca); magnesium (Mg); potential acidity (H+Al), base saturation (V); Ca/Mg ratio and % of Ca e Mg in potential CEC in samples collected after the 2019, 2020 and 2021 maize harvests.

Treat.	pH	Ca	Mg	H+Al	CEC	V	$Ca/_{CEC}$	$Mg/_{CEC}$	Ca/Mg
		$cmol_c\ dm^{-3}$				%			
2019 (09 months)									
T1	5,8 d	2,4 b	0,7 b	4,0 a	7,2	46 c	34 d	10 c	3,4 b
T2	6,1 b	2,9 b	0,9 b	2,9 b	6,7	58 b	43 c	14 b	3,1 c
T3	6,0 c	3,2 b	1,3 a	3,7 a	8,2	55 b	39 d	16 b	2,4 d
T4	6,2 b	3,0 b	1,3 a	2,8 b	7,1	61 b	42 c	19 a	2,3 d
T5	6,1 c	3,3 b	0,8 b	2,5 b	6,8	63 b	48 b	14 b	3,5 b
T6	6,2 b	3,2 b	0,9 b	3,4 a	7,5	56 b	43 c	12 c	3,7 b
T7	6,2 b	3,6 b	0,8 b	2,9 b	7,4	61 b	49 b	11 c	4,5 a
T8	6,5 a	4,4 a	1,1 b	1,6 c	7,2	78 a	62 a	15 b	4,3 a
CV	2,1	13,2	19,4	18,7	13	7,6	8,7	12,5	14,2
2020 (21 months)									
T1	6,0 d	2,4 c	0,7 c	3,1 a	6,2	50 d	38 d	11 e	3,7 b
T2	6,1 c	2,5 c	1,0 b	2,7 a	6,2	57 c	40 d	16 b	2,5 c
T3	6,2 b	3,0 b	1,2 a	2,7 a	7,0	61 b	43 c	18 b	2,5 c
T4	6,3 b	2,6 c	1,3 a	2,5 b	6,5	62 b	41 d	20 a	2,0 d
T5	6,3 b	3,0 b	0,9 b	2,4 b	6,3	62 b	48 b	14 c	3,5 b
T6	6,2 b	3,2 b	0,9 b	2,9 a	7,0	58 c	45 c	12 d	3,7 b
T7	6,4 b	3,2 b	0,8 c	2,2 b	6,3	65 b	51 a	12 d	4,1 a
T8	6,6 a	3,7 a	1,0 b	2,1 b	6,8	69 a	54 a	14 c	3,9 b
CV	2	11	12	14	10	6	6,1	7	6,7
2021 (33 months)									
T1	5,6 c	3,5 b	0,7 b	5,3 a	9,5	45 c	37 b	7 b	5,3 a
T2	6,0 a	4,1 b	1,3 a	3,5 b	8,9	62 a	47 a	14 a	3,4 b
T3	6,1 a	4,3 a	1,4 a	3,3 b	9,1	64 a	48 b	15 a	3,3 b
T4	6,2 a	4,4 a	1,6 a	2,9 b	8,9	68 a	50 a	18 a	3,1 b
T5	5,9 b	3,6 b	0,8 b	3,4 b	7,9	57 b	45 a	10 b	4,6 a
T6	6,2 a	4,8 a	1,3 a	3,3 b	9,4	67 a	52 a	14 a	4,1 a
T7	6,2 a	5,3 a	1,2 a	3,1 b	9,7	68 a	55 a	12 a	4,5 a
T8	6,3 a	4,7 a	1,3 a	2,6 b	8,7	70 a	54 a	15 a	3,6 b
CV	2,4	13,6	23,3	23,5	11,7	9,7	21,43	12,1	23,8

Treatments: T1 – Control – no liming; T2 – V% 75, surface-applied (Dolomitic); T3 – V% 100, surface-applied (Dolomitic); T4 – V% 150, surface-applied (Dolomitic); T5 – % of Ca and Mg in CEC to 80%, surface-applied (60% and 20%); T6 – % of Ca and Mg in CEC to 100%, surface-applied (75% and 25%); T7 - V% 150, 50% surface-applied (Calcitic) on 09/26/2018 and 50% surface-applied (Dolomitic) on 07/27/2019; T8 - V% 150, 50% deeply incorporated (Calcitic) and 50% surface-applied (Dolomitic). Treatments with the same letter do not differ statistically according to the Scott-Knott method at a 10% probability level.

