Chemical changes in the soil profile with phosphogypsum

Marcio Veronese[AC], Julio Cesar Boggiani[A], Leandro Zancanaro[B] and Ciro Antonio Rosolem[A]

[A] School of Agricultural Sciences, São Paulo State University, Botucatu, SP, Brazil.
[B] Fundação de Apoio a Pesquisa Agropecuária de Mato Grosso, Rondonópolis, MT, Brazil
[C] Email marcioveronese@fca.unesp.br

Abstract
Liming is the most used practice to correct soil acidity. However, limestone presents low solubility and low mobility, and its effect is limited to the application area. Phosphogypsum (calcium sulfate), a byproduct of the phosphate fertilizer industry, can be used to improve the root environment at depth. The aim of this study was to evaluate alterations in the chemical characteristics of the surface and subsurface soil, and soybean productivity with phosphogypsum application. The experiment was carried out for the 2007 and 2008 harvests in the region of Primavera do Leste, MT, Brazil. The treatments were two phosphogypsum doses and, a control with sampling from four layers. The pH, K, Ca, Mg, CTC, V%, m%, S and Organic Matter were analyzed and the soybean productivity was measured. Considering the 15-month effect time, the official recommendation for phosphogypsum application was not effective to correct exchangeable soil acidity in subsurface and the productivity was not influenced by the applied phosphogypsum doses. Soil capacity to absorb S is under the amount added in the treatments with phosphogypsum.

Key Words
Acidity, aluminum, correction, soybean.

Introduction
Acidity is a general characteristic of Brazilian agricultural soils, and it decreases the availability of Ca^{+2}, Mg^{+2}, K^{+} nutrients and increases solubility of H^{+} and Al^{+3} toxic cations (Franchini *et al.* 2001). In order to correct acidity, liming is the most used practice because it increases pH and basic cations, as well as reduces exchangeable Al. However, lime has low solubility and slow mobility and its effect is limited to the application area (Caires *et al.* 2000).

Ca deficiency and Al toxicity are the main chemical limitations to root growth, and the consequences are seen in the nutritional and hydric stress in the plant (Ritchey *et al.* 1980). In annual crops, there is a great response to phosphogypsum if the aluminum saturation is over 20% or if Ca content is smaller than 5 $mmol_c/dm^3$. (Sousa 2004).

In vast regions of Central Brazil, as in the Brazilian savannah, there are long periods of drought during the summer harvest (also called “Indian summers”); therefore, soil acidity correction is recommended under 20 cm depth to improve deep rooting of cultivated plants and minimize risks of production decrease (Ritchey *et al.* 1980; Sousa and Ritchey 1986).

Phosphogypsum ($CaSO_4.2H_2O$ – calcium sulfate), a byproduct from the phosphate fertilizer industry, can be used to improve root environment. This product, when applied to soil after its dissolution, causes alterations in the chemical characteristics of sub superficial layers because of the high mobility of sulfate and calcium ions on the limed layer. That promotes the root deepening, allows plants to overcome Indian summers, and use nutrients applied to the soil efficiently (Sousa *et al.* 1995). The aim of this study was to evaluate surface and subsurface soil chemical alterations, and soybean productivity with phosphogypsum applications.

Methods
This study was carried out during the 2007 and 2008 harvests, in a commercial soybean plantation, in the region of Primavera do Leste, MT, Brazil, 15º01’ S, 53º40’ W, 590 m altitude and weather defined as Aw, according to Köppen. The soil was classified as Hapludox, medium texture (EMBRAPA, 1999). Average rainfall in the region is 1200 mm/year.

The experimental had randomized 3x4 factorial block design with five replications. The treatments were two doses of phosphogypsum, one witness and sampling from 4 depths. Phosphogypsum doses were 0.0, 0.9 and 2.7 Mg/ha, according to the recommendation of Sousa and Lobato (2004). Soil samplings were from 0.0-0.1, 0.1-0.2, 0.2-0.3 and 0.3-0.4 m layers.

In late August 2006, 2.0 Mg/ha of lime (PRNT 75%) was applied, incorporated into the plowing grid at about 0.2 m. Soybean was sowed on November 11, 2007 and May 11, 2008, using 0.45 spacing. 50 kg/ha of P_2O_5, 80 kg/ha of K_2O, and 30 kg/ha of S were applied every year. Treatments with phosphogypsum were manually spread on the surface at 5 days after sowing.

Soybean was harvested on February 24, 2007 and February 21, 2008. Fifteen soil subsamples were taken from each depth and combined into one composite sample of each plot. These samples were analyzed for the following soil chemical attributes: pH, K, Ca, Mg, CEC_{pH7}, V%, m%, S, O.M. (Embrapa, 1997). The original data were submitted to variance analysis, and for the significant effects, the averages were compared by t test at 5%.

