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Effect of gypsum and potassium on corn yield and on the exchangeable bases of an acid soil in La Frailesca, Chiapas

Camas-Pereyra, Rausel[1]; , **Camas-Gómez, Robertony**[2*]; **Ramírez-Valverde, Gustavo**[1]; **Padilla-Cuevas, Juliana**[1]; **Etchevers, Jorge D.**[1]

[1] Colegio de Postgraduados, Campus Montecillo, Texcoco, Estado de México, C.P. 56264.
[2] Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, Campo Experimental Centro de Chiapas, Carretera Ocozocoautla-Cintalapa, Chiapas, C.P. 29140.
* Correspondence: camas.robertony@inifap.gob.mx

ABSTRACT

Objective: To evaluate the residual effect of gypsum in corn crops (2 years after its application in a previously limed soil), as well as the result of a new addition of gypsum combined with potassium in La Frailesca, Chiapas, Mexico.

Design/Methodology/Approach: We used a composite factorial design. The initial arrangement (2017) consisted of four levels of gypsum (0, 1.25, 2.5, and 5 t ha-1) and four levels of potassium (0, 60, 120, and 180 kg K_2O ha^{-1}). In 2019, the gypsum-treated plots were divided in half: the same amount of gypsum applied in 2017 was added to the first half and the other half was used to assess the residual effect of the initial treatment. The potassium doses were the same as the original. Corn grain yield, pH, exchangeable bases, and aluminum saturation percentage were measured at 0 to 7 and 7 to 14 cm below ground level.

Results: The greatest effect on yield was obtained with 2.5 t ha^{-1} of gypsum applied in 2017; no significant increases were recorded with higher gypsum doses. The exchangeable calcium content and pH level increased, while magnesium, potassium, and aluminum in the soil decreased.

Study Limitations/Implications: Suspected presence of Tar Spot Complex was diagnosed.

Findings/Conclusions: An excessive application of gypsum generates an imbalance in exchangeable potassium and magnesium in the soil; therefore, producers must exercise caution in the use of these products as part of their fertilization plan.

Keywords: Frailesca, acidity, gypsum, potassium, aluminum.

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INTRODUCTION

The Frailesca region is considered the granary of Chiapas, due to its high corn production. Its Regosols have low exchangeable calcium (Ca), magnesium (Mg), and potassium (K) contents. Among other factors, this phenomenon is caused by the erosion resulting from the burning of crop residues (that leaves the soil unprotected from the intense rainfall), as well as from the excessive use of ammonia fertilizers (that contribute to its acidification).

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Furthermore, the high exchangeable aluminum (Al) content in the soils limits the land productivity of approximately 35,000 ha^{-1} cultivated with corn, where yields ranging from 0.8 to 1.2 t ha^{-1} are obtained, affecting the income of around 14,000 producers.

Dolomitic lime could be applied to counteract the acidity of the soil, at a depth of 0 to 15 cm (Bossolani *et al.*, 2020). This product has local action, because of its low solubility (0.013 g L^{-1}) (Zapata, 2014). Its application dose in La Frailesca is calculated with the formula proposed by Yost (1991), modified, and adjusted by Camas *et al.* (2019).

The addition of Ca improves the fertility of acid soils; dolomitic lime and agricultural gypsum contribute Mg and S, respectively. Zoca and Penn (2017) pointed out that there is no exact scientific method to accurately and a priori estimate the gypsum that must be added to the soil.

The recommended dose of gypsum for the Frailesca is the result of the work carried out by Tasistro *et al.* (2015), who established a 1.25 t ha^{-1} of gypsum as an agronomically and economically recommended dose, during the first year of evaluation. These authors also reported that most of the soils in this area have low concentrations of exchangeable K and that K deficiency symptoms are common in corn crops. However, there is insufficient evidence about how this crop responds to the application of K; this response is attributed to the limitations imposed by soil acidity. The objective of this work was to evaluate the residual effect of agricultural gypsum and potassium on corn yield (2 years after their application), as well as the result of a second amendment application (particularly on exchangeable soil bases).

