Over-liming in the construction of the fertility of red yellow latosol with different phosphorus sources

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Authors' contributions:

This work was carried out in collaboration between all authors. JSSC and LCM performed data collection in the field, statistical analysis, wrote the protocol and wrote the first draft of the manuscript. JHSL, EVR and GAF managed the study analysis, data analysis and helped in the execution of the project. BHDNN and HPO managed searches in the literature, translation of the manuscript, all revisions and general corrections together with GCA and RRSguided the students during the work. All authors read and approved the final manuscript

ABSTRACT—*The availability of P in Cerrado soils is a limiting factor for the satisfactory development of crops. It is known that the efficiency of phosphate fertilization is low and depends on several factors, such as solubility of fertilizers, soil texture, and soil acidity. Thus, the objective of this work was to evaluate the availability of phosphorus as a function of different phosphate sources under the influence of pH, as well as to determine its fertilization efficiency in a red latosol. The experiment was carried out in a greenhouse at Tocantins federal university, in DIC, was used, in a 3 x 5 + 1 scheme. A red-yellow Latosol was used and three sources of phosphate fertilization were evaluated: Mono-ammonic phosphate - MAP, single superphosphate - SS and Natural phosphate - FN, plus one treatment without fertilization, in five evaluation periods (0, 7, 14, 21 and 28 days). Therefore, the pH in $CaCl_2$ of the soil stabilized between (5.5 – 6.5) in approximately 83 days of incubation with the acidity concealer. The SS and MAP phosphate fertilizers promoted the highest available P contents, with 6.32 and 6.23 mg.d m^{-3}, respectively. The use of FN showed low P levels during the evaluated incubation period, mainly due to its lower solubility.*

Keywords— adsorption, fertilization efficiency, soil incubation

1. INTRODUCTION

The Cerrado is the second largest Brazilian biome, covering about 25% of the total area of Brazil [1]. Through the intensive use of knowledge and technology, the agricultural frontier is expanding and, in this scenery, the Cerrado gains prominence in the conjuncture of the national agribusiness, especially the Maranhão, Piaui, Tocantins and Bahia (MATOPIBA) region, the most recent Brazilian agricultural frontier [2]. Approximately 80 million hectares (40% of the total Cerrado area) have been cultivated with different types of land use, such as cultivated pastures and agricultural crops, in which soybean presents itself as the main culture responsible for the expansion of agribusiness in this region [3].

According to the last survey of Conab (2018) [2], soybean production in the Cerrado represents 78% of the amount produced in Brazil. The region comprised of Maranhão, Tocantins, Piauí, and Bahia (MATOPIBA) is responsible for 12% of Brazilian production, with the expected increase in the coming

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years.

The soil classes with the highest representatives of the region are the Latosols, Neossols, Argissols, Plinthosols, lytic soil and Cambisols [4]. Of these, the Latosols class occupies the largest territorial extension reaching 46% of the total Cerrado area, with great potential for agriculture [5, 6]. The Latosols comprise soils that present an advanced stage of tempering, consisting of mineral material, with a horizon diagnosis of the Latosol B immediately below any of the types of horizons, except the hystic. Generally, acidic soils, low clay content, low organic matter content, present colloidal material with low ability to exchange cations (CTC) and low natural fertility, emphasizing phosphorus (P) and potassium (K) [4].

The amount of available nutrients found in the soils in the form available to plants is one of the main study objectives when it comes to evaluating soil fertility. However, the construction of soil fertility is not easy, because there is a great complexity of the processes that involve the dynamics of nutrients in the soil-solution-plant system [7].

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Among the factors influencing soil fertility, acidity is a limiting factor in plant growth. Whenever the pH is low (acidity is high), one or more harmful effects may affect crop growth. For practical purposes, the pH considered appropriate for the majority of plants cultivated in Brazil is in the range between 6.0 and 6.5. Therefore, as the mineralogy of Brazilian soils are generally acidic, the use of liming stands out, which in turn allows the majority of essential nutrients to be readily available [8].