Table 3. Effect of liming on pH, calcium (Ca); magnesium (Mg); potential acidity (H+Al), base saturation (V); Ca/Mg ratio; and % of Ca and Mg in potential CEC, in samples collected after the soybean harvest in February 2022, approximately 41 months after liming.

Treat.	pH	Ca	Mg	H+Al	CEC	V	$Ca/_{CEC}$	$Mg/_{CEC}$	Ca/Mg
		$cmol_c\ dm^{-3}$				%			
0-10 cm (41 months)									
T1	5,6 d	3,2 d	0,9 c	4,7 a	8,8	47 d	36 d	10 d	3,8 b
T2	6,0 c	3,4 d	1,4 b	3,3 c	8,1	60 c	42 c	17 b	2,5 c
T3	6,1 c	4,0 c	1,6 a	3,5 b	9,3	62 c	43 c	17 b	2,5 c
T4	6,4 b	3,9 c	1,9 a	2,6 c	8,5	69 b	46 c	22 a	2,1 c
T5	6,2 b	3,8 c	1,1 c	2,8 c	7,7	64 c	49 c	14 c	3,6 b
T6	6,4 b	4,5 b	1,2 b	2,7 c	8,5	69 b	53 b	14 c	3,8 b
T7	6,5 b	4,8 b	1,1 c	2,5 c	8,5	71 b	57 b	13 c	4,5 a
T8	6,8 a	5,8 a	1,3 b	2,0 c	9,2	80 a	65 a	14 c	4,9 a
CV	3,61	10,14	15,97	24,31	9,77	10,45	11,92	13,13	17,83
10-20 cm (41 months)									
T1	5,4 c	2,1 d	0,5 c	4,7	7,5	37 c	29 c	7 c	4,1 b
T2	5,5 c	2,1 d	0,8 b	4,0	7,0	43 c	30 c	11 b	2,7 c
T3	5,5 c	2,3 d	0,8 b	4,6	7,8	41 c	29 c	11 b	2,8 c
T4	5,7 c	2,3 d	1,1 a	3,7	7,2	48 b	32 c	15 a	2,1 c
T5	5,8 b	2,6 c	0,7 c	3,6	7,0	48 b	38 c	9 b	4,0 b
T6	5,8 b	2,9 c	0,8 b	3,8	7,5	49 b	40 c	10 b	3,7 b
T7	5,9 b	3,4 b	0,8 b	3,9	8,0	52 b	42 b	9 b	4,5 b
T8	6,2 a	4,4 a	0,9 b	3,2	8,5	64 a	53 a	10 b	5,3 a
CV	4,64	15,49	19,84	21,26	11,77	15,75	17,83	17,45	19,85
0-20 cm (41 months)									
T1	5,5 c	2,7 d	0,7 d	4,7 a	8,1	42 d	32 c	8 d	3,9 b
T2	5,8 c	2,8 d	1,1 c	3,6 b	7,6	52 c	36 c	14 b	2,6 c
T3	5,8 c	3,2 d	1,2 b	4,1 a	8,5	51 c	36 c	14 b	2,6 c
T4	6,0 b	3,1 d	1,5 a	3,2 b	7,8	59 b	39 c	19 a	2,1 c
T5	6,0 b	3,2 d	0,9 d	3,2 b	7,3	56 b	43 c	11 c	3,8 b
T6	6,1 b	3,7 c	1,0 c	3,2 b	8,0	59 b	46 b	12 c	3,8 b
T7	6,2 b	4,1 b	0,9 c	3,2 b	8,3	61 b	49 b	11 c	4,5 a
T8	6,5 a	5,1 a	1,1 c	2,6 b	8,9	72 a	59 a	12 c	5,1 a
CV	3,75	11,23	16,04	21,6	10,14	12,25	14,07	13,84	18,3

Treatments: T1 – Control – no liming; T2 – 75% surface-applied (Dolomitic); T3 – 100% surface-applied (Dolomitic); T4 - V% 150, surface-applied (Dolomitic); T5 - % of Ca and Mg in CEC to 80%, surface-applied (60 and 20%); T6 - % of Ca and Mg in CEC to 100%, surface-applied (75 and 25%); T7 - V% 150, 50% surface-applied (Calcitic) on 09/26/2018 and 50% surface-applied (Dolomitic) on 07/27/2019; T8 - V% 150, 50% deeply incorporated (Calcitic) and 50% surface-applied (Dolomitic). Treatments with the same letter do not differ statistically according to the Scott-Knott method at a 10% probability level.