MATERIALS AND METHODS

Corn was used as an indicator crop for this experiment, which was carried out in the municipality of Villa Corzo, Chiapas (16.2025 N and −93.3382 W), an area characterized by hillocks, variable fertility, and scarce organic matter. The local soil belongs to the Dystrudepts group (Tasistro *et al.*, 2022). The trial followed up an experiment established in the spring-summer (SS) 2017 cycle to measure the response to the application of dolomitic lime, gypsum, and potassium. The applied lime dose was calculated using Yost's formula (1991) for an aluminum saturation of 47%, at a depth of 0 to 13 cm. The said dose was applied to the entire experiment.

The 2017 treatments consisted of a factorial arrangement of four levels of gypsum (0, 1.25, 2.5, and 5 t ha^{-1}) and four levels of potassium chloride (0, 60, 120, and 180 kg K_2O ha^{-1}) arranged in random blocks. The experiment consisted of three replications per treatment.

For the SS 2019 cycle, the experimental units with 1.25, 2.5, and 5 t ha^{-1} of gypsum were divided into two, with four 6-m long rows and 0.8 m between rows each one. The same dose of gypsum was applied to one half and the other half was used to evaluate the residual effect of the 2017 application. In the resulting 28 treatments, the potassium levels were the same as in the first application, while the controls did not receive doses of gypsum and potassium.

On July 6, 2019, the H-318 hybrid was manually established, depositing one seed every 19 cm; consequently, an approximate density of 65,000 seeds ha^{-1} was obtained. One day after sowing, 20% (*i. e.* 40 kg ha^{-1}) of the total scheduled N (200 kg ha^{-1}), 100% of the phosphorus (60 kg P_2O_5 ha^{-1}), and 100% of K (0, 60, 120, and 180 kg K_2O ha^{-1}) were applied. The treatment was applied in a line that ran 10 cm apart from the planting furrow. In the V5 and V10 phenological stages (Ritchie and Hanway, 1982), 40% of N (80 kg ha^{-1}) was applied in each one. The sources of the fertilizers used were urea, diammonium phosphate, and potassium chloride. The second application's gypsum was distributed over the soil 10 days after the emergence of the corn and was incorporated with a mattock at a 7.0 cm depth. This amendment contained calcium carbonate as impurities (32% PRNT).

The corn was grown under an efficient agronomic management, avoiding the presence of other factors that could interfere with those of the study. The response variable measured was corn grain yield, expressed on a 14% moisture basis. The harvest was carried out in the two central furrows of each plot, excluding 1 m at each end of the plot.

At the beginning and end of the SS 2019 cycle, composite soil samples were collected from each plot. Each sample consisted of 16 subsamples obtained from the two central furrows at two depths (0 to 7 and 7 to 14 cm), including the area where the fertilizer was applied alongside the furrow.

The chemical determinations carried out on the soil samples were pH in 1N KCl; exchangeable Ca, Mg, Na, and K with 1N ammonium acetate pH7 (Knudsen *et al.*, 1982), exchangeable acidity ($Al^{3+}+H^{+}$) in 1N KCl (Lin and Coleman, 1960). The effective cation exchange capacity (ECEC) and the Al saturation percentage were calculated based on the previous data. An analysis of variance (ANOVA) —using the test described by Shapiro-Wilk (α=0.05)— was performed to determine normality and Levene's test (α=0.05) was used to verify the homogeneity of variances.

All variables were analyzed using a randomized complete block factorial design. The factors were: depth (0 to 7 and 7 to 14 cm), number of gypsum applications (2017 and 2017+2019), and potassium dose (0, 60, 120, and 180 kg K_2O ha^{-1}). The pH values were transformed into the antilogarithm of the molar concentration of hydrogen ions. Meanwhile, the percentage data of the Al saturation were transformed by arcsin of the square root. The ANOVA was performed with the INFOSTAT V.20181 software and, when a significant difference was found, a comparison of means was made through Tukey's test (α=0.05).

