Residual Effect of Gypsum and Phosphate Fertilization on the Second Corn Crop

Héliton de Oliveira Resende[1], Magno Gonçalves Braz[1], Alex Oliveira Smaniotto[1], Izamara Fonseca Tempesta[1], Claudio Hideo Martins da Costa[1] & Simério Carlos Silva Cruz[1]

[1] Goiás Federal University, Jataí, Goiás, Brazil

Correspondence: Alex Oliveira Smaniotto, Goiás Federal University, Jataí, Goias, Brazil. Tel: 55-649-9613-5158. E-mail: aosmaniotto@gmail.com

Abstract

The objective of this study was to evaluate the residual effect of the gypsum when used with phosphate fertilization on the mineral nutrition, development and yield of second corn crop. The experiment was conducted at UFJ, with an experimental design consisting of 15 treatments established in randomized blocks in a 5×3 factorial scheme, with 4 replicates. The first factor corresponded to doses of gypsum (0, 1, 2, 4 and 8 Mg ha^{-1}) and the second factor corresponded to doses of phosphorus (0, 40 and 80 kg ha^{-1}). 16 months after the application of the various doses and treatments of agricultural gypsum, the following components were evaluated: dry root mass, macro and micronutrient contents in the leaves, production components and grain yield. The residual effect (16 months) of gypsum did not increase efficiency of phosphate fertilization for second corn crop. Under water stress conditions, the yield of corn grains responds to the application of agricultural gypsum above that of the dose recommended by the formula NP = $5 \times$ g kg^{-1} of clay, which for this research is 2.93 Mg ha^{-1} of gypsum. Phosphorus provides increases in corn grain yield only when 100% of the recommended dose is applied.

Keywords: Gypsum, phosphorus, soil, yield, *Zea mays* L.

1. Introduction

The cultivation of plants and the raising of livestock are complementary and elementary activities for the growth of a region. In this context, the corn crop (*Zea mays*) is of great importance. With this, the small crop or second corn crop of the year, known locally in Brazil as milho safrinha, which is sown from January to March, stands out as one of the main grain crops produced in Brazil, mainly in the South, Southeast and Center West, being sown immediately after the soybean harvest (CONAB, 2017).

Due to the time it is sown, the second corn crop often faces periods, sometimes long, of water stress. Therefore, the management of the soil in areas where the cultivation of this crop is common must provide optimum conditions for the full root development of corn, especially in terms of depth, since this practice will allow farmers to take advantage of a greater volume of soil, and consequently, a greater access to water and nutrients, focusing on those with low mobility or soil with the correct properties such as that with phosphorus (P), for example.

Among the main factors of the soil that limit the full development of the root system of agricultural crops are those of a physical nature, such as compaction, reduction of porosity and soil aeration, as well as those of a chemical nature, such as an excess of aluminum (Al^{3+}) and the low levels of calcium (Ca^{2+}) and P in subsurface.

Liming has long been the main tool for the correction of acidity and the supply of Ca^{2+} and Mg^{2+} to the soil, but in established no-till farming areas, the application of this corrective process is limited to the soil surface since excessive soil disturbance is avoided when liming. Thus, the benefits of liming are mostly restricted to the first few years and to the surface of soil, and therefore, does not solve the subsurface acidity problems.

Thus, the application of soil conditioners, such as agricultural gypsum, due to its greater solubility, reduces Al^{3+} activity and increases nutrient availability in the deeper layers of the soil (Ritchey, Silva, & Costa, 1982). The combination of agricultural gypsum with liming may favor root development at greater soil depths, especially in

areas under no-till farming, allowing for greater efficiency of water and nutrient absorption, as previously mentioned (Caires, Chueiri, Madruga, & Figueiredo, 1998).

The edaphic conditions in which gypsum use is recommended are the following: Ca^{2+} content less than 0.5 cmolc dm^{-3}, and saturation of Al^{3+} greater than 20% in the 20-40 and 40-60 cm layers of soil (Sousa & Lobato, 2004). However, the application of gypsum in soils where previously reported chemical conditions are not evident has been reported, in the literature, to have a positive effect on crops, especially corn (Maschietto, 2009).