Moraes et al., 2023). The greatest responses in 2021 and 2022 coincide with the time required for lime reaction. Caires et al. (2000) observed a more pronounced increase in V% values only 28 months after surface liming, and Chapla (2017), in the same region as this study, found an average V% of 42% at 10 months and 53% as early as 22 months after surface liming. However, due to acidification caused by nitrogen fertilizers used in maize crops and annual harvests, there is a reduction in pH and base saturation over time (Caires, 2013; Cecagno et al., 2019).

V% values of up to 78% were observed in 2019, even in treatments where the recommended lime rates exceeded the amount needed to achieve 100% base saturation. Note that pH values did not exceed 6.5 for the 0–20 cm layer even at the highest rates. Even when considering only the 0–10 cm layer, V% values of up to 80% were observed in 2022.

Ca/Mg ratio was narrower (<3:1) in treatments where 2.7 to 8.7 t ha^{-1} of dolomitic lime was applied, consistent with Caires (2013). The literature emphasizes that the Ca/Mg ratio is of little importance for crop production within a wide range of 0.5:1 to 30:1, provided that the levels of these nutrients in the soil are not close to the deficiency threshold (Quaggio & Raij, 2022).

The reaction of the liming material was faster in treatments with calcitic lime, demonstrating that the reaction depends on conditions such as moisture, temperature, soil chemical characteristics, and the chemical and physical properties of the corrective (Rodrighero et al., 2015; Moraes et al., 2023; Santos et al., 2024), a factor linked to the characteristics of the rock from which the soil amendment originates. The faster reaction of calcitic lime is attributed to the lower hardness of the rock from which it is obtained, which explains the more immediate responses. Dolomitic lime reacts more slowly due to the greater stability of dolomite (Barber, 1984).

Soybean Production and Productivity Factors

In the first evaluation, 18 months after liming, plant density (PD) was lower in the absence of liming, a result of soil chemical conditions such as acidity and lower availability of Ca and Mg, which influence seed germination and crop establishment. Ca deficiency impairs biological N fixation, as Ca is essential for nodulation; it also acts at growth points, and its deficiency causes root atrophy, petiole collapse, and death of the apical bud (Malavolta et al., 1997). Mg, in addition to being a constituent of chlorophyll, is an enzyme activator and a cofactor for phosphorylating enzymes; its deficiency causes reduced root penetration and expansion. The number of seeds per plant (NSP) was lower in the absence of liming (83.8 grains), which, combined with lower PD and thousand-seed weight (TSW), significantly reduced productivity to 3.94 t ha^{-1} in the 2019/20 crop (Table 4).

Appropriate Ca concentrations (>3.2 cmolc dm^{-3}), with a Ca/Mg ratio greater than 3:1, promoted PD, TSW, and NSP, leading to better results in treatments where more than 50% of the application was via calcitic lime (3.4–5.3 t ha^{-1}), with a yield of 5.2 t ha^{-1}, a result 32% higher than the control and 18% higher than the traditional recommendation. Joris et al. (2016) also associated higher Ca levels with root development and photosynthesis.

In the 2020/21 harvest, there were no significant results for TSW (179.2 g) and NSP (117.6) following the application of 3.4 t ha^{-1} of calcitic lime and 2.7 t ha^{-1} of dolomitic lime, an increase in Ca and Mg saturation in CEC_{pH7} to 75% and 25%, respectively, which resulted in a yield of 4.57 t ha^{-1}, 0.9 t ha^{-1} higher than the control treatment. In the 2021/22 harvest, the treatments that received only dolomitic lime stood out, yielding 4.91 t ha^{-1}, approximately 520 kg more, justifying the use of lime after three crops and demonstrating the effect of dolomitic lime, which has a slower reaction and long-term effect.