RESULTS AND DISCUSSION

Effect of gypsum and potassium on corn grain yield

Corn grain yield was affected by gypsum, but not by potassium or gypsum×potassium interaction. Although the levels of exchangeable K in the soil increased according to K_2O increases, these levels did not influence the yield, because they did not exceed the critical level of 0.23 mEq/100 g (FAO, 2013).

The highest corn yield (6.2 t ha^{-1}) was obtained with the 2.5 t ha^{-1} of gypsum treatment applied in 2017; this result was like that achieved with the application of 2.5 t ha^{-1} (6.0 t ha^{-1}), divided into two doses of 1.25 t ha^{-1} of gypsum each (one applied in 2017 and another in 2019). Clearly, similar yields can be obtained with the application of either modality. Tasistro *et al.* (2022) indicated that, in agronomical and economical terms, the 1.25 t ha^{-1} dose of gypsum was the most adequate in the first year of application. However, our results suggest that, after two years, a new 1.25 t ha^{-1} dose has to be applied, given the residual loss of the amendment; another option is to apply 2.5 t ha^{-1} of gypsum in the first year to obtain a residual effect until the third year.

The highest gypsum doses applied —5 t ha^{-1} in 2017 or 10 t ha^{-1} (5 t ha^{-1} in 2017 and 5 t ha^{-1} in 2019)— led to a decreasing trend in corn grain yield (Figure 1).

At the beginning of the experiment (2017), prior to liming, the Al saturation percentage at 0 to 13 and 13 to 27 cm depths was 47% and 63%, respectively —which are considered toxic levels. This percentage substantially decreased, reaching less than 10% at the beginning of 2019; however, this decrease did not result in the increase in corn yields that same year. Tiecher (2018) pointed out that an increase in corn grain yield can be obtained, with a $<$10% Al saturation in the soil and when the application of rising doses of gypsum increases the Ca content. However, although both conditions were met in this study, no significant increase was observed. The second gypsum application (carried out in 2019) caused a decrease in the exchangeable K and Mg content of the soil and a change in their relationships with other cations, which could explain the lack of the expected response.

Effect of gypsum and potassium on soil pH

Figure 2 shows that, as the doses increased, the soil pH of the plots treated with gypsum showed an almost linear increase; this phenomenon was more evident in 2019. Our results suggest that a part of the 2017 amendment reached the deeper layers after 2 years, possibly because of the erosive effect. The soil had a sandy texture and scarce residue cover, as a result of the intense grazing to which it is subjected each year at the end of the harvest.

According to Bacca *et al.* (2011) gypsum (a neutral salt) has no effect on the pH. However, Tasistro *et al.* (2022) increased the amounts of this amendment in the same soil studied in this experiment (SS 2017 cycle) and reported pH variations in the order of 0.2 to 0.3 units. An *a posteriori* analysis of the gypsum used in this study determined the carbonate content as an impurity (32% PRNT), which would explain its influence on the soil pH at a depth of 0 to 7 cm and 7 to 14 cm (Zoca and Penn, 2017).

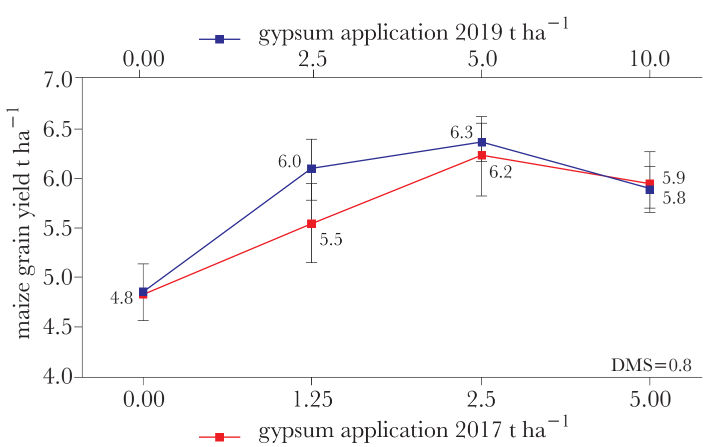

Figure 1. Effect of gypsum application in 2017 and 2019 on corn grain yield.