Results

The soil active acidity was reduced at depth, regardless of phosphogypsum application (Table 1a). The pH was not affected by phosphogypsum doses in 2007, but there was a significant difference from the control for the 2008 harvest. For all doses, there was significant difference between the harvests only in the 0.0-0.1 m layer, and the highest values were for the 2008 harvest. The pH increased because of the residual effect of the liming since ECC was 75%.

The treatments that received phosphogypsum caused K leaching in 0.0-0.10 m layer in the first cultivation year (Table 1b). In the second year, 2.7 Mg/ha dose presented less K, which was significant in relation the 0.9 Mg/ha dose, but it did not differ from the treatment that did not receive phosphogypsum. Comparing contents in 2007 and 2008 harvests, it is observed that the second harvest presents lower contents in the treatment that did not receive phosphogypsum and in the treatment that received the biggest dose. These values can be related with the absorption and exportation nutrients due to soybean cultivation, which was bigger in the 2008 harvest. Even without statistical difference, the treatment with 0.9 Mg/ha had the lowest production in the 2008.

In the first cultivation year, in the 0.0-0.2 m layer, the Ca content rose with the increase of phosphogypsum dose, but only the highest dose was significant when compared to the control (Table 1c). This increase is related to the presence of the element in the chemical composition of phosphogypsum. In the second year, the same effect occurred but it was limited to the 0.0-10 m layer. The applied doses of phosphogypsum were not enough to carry Ca to the subsurface.

The treatment that did not receive phosphogypsum was the one that had the highest Mg content, in the 0.0-0.1 m layer; however, there was not a significant difference when compared to the highest dose. Comparing contents between the 2007 and 2008 harvests, all the treatments in 0.0-0.1 m layer had a significant effect (Table 1d).

Only for the 0.1-0.2 m layer, was there was a significant increase in the CEC for the highest phosphogypsum dose for the 2007 harvest (Table 1e). This fact can be related to the organic matter content increase in the same parcel. Comparing the two harvests, there was a reduction of the CEC in 2008 harvest in some layers and for all phosphogypsum doses. This alteration would firstly be related to the soil O. M. content reduction in between harvests.

Only for the 2008 harvest, in the 0.0-0.1 m layer, was there was a significant difference of V% values (Table 1f). It is probable that this effect was related to the Ca content increase in the same soil. However, this was not observed for the 2007 harvest.

In the Table 1g, the m% values are presented. In the first harvest, the effect of the treatment was significant only in the 0.3-0.4 m layers for the parcels that received the highest doses of phosphogypsum (2.7 Mg/ha), but it did not reduce the m% values to the appropriate levels in the subsurface. In the second year, there was a reduction of the m% value for the highest phosphogypsum dose in the 0.1-0.2 m layer. Comparing the effect between the two harvests, it is observed that there was an increase in the m% values for the phosphogypsum treatments in the 0.3-0.4 m layer, and for the control in the 0.2-0.3 m layer.

Table 1. Chemical characteristics of the soil at different depths, submitted to the phosphogypsum application for the 2007 harvest and 2008 harvest: (a) pH, (b) K, (c) Ca, (d) Mg, (e) CTC, (f) V%, (g) m%, (h) S, (i) O.M. and (j) soybean productivity.

a) pH ($CaCl_2$)

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	5.0 Aa	(5.2) Ab	5.0 Aa	(5.4) Bb	5.1 Aa	(5.4) Bb
0.1-0.2	4.6 Aa	(4.5) Aa	4.6 Aa	(4.6) ABa	4.7 Aa	(4.7) Ba
0.2-0.3	4.5 Aa	(4.4) Aa	4.5 Aa	(4.5) Aa	4.6 Aa	(4.5) Aa
0.3-0.4	4.5 Aa	(4.4) Aa	4.5 Aa	(4.4) Aa	4.5 Aa	(4.4) Aa

CV: 3.0 (%)

b) K^+ (mg dm^{-3})

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	60 Bb	(49) ABa	51 Aa	(50) Ba	50 Ab	(42) Aa
0.1-0.2	32 Aa	(34) Aa	25 Aa	(33) Ab	27 Aa	(28) Aa
0.2-0.3	29 Aa	(29) Aa	24 Aa	(27) Aa	25 Aa	(23) Aa
0.3-0.4	28 Aa	(23) Aa	25 Aa	(24) Aa	25 Aa	(20) Aa

CV: 18.3 (%)

c) Ca^{2+} ($mmol_c$ dm^{-3})

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	20 Aa	(20) Aa	22 ABa	(23) ABa	24 Ba	(26) Ba
0.1-0.2	11 Aa	(09) Aa	11 ABa	(10) Aa	15 Bb	(11) Aa
0.2-0.3	07 Aa	(05) Aa	07 Aa	(06) Aa	08 Aa	(07) Aa
0.3-0.4	04 Aa	(04) Aa	06 Aa	(04) Aa	06 Aa	(04) Aa

CV: 25.0 (%)

d) Mg^{2+} ($mmol_c$ dm^{-3})