Liming with rates higher than those traditionally applied increases average yield. When analyzing the three soybean crops, the treatment that received 3.4 t ha^{-1} of calcitic lime and 2.7 t ha^{-1} of dolomitic lime produced 4.71 t ha^{-1} (78.5 bags per hectare, or sc ha^{-1}), with % Ca and %Mg in CEC_{pH7} close to 45–50% and 12–14%, respectively, and Ca/Mg at 3.7:1. In the absence of soil corrections, yield was only 4.0 t ha^{-1} (66.6 sc ha^{-1}), indicating a gain of ~35 sc ha^{-1} over three years (Table 4). It should also be noted that, after three crops, there was no difference in soybean yield whether or not the corrective agent was incorporated, corroborating the findings of Joris et al. (2016). Thus, the increase in lime application rates after three crops is justified, supported by good Ca and Mg levels, V% >60, a Ca/Mg ratio >3:1, and higher yields. Compared to the traditional recommendation (2.7 t ha^{-1} of dolomitic lime), which yielded an average productivity of 4.34 t ha^{-1} over three crops, versus the most productive treatment, there is a gain of ~18 sc ha^{-1} at the end of the three years. Literature highlights the positive effect of liming, even when applied superficially, on soybean and maize yields. In soil already under agricultural use, rates higher than those recommended have proven viable (Rodrighero et al., 2015; Costa et al., 2016; Crusciol et al., 2016; Joris et al., 2016; Esper Neto et al., 2019; Moraes et al., 2023). All treatments that received rates higher than the recommended yielded more than 4.4 t ha^{-1}.

Maize Production and Productivity Factors

Thousand-kernel weight (TKW), kernels per ear (KPE), and grain yield (GY) were affected by the treatments (Table 5). Larger kernels are directly associated with higher maize yields (Lange et al., 2024). Normally, this behavior is linked to better utilization of K; however, in the present study, in no situation did the treatments influence soil K, nor was there a correlation between K and yield (Table 6).

In 2019, there was no significant difference among the treatments, a result of the reduced interval between liming and cultivation (Chapla, 2017; Moraes et al., 2023). In the 2020 and 2021 crops, as well as the final average grain yield (AGY) across the three crops, significant gains were observed due to liming. In 2020, the highest yield (8.38 t ha^{-1}) was observed with the application of 8.7 t ha^{-1} of dolomitic lime on the soil surface. In 2021, the AGY for all liming treatments exceeded the control, which

Table 4. Effect of liming on plant density (PD), seeds per plant (SPP), thousand-seed weight (TSW), grain yield (GY), and three-year average grain yield (AGY) of soybeans for the 2019/20 (18 months after liming), 2020/21 (30 months after liming), and 2021/22 (41 months after liming) crops. Querência – MT.

Treat.	PD	SPP	TSW	GY	PD	SPP	TSW	GY	PD	SPP	TSW	GY	AGY
	thous.	-	g	Mg ha^{-1}	thous.	-	g	Mg ha^{-1}	thous.	-	g	Mg ha^{-1}	Mg ha^{-1}
	2019/20				2020/21				2021/22				
T1	230,0 b	83,8 d	186,0 b	3,94 d	220,3	88,7	167,3	3,67	372,8	86,4	134,2	4,39 b	4,00 c
T2	245,3 a	90,7 c	188,2 a	4,38 c	200,5	99,3	176,9	3,98	395,0	86,5	135,1	4,65 a	4,34 b
T3	246,3 a	86,3 d	188,6 a	4,32 c	212,8	87,5	189,4	4,20	386,3	89,2	137,6	4,59 a	4,37 b
T4	236,8 b	90,4 c	183,5 b	4,43 c	208,8	106,5	179,4	4,14	390,0	86,7	136,0	4,91 a	4,49 b
T5	237,3 b	94,7 b	184,0 b	4,60 b	219,3	101,3	171,2	3,86	383,3	84,2	133,2	4,41 b	4,29 b
T6	231,3 b	107,9 a	188,5 a	5,20 a	195,0	117,3	179,2	4,57	380,3	84,3	132,9	4,35 b	4,71 a
T7	243,5 a	96,0 b	187,0 a	4,72 b	210,3	101,0	186,0	4,04	390,8	86,7	135,5	4,49 b	4,42 b
T8	244,3 a	98,5 b	185,1 b	4,72 b	200,5	104,2	170,9	4,14	377,3	85,6	131,9	4,32 b	4,39 b
MD	239,3	93,5	186,4	4,54	208,4	100,7	177,5	4,07	384,4	86,2	134,6	4,52	4,38
CV	3,87	3,61	1,02	2,56	9,16	12,37	6,11	8,52	6,89	14,60	2,10	5,6	3,16

Treatments: T1 – Control – no liming; T2 – 75% surface-applied (Dolomitic); T3 – 100% surface-applied (Dolomitic); T4 - V% 150, surface-applied (Dolomitic); T5 - % of Ca and Mg in CEC to 80%, surface-applied (60 and 20%); T6 - % of Ca and Mg in CEC to 100%, surface-applied (75 and 25%); T7 - V% 150, 50% surface-applied (Calcitic) on 09/26/2018 and 50% surface-applied (Dolomitic) on 07/27/2019; T8 - V% 150, 50% deeply incorporated (Calcitic) and 50% surface-applied (Dolomitic). Treatments with the same letter do not differ statistically according to the Scott-Knott method at a 10% probability level.