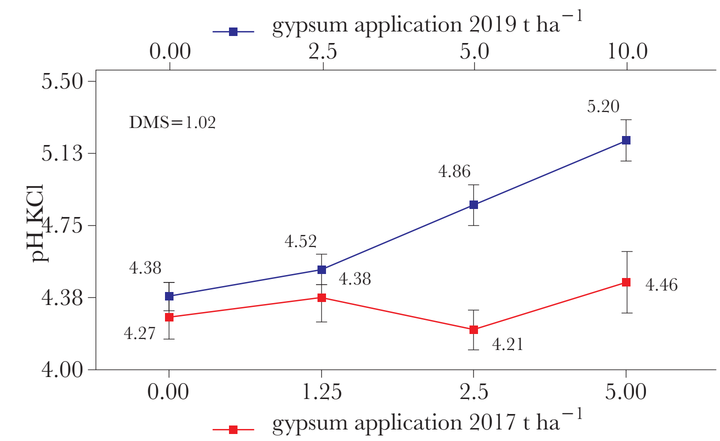

Figure 2. Effect of the gypsum application (2017 and 2019) on the pH at a depth of 0 to 7 and 7 to 14 cm.

Effect of gypsum and potassium on exchangeable calcium in the soil

The calcium extracted from the soil at a depth of 0 to 7 cm was higher as the gypsum dose increased (sum of the 2017 and 2019 applications) (Figure 3); however, the Ca content was lower at a depth of 7 to 14 cm. According to Caires (2004), the greater ionic radius of Ca (regarding Mg and K) and its lower mobility in the soil profile could cause this phenomenon.

Authors like Crusciol *et al.* (2016) observed that, 3 months after the application of gypsum, the Ca content in the tillable layer (0 to 10 cm) of the soil had increased; however, this element descended towards the 10 to 20 cm layer after a year. Therefore, the Ca in this study is likewise expected to reach deeper layers over time. If the objective of the practice is to increase the Ca concentration in the soil solution, gypsum is the most efficient amendment, since it can induce higher corn yields (Shainberg *et al.*, 1989). However, although the Ca contents increased in our study site during the SS 2019 cycle, no significant increases in corn production were observed, which suggests the existence of other nutritional problems (Figure 4).

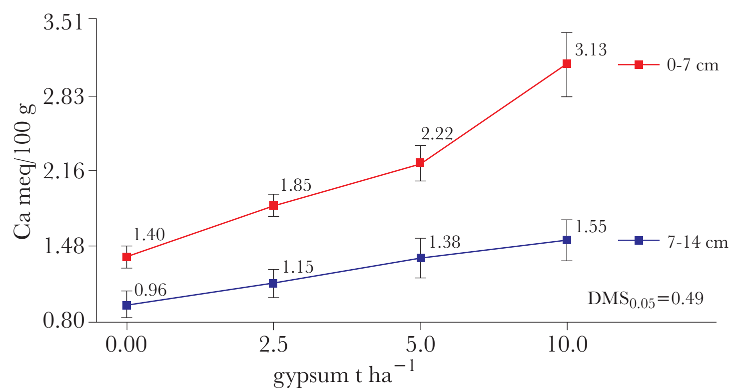

Figure 3. Joint effect of two gypsum applications (2017+2019) on exchangeable Ca, at 0 to 7 and 7 to 14 cm depths.