Liming and phosphate fertilization are practices used in the management of fertility, where the yield of crops is raised, especially in the regions where acidic and deficient soils in phosphorus are excelled [9]. The correction made with limestone elevates the contents of Ca and Mg, decreasing or even eliminating the exchangeable Al, and with this practice increases the negative loads in these soils. These chemical alterations that occur in the soil may, however, influence some physical properties of the soil, by altering the electrochemical behavior of the colloids [10].

Phosphorus is one of the macro-nutrients less demanded by plants, but its low availability in the soil limits production, mainly in annual crops. More than 90% of the soil analyses in Brazil show a deficiency of this nutrient, with emphasis on the Cerrado soils, where the contents of this element are even smaller, reaching the worrying values of 1 mg dm^{-3} [11]. The P dynamics in Cerrado soils is quite complex due to its chemical characteristic, favoring great interaction with the soil, such as P adsorption to Fe and Al Oxy-hydroxides, which are predominant in the Latosols, which is the most representative class of soil in tropic regions [12]. This process can reduce the efficiency of phosphate fertilization by 70% and thus the use of high fertilizer dosages [5].

Currently, there are numerous fertilizers available on the market, which have differentiated solubility, as well as agronomic efficiency [13]. In addition, the efficient use of fertilizer can, in addition to providing greater productivity, reduce production costs and reflect on a positive margin at the end of the harvest.

Therefore, different studies are being developed to improve the quality and efficiency of fertilizers, in order to decrease losses in the field [14].

According to Sousa & Lobato (2004) [15] the quality of the fertilizer used, soil type, an epoch of application, a form of application, uniformity of fertilizer application, are factors that when associated with soil moisture and management of the field interfere in fertilization efficiency.

Therefore, knowledge of phosphorus availability in Cerrado soils is of great importance for the measurement of fertility, seeking the best sources for the phosphate fertilization required to supply the needs of the crops, taking into account the interaction of nutrients with the soil. Therefore, the objective of the study was to evaluate the availability of phosphorus as a function of different phosphate sources under pH influences, as well as to determine its efficiency in a red-yellow latosol.

2. MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the University Federal of Tocantins (UFT), campus Gurupi, located in the southern region of the state of Tocantins, with the coordinates: 11 ° 44’44" S and 49 ° 03’ 04" W. The soil used for the conduction of this assay was a red-yellow Latosol [4], which was collected in the depth of 0 – 20 cm in the experimental farm of the UFT. The physical and chemical attributes were determined according to [16] in the Soil Laboratory - UFT (Table 1).

Table 1. Chemical and Physical (0 – 20 cm) initial attributes of the red-yellow latosol. Gurupi – TO, 2018.

Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	CTC(T)	SB	CTC(t)		K	P	
		..............................cmol$_c$ dm^{-3}..............................						....mg dm^{-3}....		
0,66	0,43	0,12	2,78	3,92	1,14	1,26		18	1,04	
V	M	Organic matter.	pH $CaCl_2$	Sand	Silt	Clay	Cu	Zn	Fe	Mn
.....................(%).................				.........Texture (%)........				....mg dm^{-3}....		
29,1	9,52	2,57	4,73	49,02	13,6	37,39	0,4	0,54	42,31	5,72

A completely randomized experimental design (CRD) was used, in a 3 x 5 + 1 scheme, where three sources of phosphate fertilization were evaluated: Mono-ammonium-phosphate - MAP (N - 11%, P_2O_5- 45%), single superphosphate — SS (P_2O_5 - 18%, Ca — 18%, S — 11%) and rock phosphate - FN (P_2O_5 - 7.5%, CaO — 4%, MgO — 0.5%, Si — 4%), with five replications and in five evaluation periods (0, 7, 14, 21 and 28 days), in addition to a treatment without fertilization (control). The dosage of P_2O_5 and Fritted Trace Elements (FTE) Brazil (BR) 12 (9% Zn — 1.8% B — 0.8% Cu — 2% Mn — 3.5% Fe — 0.1% Mo) were fixed in 120 kg ha^{-1} e 100 kg ha^{-1} for all sources, respectively.