Table 5. Effect of liming on the number of kernels per ear (NKE), thousand-kernel weight (TKW), plant density (PD), grain yield (GY), and cumulative yield over three crops (CY) of maize for the 2019, 2020, and 2021 crops. Querência – MT.

Treat.	NKE	TKW	PD	GY	NKE	TKW	PD	GY	NKE	TKW	PD	GY	CY
		g	thous.	Mg ha^{-1}		g	thous.	Mg ha^{-1}		g	thous.	Mg ha^{-1}	Mg ha^{-1}
	2019				2020				2021				
T1	587,6	279,9	42,8	6,49	506,4 b	275,0 a	49,0	6,75 d	428,1	289,9 a	58,0	6,45 b	6,56 b
T2	610,4	274,3	43,6	6,80	518,3 b	263,3 b	51,4	8,28 a	432,9	284,3 a	57,8	7,15 a	7,41 a
T3	580,3	276,1	45,3	6,88	508,3 b	283,3 a	49,4	7,28 c	421,4	296,0 a	56,8	7,46 a	7,21 a
T4	583,6	270,9	45,3	6,73	538,4 a	262,5 b	53,6	8,38 a	428,4	289,2 a	58,0	7,31 a	7,47 a
T5	582,6	261,1	45,8	6,90	497,9 b	262,5 b	51,0	8,15 a	429,6	258,8 b	58,3	7,57 a	7,54 a
T6	565,4	267,6	46,1	6,70	499,5 b	275,0 a	50,0	7,88 b	446,4	265,9 b	57,0	7,31 a	7,29 a
T7	605,9	277,2	43,3	6,75	516,2 b	277,5 a	50,4	7,68 b	465,2	263,9 b	56,8	7,40 a	7,28 a
T8	591,7	274,4	49,2	6,99	541,9 a	267,5 b	49,4	8,17 a	445,3	286,9 a	55,5	7,34 a	7,50 a
MD	588,4	272,7	45,2	6,77	515,9	270,8	50,5	7,82	437,1	279,4	57,3	7,25	7,28
CV	5,38	4,18	9,35	6,70	3,75	4,55	7,68	4,30	8,69	7,59	3,84	7,23	3,57

Treatments: T1 – Control – no liming; T2 – 75% surface-applied (Dolomitic); T3 – 100% surface-applied (Dolomitic); T4 - V% 150, surface-applied (Dolomitic); T5 - % of Ca and Mg in CEC to 80%, surface-applied (60 and 20%); T6 - % of Ca and Mg in CEC to 100%, surface-applied (75 and 25%); T7 - V% 150, 50% surface-applied (Calcitic) on 09/26/2018 and 50% surface-applied (Dolomitic) on 07/27/2019; T8 - V% 150, 50% deeply incorporated (Calcitic) and 50% surface-applied (Dolomitic). Treatments with the same letter do not differ statistically according to the Scott-Knott method at a 10% probability level.

Table 6. Pearson correlation coefficients between the parameters assessed in soybean and maize crops (average yield from three crops) and soil variables (average from four sampling periods at 0–20 cm). .

	Soybean	Maize	pH	P	K^+	Ca^{2+}	Mg^{2+}	H+Al	CEC	V	Ca/Mg	Ca	Mg
Soybean	1,000												
Maize	0,427*	1,000											
pH	0,506***	0,612***	1,000										
P	-0,309	-0,171	-0,112	1,000									
K^+	-0,297	0,153	0,161	0,227	1,000								
Ca^{2+}	0,274	0,392*	0,798***	0,242	0,141	1,000							
Mg^{2+}	0,347	0,407*	0,434*	0,150	0,032	0,270	1,000						
H+Al	-0,499***	-0,521***	-0,806***	0,355*	0,247	0,247*	-0,211	1,000					
CEC	-0,153	-0,058	-0,005	0,550***	0,609***	0,609***	0,299	0,579***	1,000				
V	0,517***	0,587***	0,977***	-0,144	0,049	0,711**	0,399*	-0,895***	-0,163	1,000			
Ca/Mg	-0,148	-0,135	0,139	0,018	0,289	0,420*	-0,741***	-0,026	0,083	0,100	1,000		
%Ca	0,397*	0,473***	0,920***	-0,113	0,141	0,789***	0,085	-0,815***	-0,121	0,932***	0,443*	1,000	
%Mg	0,411*	0,440*	0,441*	-0,091	-0,252	0,023	0,883***	-0,486***	-0,173	0,482***	-0,805***	0,138	1,000