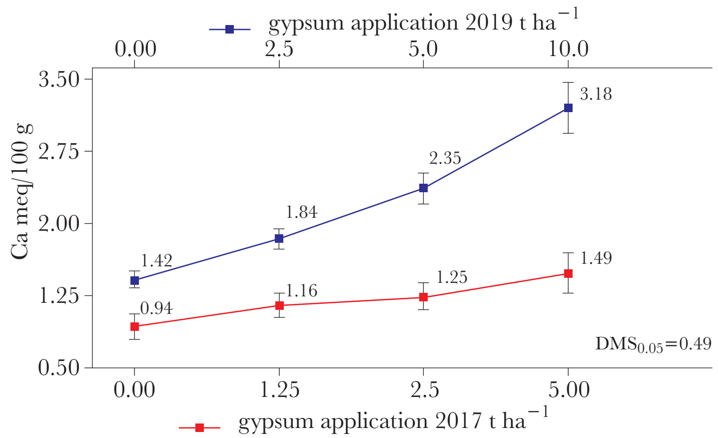

Figure 4. Effect of gypsum application (2017 and 2019) on the exchangeable Ca in the soil.

Effect of gypsum and potassium on the exchangeable magnesium in the soil

As a consequence of the generalized application of 1.9 t ha^{-1} of dolomitic lime (2017), the levels of exchangeable Mg in the treatment without gypsum increased; however, as the doses of gypsum applied jointly in 2017 and 2019 increased, a decreasing trend was recorded (Figure 5). In 2017, the extractable magnesium in the 0 to 7 cm layer was above the 0.3 cmolc kg^{-1} critical level considered by Kopittke and Menzies (2007); meanwhile, it was lower in the 7 to 14 cm layer, possibly as a result of the incorporation of lime at a depth of just 10 cm.

The second application of gypsum carried out in 2019 caused a decrease in exchangeable Mg at a depth of 0 to 7 cm. However, at a depth of 7 to 14 cm, no significant changes in this element were recorded. As in other abovementioned cases, we assume that gypsum, despite its high solubility, did not reach the deepest layers of the soil. Zoca and Penn (2017) argue that Mg and K leaching largely depends on the amount of gypsum applied, as well as on the texture and mineralogy of the soil. The results suggest that adding magnesium fertilizer would compensate for its decrease.

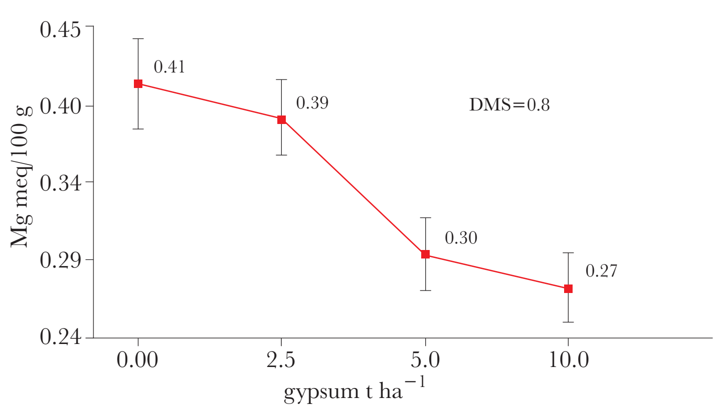

Figure 5. Joint effect of two gypsum applications (2017+2019) and two depths (0 to 7 and 7 to 14 cm) in the exchangeable magnesium of the soil.

Effect of gypsum on the exchangeable potassium in the soil

As the joint amounts of gypsum doses applied in 2017 and 2019 increased, the exchangeable K decreased (Figure 6), below the 0.23 cmol/100 g critical level in the soil (FAO, 2013).