As mentioned previously, in addition to Ca^{2+}, P is a very important element for root development (Resende, Bustamante, Markewitz, Klink, & Davidson, 2011); however, since tropical soils are naturally poor in nutrients, especially in P, there wouldn't have been the remarkable performance in the production of grain, under the current Brazilian model of agriculture, without the addition of adaquate fertilizers, since they usually present low concentration of P and high power of "fixation" or "retention" of the P provided by fertilization (Eberhardt, Vendrame, Becquer, & Guimarães, 2008).

There is a hypothesis that the greater development of the root system through the use of agricultural gypsum, often reported in the literature (Raij, 1988; Caires, Fonseca, Mendes, Chueiri, & Madruga, 1999; Garbuio, 2006; Zandoná, Beutler, Burg, Barreto, & Schmidt, 2015; Soares, 2016), can increase the absorption efficiency of P by the plants due to the greater volume of soil exploited by the plant, since this nutrient is practically immobile in soil.

The objective of this study was to evaluate the effect of phosphate fertilization under the residual effect (16 months) of agricultural gypsum on mineral nutrition, development and yield of second corn crop under no-till farming.

2. Materials and Methods

The experiment was conducted in the municipality of Jataí/GO, during the second corn crop of the agricultural year 2015/2016, in the experimental field of the Federal University of Jataí whose geographic coordinates are 17°55′32″ S and 51°42′32″ W at an altitude of 685 m.

The predominant climate in the region is the Aw type, typical of savannas with two well defined seasons: one dry and cold (autumn and winter) and one hot and humid (spring and summer), according to the Köppen classification. The meteorological data measured during the experiment is presented in Figure 1.
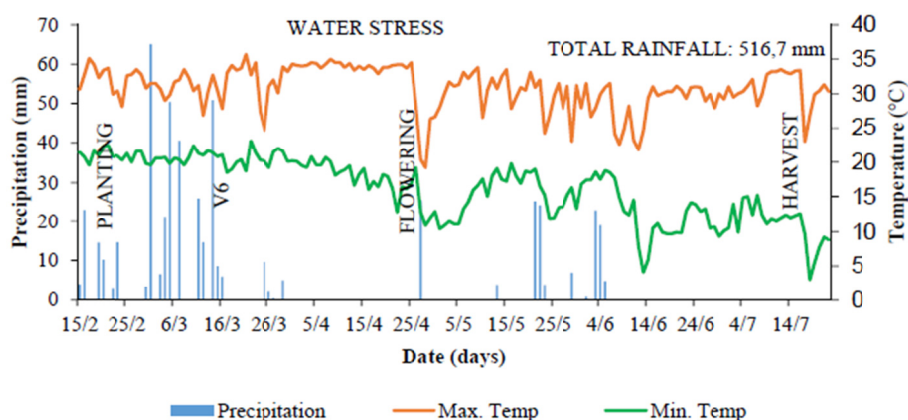

Figure 1. Rainfall (mm), maximum and minimum temperatures (ºC), in the experimental area from February to July 2016

Source: INMET (2016).

The soil in the area was classified as dystroferric Red Latosol (LVdf), with a clay texture. Prior to the start of the research, the area had been cultivated for at least 10 years with soybean followed by corn or sorghum as a second crop using no-till farming and sometimes using simple superphosphate as the main source of phosphate fetilizer.

This research with its treatments (doses of gypsum and phosphorus) began during the first crop of 2014/2015 and is the only year in which gypsum was applied. Since then, the area has been cultivated in sequence with the following crops: soybean, second corn crop intercropped with brachiaria and soybean again. Therefore, 16

months after the application of gypsum, the corn sown in the second crop of 2015/2016 was in fact the fifth crop cultivated.

The treatments related to P_2O_5 received fertilizers to increase productivity of soybean and second corn crop at their respective doses, which were 0, 50 and 100% of the recommended dose of P_2O_5.

For the chemical and textural analysis of the soil before the research, 10 simple soil samples were collected, before the 2014/2015 harvest, with the aid of a probe to compose a composite soil sample of the soil layers 0-20 and 20-40 cm deep (Table 1).