The experiment was carried out in plastic bags with 1 kg of soil previously passed through a 2 mm sieve. Subsequently, dolomitic limestone (30% CaO, 18% — MgO — PRNT = 97.55%) was applied, and gypsum (30.70% CaO and 19.40% S). The lime and gypsum dosages used were 6 t ha^{-1} and 1.8 t ha^{-1}, respectively, according to calibrated dosage in work performed by [17]. The soil was incubated for 55 days until the complete reaction of limestone and plaster, during this period the humidity was maintained

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at ideal levels, by adding distilled water, containing 5 ml, whenever necessary. Subsequently, phosphate fertilization (MAP, SS, and FN) was added in each plot and soon after a new incubation cycle was performed for another 30 days.

The evaluated characteristics were the pH values ($CaCl_2$) and the P content in the soil. Soil sampling for the evaluations was performed before fertilization (0 days), at 7, 21 and 28 days after fertilization (DAA), which represents the days 55, 62, 69, 76 and 83 days after the beginning of the experiment. The soil was forwarded to the soil laboratory of the UFT and prepared as TFSA for the chemical analysis of P ($Mehlich^{-1)}$) and also the pH values ($CaCl_2$). The total P and pH ($CaCl_{2)}$ analyses were performed according to the methodology proposed by Embrapa (2017) [16].

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The data obtained will be submitted to variance analysis and later the media will be compared by Tukey's test using the Software Sisvar 6.5 [18] adopting 1 and 5% probability of error. The graphics will be plotted using the program SigmaPlot version 10® [19].

The fertilization efficiency with the sources was calculated based on Eq. 1.

$$\text{Efic.}\,(\%) = \frac{(\text{P initial} - \text{P added})}{\text{P sample}} * 100 \qquad \text{Eq.1}$$

Where: P_{sample} P content available after treatments (mg/dm^{-3}),
$P_{initial}$ P content available in the initial condition (mg/dm^{-3}) and
P_{added} P dosage of applied p (26.20 mg/dm^{-3}).

3. RESULTS AND DISCUSSION

The analysis of variance and significance level, as well as the general mean and coefficient of variation for the characteristics P content and pH values, is presented in Table 2. For P contents, there was a significant effect ($p \leq 0.01$) for sources of variation, sources, epoch and interaction, and between source and epoch. The same result was observed for the pH values, except for the source. There is a low coefficient of variation for P and pH values in this study, which, according to Silva *et al.*, (2010) [20], demonstrates homogeneous results for both traits.

Table 2. Analysis of variance, level of significance, general mean and coefficient of variation related to phosphorus content (p), and pH as a function of phosphate fertilizer sources (MAP, SS and FN, and 120 kg $there^{-1}$ of $P_2 0_5$), Gurupi-TO, 2018.

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Features	Source of variation				General average	C.V. (%)
	Sources	Epoch	Source x Epoch	Waste		
	Degree of freedom					
	3	4	12	80		
P	162,54**	62,7**	10,88**	9,82	4,07	8,6
pH	0,009^{ns}	2,92**	0,03**	0,007	6,75	1,25

C.V.: Coefficient of variation. * *: Significant at level 1% probability ($P \leq 0.01$); *: Significant at 5% probability level ($0.01 \leq p < 0.05$); ^{NS}: Non-significant ($p \geq 0.05$) by F test.

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The soil pH ($CaCl_2$), regardless of the source of P applied, obtained a quadratic response due to the days of evaluation after the liming with 6 t ha^{-1} (Figure 1). The phosphate sources did not influence the soil pH, because the values in these treatments are equal to the values found for the treatment without application of P. The pH ($CaCl_2$) of the soil increased on average up to 72 days after the liming (6 t ha^{-1}), and thus obtained an increase of 29.8% in relation to the beginning of the experiment.

Liming provided neutralization of soil acidity and it was verified that despite the decrease of pH with 72 days, the applied lime continued reacting the acidity until the end of incubation, this happens due to the buffer power of the soil that has strong capacity of to resist pH change, according to Lopes (1995) [8].