*, **, ***: Significant at 5%, 1% and 0.1%, respectively, according to the F-test (P < 0,05, 0,01 e 0,001).

yielded ~6.5 t ha^{-1}, while the liming treatments yielded ~7.4 t ha^{-1}. These results are due to the time elapsed between the application of the corrective agent and its subsequent reaction, which provided several benefits, including increased availability of Ca and Mg, reduced pH, and improved root development and utilization of water and nutrients, directly reflecting on yield (Rodrighero et al., 2015; Costa et al., 2016; Crusciol et al., 2016; Moraes et al., 2023).

Correlations

Pearson's correlation test confirms that soil chemical properties, particularly those related to soil acidity (pH, Ca, and Mg, V%, and % of Ca and Mg in CEC_{pH7}), influenced crop yield, with an increase in grain yield resulting from pH correction. The improvement in soil chemical quality, as shown by the values for pH (~6.5), Ca (4.0–5.0 $cmol_c$ dm^{-3}), Mg (1.0–1.2 $cmol_c$ dm^{-3}), V% (70–75%), % Ca in CEC_{pH7} (~55%), and %Mg in CEC_{pH7} (~18%), justify the positive results, especially when comparing the application of the corrective agent versus its absence, or with increased rates.

Considerations

Incorporation of part of the lime rate, when higher rates than those traditionally recommended are used, despite improvements in soil acidity-related parameters in relation to surface application, does not result in significant increases in crop yields. Furthermore, only surface application corrects the soil profile after a three-year period. Therefore, it is essential to improve certain soil fertility indicators in the high-yield soybean/maize rotation system in the region, where yields reach 4.5 t ha^{-1} of soybeans and 7.5 t ha^{-1} of maize (12,000 kg ha^{-1} $year^{-1}$) or more, as crop demands have increased each year, raising the need for lime and fertilizers. Furthermore, considering the residual effect of acidity correctives, especially when applied to the surface, takes one full crop to show results. Therefore, the producer must ensure that this input is applied in advance, knowing that Ca, Mg, and V% levels will yield satisfactory results one year after application, thereby preventing soil fertility levels from declining.

Conclusions

The application of lime rates higher than recommended, with half incorporated and half surface-applied, is more effective in increasing pH, Ca, Mg, potential acidity (H+Al), base saturation (V), and the percentage of Ca and Mg in CECpH7.

After three soybean crops, the surface application of 3.4 t ha^{-1} of calcitic and 2.7 t ha^{-1} of dolomitic lime achieved an average V of 60%, with % Ca and Mg in CECpH7 equal to 46 and 12, respectively, and an average yield of 4.71 t ha^{-1}, exceeding the control treatment by 0.71 t ha^{-1}.

The average maize yield, after three crops, regardless of the rate or type of lime applied, exceeded that of the control treatment.

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References

ACOMPANHAMENTO da Safra Brasileira [de] Grãos: safra 2024/25: 8º **levantamento, v. 1**2, n. 8, maio 2025. Brasília, DF: Conab, 2025. Available at: https://www.gov.br/conab/pt-br/atuacao/informacoes-agropecuarias/safras/safra-de-graos/boletim-da-safra-de-graos/8o-levantamento-safra-2024-25/boletim-da-safra-de-graos. Accessed on: 23 May 2026.

BARBER, S. A. Liming materials and practices. In: ADAMS, F. (ed.). **Soil acidity and liming**. Madison: American Society of Agronomy, 1984. v. 2, cap. 4, p. 171-209.

BORTOLUZZI, E. C.; PARIZE, G. L.; KORCHAGIN, J.; SILVA, V. R.; RHEINHEIMER, D. S.; KAMINSKI, J. Soybean root growth and crop yield in reponse to liming at the beginning of a no-tillage system. **Revista Brasileira de Ciência do Solo**, v. 38, n. 1, p. 262-271, 2014. DOI: https://doi.org/10.1590/S0100-06832014000100026.

CAIRES, E. F. **Correção da acidez do solo em sistema plantio direto**. Piracicaba: IPNI, 2013. 13 p. (Informações Agronômicas, 141).