Table 1. Chemical and textural analysis of the soil at 0-20 and 20-40 cm depths of the experimental area before carring out the experiment in 2014, Jataí, GO, 2018

Porperties										
Depth	pH	M.O.	P (mel.)	K	Ca	Mg	Al	H+Al	CTC	V%
cm	(H_2O)	g kg^{-1}	mg dm^{-3}	---------------------------- cmolc dm^{-3} ----------------------------						
0-20	5.7	45.2	8.5	0.16	2.26	1.37	0.10	5.1	8.9	42.6
20-40	5.8	36.1	4.3	0.13	1.75	0.95	0.07	4.3	7.1	39.9

Since it is an experiment in which the effects of the treatments have been evaluated over time since the beginning of the first crop of the agricultural year of 2014/2015 and that the chemical analysis of the soil is always carried out after the harvest of the second corn crop, the soil's chemical analysis performed after the harvest of the second crop of the year of 2015 have also been presented in table 2 for a better explanation of the data.

The values of the chemical components in Table 2 are presented per plot according to the chemical changes occurring in the soil after the first application of the treatments (doses of gypsum and phosphorus). As P levels in the soil showed no response in the first year after application (year prior to this experiment), the mean values of P (Mehilch^{-1}) of treatments which received different doses of P_2O_5 were taken into account (Table 2).

Table 2. Chemical and textural analysis of the soil in the 0-20 and 20-40 cm layers of the experimental plots sampled after the harvest of the second corn crop in 2015, Jataí, GO, 2018

Soil Layer	Gypsum	pH H_2O	H^++Al^{3+}	Exchangeable cation				
				Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	P (Mehilch^{-1})
cm	Mg ha^{-1}			---------------------------- cmol$_c$/dm^3 ----------------------------				mg dm^{-3}
0-20	0	6.08	6.79	0.03	3.28	1.55	0.15	16.18
	1	6.23	6.10	0.03	3.86	1.53	0.14	14.00
	2	6.02	6.50	0.03	3.84	0.96	0.11	15.59
	4	5.93	6.67	0.03	4.29	0.65	0.11	18.83
	8	5.89	6.26	0.01	4.95	0.42	0.13	20.19
20-40	0	5.60	6.86	0.06	1.86	0.76	0.10	4.04
	1	5.68	6.39	0.02	2.14	0.77	0.10	3.59
	2	5.58	6.41	0.04	2.11	0.68	0.08	3.35
	4	5.52	6.53	0.02	2.62	0.58	0.07	4.73
	8	5.50	6.33	0.03	3.54	0.35	0.08	5.79

Sand	Silt	Clay
-------------------- g dm^{-3} --------------------		
585	240	175

Note. Modified by Soares (2016).

The experimental design consisted of 15 treatments established in randomized blocks, in a 5 × 3 factorial scheme, with four replications, with each plot measuring 11.25 m^2 (2.25 × 5 m). The first factor corresponded to the doses of gypsum (0, 1, 2, 4 and 8 Mg ha^{-1}), and these doses represent 0, 34, 68, 136 and 273% of the

recommended dose according to Sousa and Lobato (2004). The second factor corresponded to the doses of phosphorus (0, 40 and 80 kg ha^{-1} of P_2O_5) representing 0, 50 and 100% of the recommended dose.

For soil correction 3.0 Mg ha^{-1} of dolomitic limestone (85% PRNT) was applied relying soley on gravity to penetrate the soil 3 months before sowing the soybean crop in the agricultural year of 2014/2015. The gypsum was applied only once 30 days after the limestone in each treatment's respective doses and since then the area had been cultivated every year with a rotation of soybean and corn intercropped with brachiaria. Only the residual effect of the applied gypsum in a combination with phosphate fertilization was evaluated from the first year being carried out at the time of sowing of each crop in all agricultural years. The chemical makeup of the gypsum used in this research is shown in Table 3.