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Soil pH is of fundamental importance because it determines the availability of nutrients contained in the soil or added to it and also the assimilation of nutrients by the plants. Therefore, liming is a decisive factor in the efficiency of fertilization, since most Brazilian soils have a considerable degree of acidity [21]. The solubility of phosphate fertilizers is also influenced by soil pH, that is, the degree of acidity determines the flow of P release to the soil solution. For acidulated phosphate fertilizers, such as MAP and SS, the pH range close to neutrality and considered ideal for plants (5.5 – 6.5) is that they present maximum solubility efficiency of P. Already in acidic condition, the nutrient available by these sources are quickly adsorbed by the colloids of the soil, and may not make them available to the plants. Low solubility fertilizers, such as reactive natural phosphates, require the action of H^+ in the soil so that their orthophosphates are released to the solution. Therefore, for the natural phosphates, the increase of the pH to close to neutrality decreases its power of solubilization of P for the solution of the soil [22].

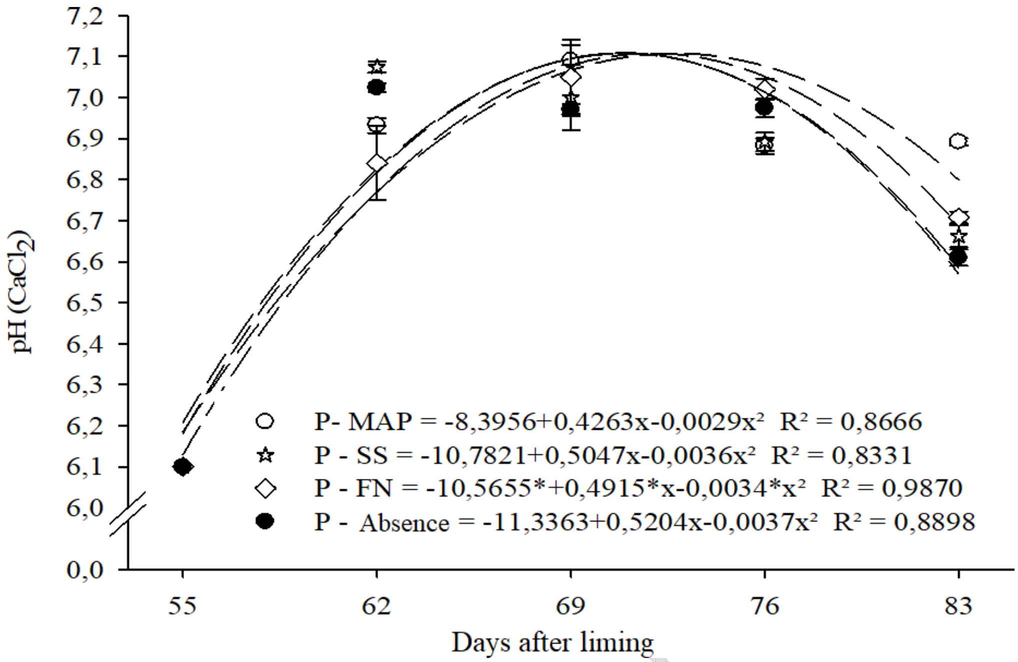

Fig 1. PH values (CaCl) in the different sources of phosphate fertilization (MAP, SS, and FN) as a function of incubation time.

The treatments with the highest P content available in the soil were SS and MAP, with 6.32 and 6.23 mg dm^{-3} of P, respectively, which represents a superiority of 68.35 and 67.89% in relation to the treatment with FN (2.0 $mg.dm^{-3}$). Moreover, the SS and MAP treatments when compared to the treatment without fertilization presented superiority of 72.62 and 72.23%. In relation to the FN, this presented P content available 13.5% higher than the treatment without the addition of P. Regarding P levels in relation to different epochs, the MAP treatment responded significantly. At 7 days after fertilization, P levels were higher than 85.71% in relation to 0 days. However, the nutrient release peak occurred between 14 and 21 days. After 28 days the contents showed a decrease being close to the values recorded on the 7th day.

For the SS, the epoch that presented the highest P contents was at 14, 21 and 28 days, statically equal to each other, these times resulted in an increase of 86.83%, 86.73%, and 86.65% higher when compared to the treatment represented for day zero. Similarly, to the SS, the treatment represented by the FN had a maximum release of P at 14, 21 and 28 days, equal statically, with results 65.20, 64.28 and 63.60% higher than the control, represented by the time zero. It is also worth noting that at 7 days, the P content in the soil did not change, being statistically equal to the control treatment.