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	07 Ba	(10) Ab	06 Aa	(09) Ab	07 ABa	(10) Ab
0.1-0.2	03 Aa	(04) Aa	03 Aa	(04) Aa	04 Aa	(04) Aa
0.2-0.3	02 Aa	(02) Aa	02 Aa	(02) Aa	02 Aa	(02) Aa
0.3-0.4	02 Aa	(02) Aa	02 Aa	(02) Aa	02 Aa	(02) Aa

CV: 31.7 (%)

e) CEC_{pH7} ($mmol_c$ dm^{-3})

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	66 Ab	(58) Aa	66 Ab	(56) Aa	70 Ab	(57) Aa
0.1-0.2	49 Aa	(45) Aa	51 ABb	(44) Aa	55 Bb	(45) Aa
0.2-0.3	35 Aa	(30) Aa	36 Aa	(31) Aa	37 Aa	(34) Aa
0.3-0.4	29 Aa	(24) Aa	32 Ab	(23) Aa	32 Aa	(26) Aa

CV: 12.0 (%)

f) Base Saturation (V%)

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	43 Aa	(54) Ab	44 Aa	(61) ABb	46 Aa	(64) Bb
0.1-0.2	30 Aa	(30) Aa	29 Aa	(31) Aa	34 Aa	(36) Aa
0.2-0.3	28 Aa	(27) Aa	26 Aa	(29) Aa	29 Aa	(30) Aa
0.3-0.4	23 Aa	(26) Aa	26 Aa	(28) Aa	27 Aa	(27) Aa

CV: 17.4 (%)

g) Aluminium Saturation (m%)

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	02 Aa	(00) Aa	00 Aa	(00) Aa	00 Aa	(00) Aa
0.1-0.2	17 Aa	(21) Ba	18 Aa	(20) Ba	10 Aa	(11) Aa
0.2-0.3	26 Aa	(35) Ab	28 Aa	(30) Aa	23 Aa	(29) Aa
0.3-0.4	37 Ba	(38) Aa	32 ABa	(39) Ab	28 Aa	(41) Ab

CV: 29.5 (%)

h) S(mg dm^{-3})

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	6.0 Aa	(7.0) Aa	7.7 Aa	(8.8) Aa	19.7 Bb	(9.2) Aa
0.1-0.2	5.9 Aa	(6.6) Aa	10.0 Bb	(7.2) Aa	20.3 Cb	(8.0) Aa
0.2-0.3	6.4 Aa	(7.5) Aa	12.6 Bb	(7.2) Aa	19.8 Cb	(8.7) Aa
0.3-0.4	7.4 Aa	(9.8) ABa	15.7 Bb	(9.3) Aa	25.7 Cb	(12.0) Ba

CV: 18.0 (%)

i) Organic Matter (g dm^{-3})

Depth (m)	phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
0.0-0.1	24 Ab	(20) Aa	25 Ab	(19) Aa	25 Ab	(20) Aa
0.1-0.2	16 Aa	(13) Aa	17 Ab	(12) Aa	20 Bb	(13) Aa
0.2-0.3	09 Aa	(08) Aa	11 Aa	(09) Aa	11 Ab	(08) Aa
0.3-0.4	06 Aa	(06) Aa	09 Bb	(06) Aa	08 ABa	(06) Aa

CV: 16.4 (%)

j) Soybean productivity (Kg ha^{-1})

phosphogypsum dose (Mg ha^{-1}) 0		0,9		2.7	
2238 Ab	(4020) Aa	2188 Ab	(3563) Aa	2266 Ab	(3894) Aa

CV: 10.6 (%)

Averages of five replications from 2007 harvest and between parentheses fron 2008 harvest.

Averages in line followed by same capital letter (crop X dose) and small letter (dose X crop) are not significantly different by t test at 5%.

The S content in the soil in the first harvest increased as phosphogypsum dose increased in all the depths, making evident the phosphogypsum mobility in the soil (Table 1h). In the 2008 harvest, all sulfur added to the soil was possibly leached under the soil sampling layer. This shows that the soil capacity to absorb this element is lower than the amount added in the treatments that received phosphogypsum.

Comparing the t soil O.M. from one harvest to another, it was observed that there was a decrease (Table 1i). The effect was significant for the treatment that did not receive phosphogypsum in the 0.0-0.1 m layer, in the 0.9 Mg/ha phosphogypsum dose, the 0.0-0.2 m and 0.3-0.4 m layers, and in the 2.7 dose of Mg/ha in the 0.0-0.3 m layer. It is probable that these different results between the two harvests are related to climatic effects.

The absence or presence of phosphogypsum did not influence productivity for both harvests (Table 1j). However, comparing the results of both harvests, there was a significant effect for all the treatments, but these values are correlated to climatic effects during plant growth (data not shown).

Conclusion

▪ The productivity was not influenced by the applied phosphogypsum.
▪ Considering the 15-month effect time, the official recommendation for phosphogypsum application as a function of the clay content was not effective for subsurface soil correction.
▪ The soil capacity to absorb S is below the amount added in the treatments that received phosphogypsum.

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