Table 3. Chemical composition and moisture of the agricultural gypsum used in the experiment. Jataí, GO, 2018

Gypsum Characteristics	Ca	S	Total Humidity	Humidity (65°)	P_2O_5	Cu	Fe	Mn	Zn
(%)	23.56	18.64	25.22	21.74	0.67	0.014	0.25	0.012	0.005

The recommended doses of N, P and K for a high yield of corn were 150 kg ha^{-1} of N and 80 kg ha^{-1} of P_2O_5 and K_2O. The sources used were urea, triple superphosphate and potassium chloride, respectively. The P_2O_5 was distributed at sowing time in the furrow at the doses for each treatment. It is important to note that for the crops prior to the second corn crop the same doses of P_2O_5 were used. N and K were manually distributed in each plot. For N, the applied urea doses were 30 kg ha^{-1} at sowing and 120 kg ha^{-1} when the crop was at the V3-V4 stage. The first and second applications of K_2O were carried out at 15 and 25 days after sowing with doses of 60 and 20 kg ha^{-1} of K_2O, respectively.

The sowing of the hybrid corn AG-8677 PRO 2 was carried out on February 23, 2016, using a 5 row planter tractor distributing 2.8 seeds per meter. Each plot was composed of 5 rows of 5 meters, the area of use being the 3 center rows with 0.50 m excluded from each end. Corn seeds were treated industrially with deltamethrin.

With the objective of controlling invasive plants, a dose 1.5 L ha^{-1} of commercial atrazine and 1.5 L ha^{-1} commercial glyphosate was applied during the V3-V4 stage. In order to control Spodoptera frugiperda (fall armyworm), two applications were made with the products Bulldock® 125 SC (beta-cyfluthrin) and Connect® (imidacloprid and beta-cyfluthrin), with 0.1 L ha^{-1} and 0.75 L ha^{-1}, respectively.

Weed management was performed with a post-emergence application of 2.5 L of glyphosate and 1.5 L of atrazine ha^{-1} for the control of unwanted soybean plants. Two preventive applications of fungicides with the product Approach Prima (0.3 L ha^{-1}) were applied for disease management. Pest control was performed with insecticide based on the level of weed control in the area using the products Bulldock 125 SC (0.1 L ha^{-1}) and Connect (0.75 L ha^{-1}).

At the time of the female inflorescence (silking), 5 leaves were collected per plot, opposite and below the first ear, excluding the central vein, to determine macro and micronutrient leaf contents according to Martinez et al. (1999). The leaves were kept in an oven at 60 ºC until it had a constant mass. The dry leaves were then sent to the Laboratory of Analysis of Soils and Vegetable Tissue of the State University Paulista (UNESP) "Júlio de Mesquita Filho" Ilha Solteira Campus for determination of macro and micronutrient contents according to methodology described by Malavolta et al. (1997).

Root samples were collected before harvesting the corn, where three soil samples were collected, randomly distributed within the area of use of each plot in the middle of the betweenlines, that is, 22.5 cm away from the planting lines, in the soil layers 0-20 and 20-40 cm in depth. For this operation, a probe was used which is capable of collecting a volume of 0.922 liters of soil for every 20 cm of depth. After the collection, with the aid of a sieve and running water, the soil and roots present in the sample were separated.

Subsequent to the separation, the collected root samples were left in a forced air circulation oven at 60 °C until the plant material had a constant mass, to be weighed to quantify the mass of dry roots in each plot. Subsequently, the dry root mass values obtained were corrected to a standard volume of 1.0 dm-3 of the initial soil sample.

At harvest time (07/13/2016), the ears present in the area of use of each plot were collected manually and stored in bags with the identification of their respective plots. Ten ears were randomly assigned to each plot to determine the dry mass of the ear, the number of rows of grain per ear, the length of the ear, the diameter of the ear, as well as, the diameter of the cobs. By subtracting the last two parameters and then dividing the result by two the average grain length was calculated.

Then, the ears were harvested together along with the others for grain sorting where they quantified their mass for calculating the grain yield per plot. Which was later transformed into kg ha^{-1} of grains with moisture corrected to 13%. For the determination of the mass of one thousand grains, the moisture was corrected to 13% and determined according to the methodology described in Brazil (2009).