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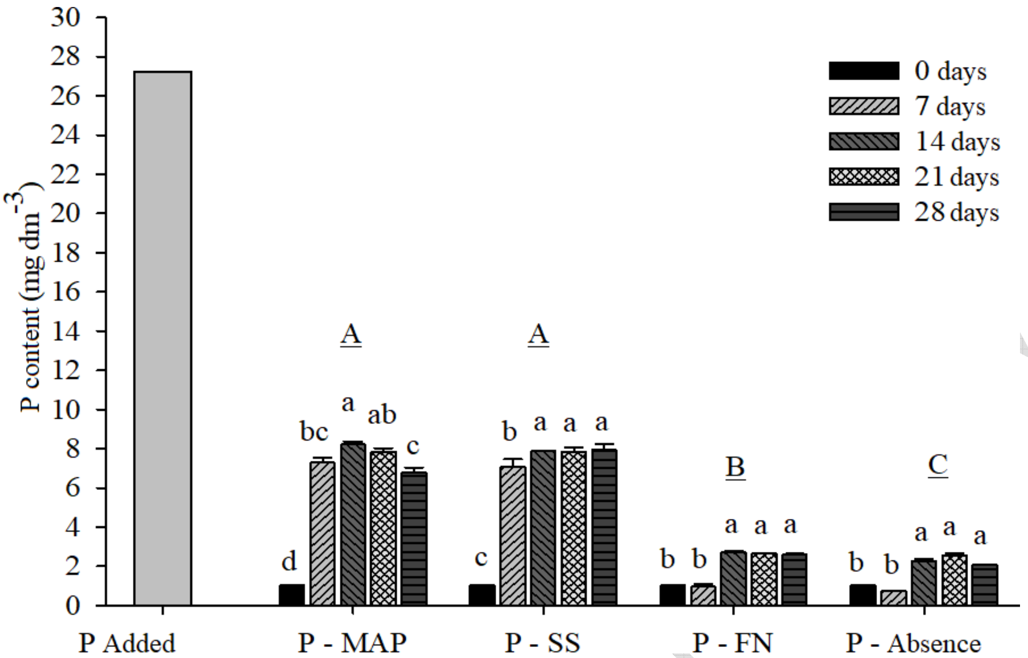

Fig 2. For the phosphorus contents, there was a significant difference between the fertilization sources and the evaluation time.

However, the treatment without fertilization (control), also had positive results at 14, 21 and 28 days, with results 68.28, 71.87, and 65.05% higher when compared to the time 0 days. In relation to the control, there is an increase in P levels as the incubation time increases, the highest levels were observed at 14, 21 and 28 days. There is a small reduction in P levels at 28 days, but this reduction was not statistically significant.

According to Monteiro (2008) [23], the best result presented by the SS in this work may have been due to its high solubility in water and for being a relatively fast action fertilizer. For Reis (2009) [24], this does not happen with FN because it presents low solubility of P in the soil as a function of epoch.

In this study, it was observed that the MAP had a faster phosphorus solubilization behavior with 14 days and the nutrient release peak, followed by a decline in the next 21 and 28 days periods. The SS obtained a higher release with 14 days and maintained the peak release in the period from 21 to 28 days.

Therefore, for the construction of P fertility in this study for the average level, it is necessary to 120 kg of P_2O_5 [25]. For the efficiency of P (Figure 3), there was also a significant difference between the fertilizer sources and the evaluation time.