CAIRES, E. F.; BANZATTO, D. A.; FONSECA, A. F da. Calagem na superfície em sistema plantio direto. **Revista Brasileira de Ciência do Solo**, v. 24, n. 1, p. 161-169, 2000. DOI: https://doi.org/10.1590/S0100-06832000000100018.

CECAGNO, D.; COSTA, S. E. V. G. A.; ANGHINONI, I.; BRAMBILLA, D. M.; NABINGER, C. Acidificação do solo sob fertilização nitrogenada de longo prazo em campo nativo com introdução de azevém. **Revista de Ciências Agroveterinárias**, v. 18, n. 2, p. 263-267, 2019. DOI: https://doi.org/10.5965/223811711812019263.

CHAPLA, M. E. **Calagem superficial em área de plantio direto**. 2017. 85 p. Dissertação (Mestrado em Agronomia) – Universidade Federal de Mato Grosso, Sinop, 2017.

COSTA, C. H. M.; CRUSCIOL, C. A. C.; FERRARI NETO, J.; CASTRO, G. S. A. Residual effects of superficial liming on tropical soil under no-tillage system. **Pesquisa Agropecuária Brasileira**, v. 51, n. 9, p. 1633-1642, 2016. DOI: https://doi.org/10.1590/S0100-204X2016000900063.

CRUSCIOL, C. A. C.; MARQUES, R. R.; CARMEIS FILHO, A. C. A.; SORATTO, R. P.; COSTA, C. H. M.; FERRARI NETO, J.; CASTRO, G. S. A.; PARIZ, C. M.;

CASTILHOS, A. M. de. Annual crop rotation of tropical pastures with no-till soil as affected by lime surface application. **European Journal of Agronomy**, v. 80, p. 88-104, 2016. DOI: https://doi.org/10.1016/j.eja.2016.07.002

ESPER NETO, M. E.; CONEGLIAN, C. F.; COSTA, A. C. S.; INOUE, T. T.; BATISTA, M. A. Short-term effects of liming on chemical attributes of tropical sandy soil and soybean (*Glycine max* L.) yield. **Australian Journal of Crop Science**, v. 13, n. 6, p. 889-894, 2019. DOI: https://doi.org/10.21475/ajcs.19.13.06.p1614.

FERREIRA, D. F. Sisvar: um sistema computacional de análise estatística. **Ciência e Agrotecnologia**, v. 35, n. 6, p. 1039-1042, 2011. DOI: https://doi.org/10.1590/S1413-70542011000600001.

JORIS, H. A. W.; CAIRES, E. F.; SCHARR, D. A.; BINI, Â. R.; HALISKI, A. Liming in the conversion from degraded pastureland to a no-till cropping system in southern Brazil. **Soil & Tillage Research**, v. 162, p. 68-77, 2016. DOI: https://doi.org/10.1016/j.still.2016.04.009.

LANGE, A.; ULRICH, T. A.; SANTOS, C. P. A. dos; MAGALHÃES, C. A. de S.; BEHLING, M.; ALVES FILHO, R. C. Evolução dos atributos químicos das análises de solo de Mato Grosso entre anos de 2016 a 2021. **Plantio Direto & Tecnologia Agrícola**, v. 2023, p. 82-91, 2023. Available at: https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1161902/1/2023-cpamt-casm-evolucao-atributo-quimico-analises-solo-mato-grosso-2016-2021.pdf. Accessed on: 23 May 2026.

LANGE, A.; BURATTO, W.; PEREIRA, C. S.; FREDDI, O. S. Sowing and topdressing-split dates in second-crop maize grown in the Cerrado-Amazon region. **Revista Brasileira de Milho e Sorgo**, v. 23, e1345, 2024. DOI: https://doi.org/10.18512/rbms2024v23e1345.

LANGE, A.; CONTESINI, M. E.; MORAES, W. C. P. Curvas de neutralização da acidez de solos na transição Cerrado-Amazônia. **Nativa**, v. 13, n. 2, p. 290-300, 2025. DOI: https://doi.org/10.31413/nat.v13i2.19143.

LOPES, A. S. Recomendações de calagem e adubação no sistema de plantio direto. In: RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ V., V. H. (ed.). **Recomendação para o uso de corretivos e fertilizantes em Minas Gerais**: 5ª aproximação. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais, 1999. p. 93-98.

MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. de. **Avaliação do estado nutricional das plantas**: princípios e aplicações. 2. ed. Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato, 1997. 319 p.