Gonzalez *et al.* (2005) and Sparks (2003) report similar results in sandy soils like the findings of the study site. The application of high amounts of gypsum in their study displaced potassium to deeper layers. Therefore, the recommendation regarding the amount of gypsum to be used to correct the exchangeable acidity must be followed with care, taking into consideration the additional K contributions required to compensate for the decrease caused by the use of gypsum.

Effect of gypsum and potassium on the exchangeable aluminum in the soil and aluminum saturation

K fertilization by itself had a significant effect on the Al saturation percentage. With the widespread application of lime in 2017 and gypsum in 2017 and 2019, AI saturation dropped to 8.1%, while, in the treatment with 60 kg K_2O, it decreased to 4.3%. A similar behavior was recorded with higher amounts (Figure 7).

This indicates that, when lime and gypsum are used to correct the Al excess, part of the temporarily unavailable K is released; by adding K_2O, K can actively participate in the neutralization of the charges of the exchange capacity in the sites previously occupied by Al and the gypsum and the lime are released to the soil solution by the application of the amendment. The exchangeable Al and the Al saturation percentage were affected by the application of gypsum (2017+2019) at both soil depths (Figure 7). At the 0 to 7 cm depth with both applications, the exchangeable Al was below the critical level (2 meq/100 g) (Casierra and Aguilar, 2007) and the Al saturation percentage was less than 20% (Tasistro, 2012), which suggests that the residual effect of the dolomitic lime and gypsum applied in 2017 persists.

In the 7 to 14 cm depth, significant changes were observed in exchangeable Al (Figure 8) and in the saturation percentage. Two years after applying the amendments, the

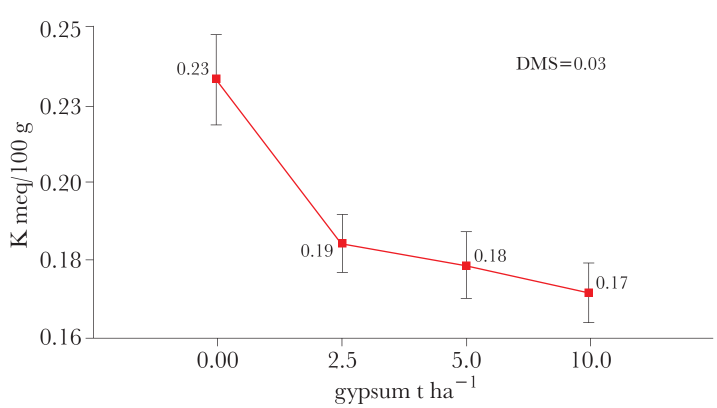

Figure 6. Joint effect of two gypsum applications (2017+2019) and two depths (0 to 7 and 7 to 14 cm) on the exchangeable K of the soil.

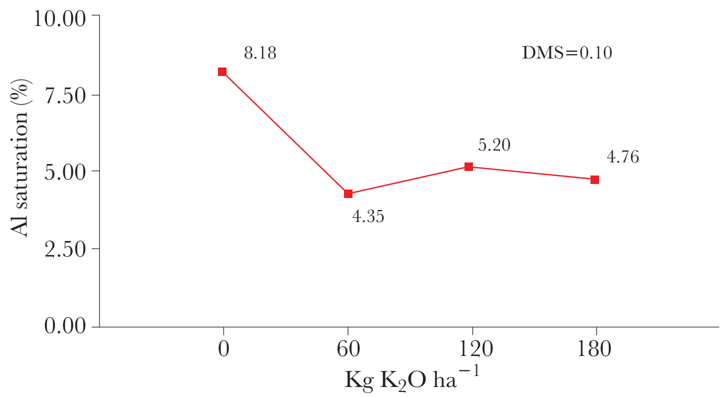

Figure 7. Effect of K_2O on the aluminum saturation percentage at a joint depth (0 to 7 and 7 to 14 cm).