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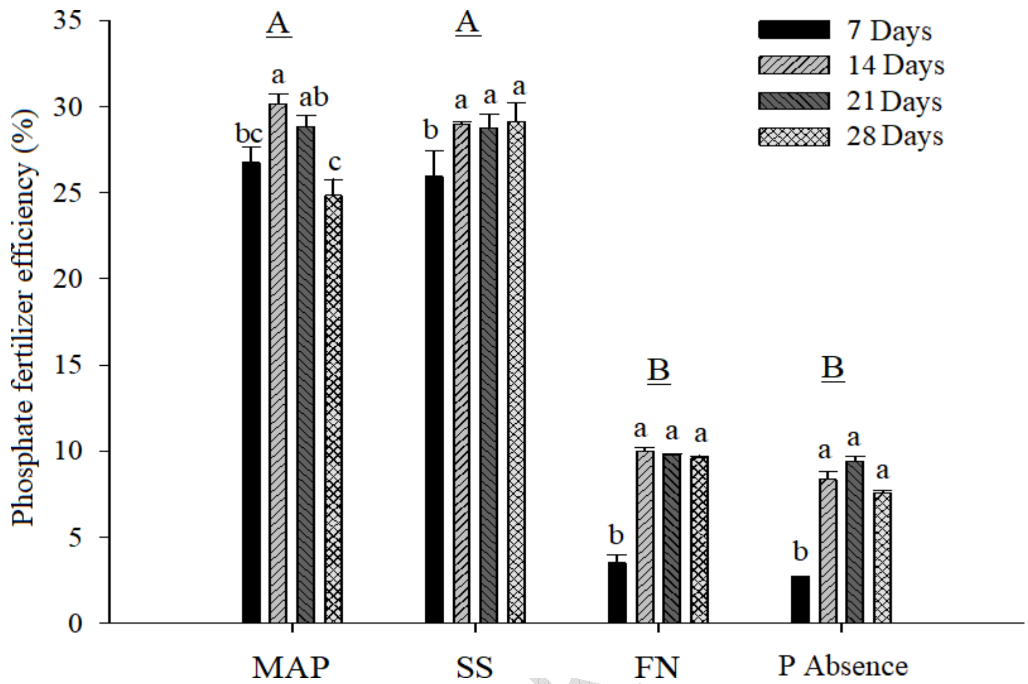

Fig 3. The efficiency of different sources of phosphate fertilizers as a function of sources and epochs.

The treatments that had higher fertilization efficiencies were SS and MAP, with 28.10 and 27.67%, respectively. These treatments had results 75.18 and 74.67% higher compared with the treatment of absence of P, which presented 7.05% efficiency. In acidic soils, FN is more efficient in solubilizing P, and with this, it presented lower results when compared to other fertilization, being slightly higher than the treatment that had an absence of P, but without statistical difference.

When it comes to efficiency in relation to different eras, the evaluation performed at 7 days after fertilization obtained an efficiency of the treatments MAP, SS, FN that corresponded to 26.73, 25.93 and 3.51%, respectively, being better to the treatment with absence of fertilization, which also presented a slight increase in P content over time. The increase in P availability in the treatment with the absence of fertilization probably occurred due to the neutralization of soil acidity by means of liming, promoting the best solubilization of the nutrient as pH reached the ideal levels [13].

At 14 days, the MAP, SS, and FN had 30.15, 28.97 and 10.01% efficiency, respectively, being relevant when compared to the treatment with an absence of fertilization that obtained 8.36% efficiency. With 21 days, the MAP, SS, and FN obtained 28.83, 28.78 and 9.76% efficiency, respectively, this efficiency is considered better when compared to the treatment with an absence of fertilization that had an efficiency of 9.40%.

At the end of the incubation period, with 28 days the MAP treatment showed decline and efficiency when compared to the previous ones (24.83%). According to Yamada & Abdalla (2004) [13], phosphate fertilizers with higher efficiency solubility are monocalcium phosphates (SS) and monoammonium phosphate (MAP), but in this work, MAP showed results of the release of unbelieving P due to times, which did not happen with SS, due to the residual left to the soil [26]. SS and FN maintained the level of efficiency in P release for a ground solution.

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4. CONCLUSIONS

The MAP, SS and FN sources promoted an increase in phosphorus content in the soil. The best fertilization efficiencies were observed with the use of MAP and SS.

The applied dosage (120 kg ha^{-1} of P_2O_5) increased the P levels at the average level of soil availability. The application of 6 t ha^{-1} of dolomitic limestone promoted an increase in pH up to 71 days after incubation.

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