MORAES, F. A.; MOREIRA, S. G.; PEIXOTO, D. S.; SILVA, J. C. R.; MACEDO, J. R.; SILVA, M. M.; SILVA, B. M.; SANCHEZ, P. A.; NUNES, M. R. Lime incorporation up to 40 cm deep increases root growth and crop yield in highly weathered tropical soils. **European Journal of Agronomy**, v. 144, e126763, 2023. DOI: https://doi.org/10.1016/j.eja.2023.126763.

PETROLI, V. **Número de usinas de etanol de milho pode subir para 19 unidades em MT, prevê Sedec**. 2023. Available at: https://matogrosso.canalrural.com.br/agricultura/milho/numero-de-usinas-de-etanol-de-milho-pode-subir-para-19-unidades-em-mt-preve-sedec/. Accessed on: 2 Feb. 2026.

QUAGGIO, J. A.; RAIJ, B. Manejo da acidez do solo. In: CANTARELLA, H.; QUAGGIO, J. A.; MATTOS JÚNIOR, D.; BOARETTO, R. M.; RAIJ, B. van (org.). **Boletim 100**: recomendações de adubação e calagem para o estado de São Paulo. 3. ed. Campinas: IAC, 2022. p. 61-83.

RHEINHEIMER, D. S.; TIECHER, T.; GONZATTO, R.; ZAFAR, M.; BRUNETTO, G. Residual effect of surface-applied lime on soil acidity properties in a long-term experiment under no-till in a Southern Brazilian sandy Ultisol. **Geoderma**, v. 313, p. 7-16, 2018. DOI: https://doi.org/10.1016/j.geoderma.2017.10.024.

RODRIGHERO, M. B.; BARTH, G.; CAIRES, E. F. Aplicação superficial de calcário com diferentes teores de magnésio e granulometrias em sistema plantio direto. **Revista Brasileira de Ciência do Solo**, v. 39, n. 6, p. 1723-1736, 2015. DOI: https://doi.org/10.1590/01000683rbcs20150036.

SÁ, J. C. M. Manejo da fertilidade do solo no sistema plantio direto. SIQUEIRA, J. O.; MOREIRA, F. M. S.; LOPES, A. S.; GUILHERME, L. R. G.; FAQUIN, V.; FURTINI NETO, A. E.; CARVALHO, J. G. (ed.). **Inter-relação fertilidade, biologia do solo e nutrição de plantas**. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; Lavras: Universidade Federal de Lavras, 1999. p. 267-310.

SANTOS, D. R. dos; TIECHER, T.; GONZATTO, R.; SANTANNA, M. A.; BRUNETTO, A. G.; SILVA, L. S. da. Long-term effect of surface and incorporated liming in the conversion of natural grassland to no-till system for grain production in a highly acidic sandy-loam Ultisol from South Brazilian Campos. **Soil & Tillage Research**, v. 180, p. 222-231, 2018. DOI: https://doi.org/10.1016/j.still.2018.03.014.

SANTOS, F. C.; RESENDE, A. V. de; SOARES, J. R.; VIANA, J. H. M.; SANTANA, M. L. T.; MOREIRA, S. G.; ALBUQUERQUE FILHO, M. R. de. Limestone reaction in sandy soil: rate effects, limestone type, moisture regime, and time. **Agrosystems Geosciences & Environment**, v. 7, n. 4, e70008, 2024. DOI: https://doi.org/10.1002/agg2.70008.

SILVA, L. A. **Calagem incorporada ao final do período chuvoso, em área de abertura, em Mato Grosso**. 2023. 40 p. Dissertação (Mestrado em Agronomia) – Universidade Federal de Mato Grosso, Sinop, 2023.

SOUSA, D. M. G. de; LOBATO, E. Correção da acidez do solo. In: SOUSA, D. M. G.; LOBATO, E. (ed.). **Cerrado**: correção do solo e adubação. 2. ed. Brasília, DF: Embrapa Informação Tecnológica; Planaltina: Embrapa Cerrados, 2004. p. 81-96.

TECNOLOGIAS de produção de soja - Região Central do Brasil 2014. Londrina: Embrapa Soja, 2013. 265 p. (Embrapa Soja. Sistemas de Produção, 16). Available at: https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/975595/1/SP16online.pdf. Accessed on: 21 May 2026.

TEIXEIRA, P. C.; DONAGEMMA, G. K.; FONTANNA, A.; TEIXEIRA, W. G. (ed.). **Manual de métodos de análise de solo**. 3. ed. rev. e ampl. Brasília, DF: Embrapa, 2017. 574 p.