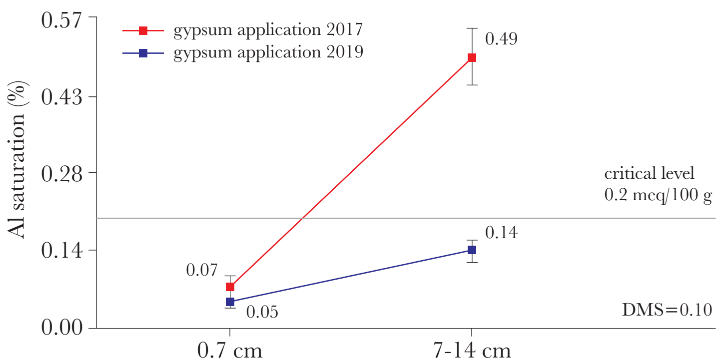

Figure 8. Effect of two gypsum applications (2017 and 2019) on interchangeable aluminum at two depths (0 to 7 and 7 to 14 cm).

exchangeable Al was above the critical level, which suggests that the gypsum may have moved downwards and reached deeper layers.

At that same depth, a second application of gypsum decreased the exchangeable Al by 0.35 meq, down to 0.14 meq and, on average, the Al saturation percentage decreased from 28% to 7%. In our study, the widespread application of dolomitic lime in 2017 (treatment 0 gypsum) kept Al saturation below the critical level, even after 2.5 years. The gypsum applications in 2017 and 2019 further decreased Al saturation; the effect was greater for the 2019 applications. This behavior may explain the increase in yield, both with 2.5 t ha^{-1} of gypsum in 2017 and the same amount but divided in two sets (1.25 t ha^{-1} each) in 2017 and 2019 (Figure 9).

Casierra and Aguilar (2007) suggest that the effect of Al on plant development depends on the tolerance of the species and on the physical and chemical properties of the soil. According to Ryan *et al.* (2011) the aluminum absorption mechanisms are not precisely known.

CONCLUSIONS

The application of gypsum resulted in increases in yield both with the treatment of 2.5 t ha^{-1} in 2017 (year 1) —which had a residual effect in the third year (2019)— and with the use of two similar applications of 1.25 t ha^{-1} of gypsum in 2017 and in 2019.

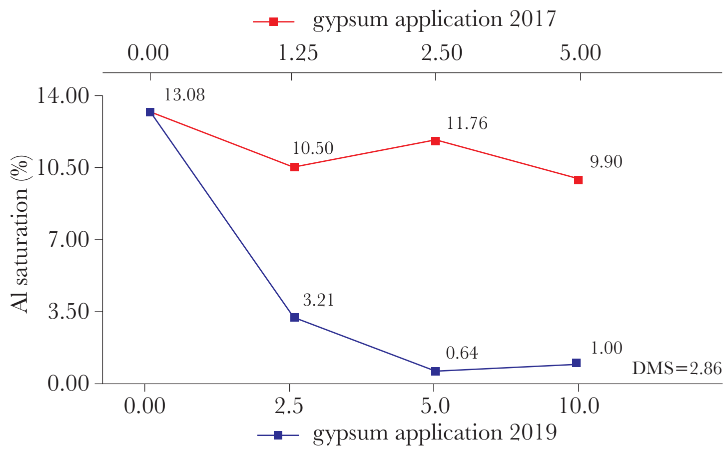

Figure 9. Effect of two gypsum applications (2017 and 2019) on the aluminum saturation percentage.

The application of higher gypsum doses in both years did not lead to an increase in corn yield; however, it increased the exchangeable calcium content and pH in the soil and decreased exchangeable magnesium, potassium, and aluminum.

The soil pH increased because of applying gypsum at a depth of 0 to 7 cm, as a result of the gypsum impurities (lime).

As a conclusion, the recommendations regarding the use of gypsum as an amendment should be taken with care since an excessive application generates a decompensation in the exchangeable K and Mg of the soil. Therefore, their incorporation into the fertilization plan should be carefully considered.

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