The data was submitted to variance analysis at 5% and/or 1% of probability using the F test, and when only 3 levels were presented the means of data referring to the doses of P when significant to the F test were compared by the Tukey test. To present more than three levels of data concerning gypsum doses when significant to the F test, the data was submitted to the regression analysis calculated for linear and quadratic equations and accepted when significant up to 5% of probability by the F test. For this, the statistical program Assistat 7.7 was used (Silva & Azevedo, 2016).

3. Results and Discussion

The summary of the variance analysis (F-Test) for foliar macronutrient content in the studied corn hybrid is shown in Table 4. It was observed that there was no interaction between the studied factors for any of the foliar macronutrient content studied. There was significant effect only for gypsum variation for the foliar content of Ca^{2+} and Mg^{2+} (Table 4). The mean values of the Ca^{2+} foliar content were adjusted to the positive linear regression equation according to the increasing doses of gypsum (Figure 2).

Table 4. Summary of variance analysis (Test F) for: block, gypsum, phosphorus and their interactions for the foliar macronutrient contents in corn.

Variation Causes	N	P	K	Ca	Mg	S
Block	0.72 ns	8.28 **	5.23 *	1.44 ns	2.16 ns	2.16 ns
Gypsum (G)	1.07 --	0.68 --	1.28 --	4.59 --	2.05 --	0.99 --
Phosphorus (P)	0.04 ns	0.30 ns	0.13 ns	0.77 ns	1.16 ns	1.08 ns
G × P	0.79 ns	1.18 ns	0.88 ns	1.26 ns	1.23 ns	0.98 ns
Polynomial Regression						
Linear Reg.	1.02 ns	0.25 ns	0.68 ns	12.00 **	2.92 ns	0.20 ns
Quadratic Reg.	0.01 ns	1.99 ns	2.11 ns	1.74 ns	5.18 *	2.36 ns

Note. Polynomial Regression. ** significant at 1% probability ($p < 0.01$). * significant at 5% probability ($0.01 \leq p < 0.05$). ns not significant ($p \geq 0.05$).
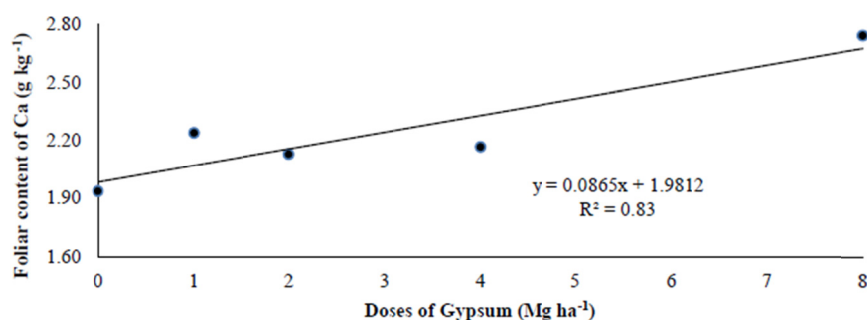

Figure 2. Ca^{2+} foliar content of corn crop due to doses of gypsum

Similar results were observed by Soares (2016) and (Caires, Blum, Barth, Garbuio, & Kusman, 2003), who verified a linear increase in Ca^{2+} concentrations in soybean foliar tissue, with the applied gypsum doses, and by (Caires, Garbuio, Churka, & Joris, 2011), who observed a positive effect of the gypsum on the Ca^{2+} foliar content in corn.

For the Mg^{2+} macronutrient content, the means were better fitted to the quadratic regression equation as a function of the gypsum doses, as can be observed in Figure 3. After deriving the quadratic equation, the highest leaf content of Mg^{2+} of 2.32 g kg^{-1} was obtained by using 2.22 Mg ha^{-1} of gypsum. This decrease in Mg^{2+} foliar content due to the use of gypsum above 2.22 Mg ha^{-1} can be explained by the reduction of Mg^{2+} in all the layers of soil. This is because, the application of gypsum in high doses can cause the movement of exchangeable

cations in the soil profile, leading Mg to move deeper through the soil, which results in the plant absorbing less of the nutrient and thus having less concentration of the nutrient in the leaf (Rampin, Lana, Frandoloso, & Fontaniva, 2011).
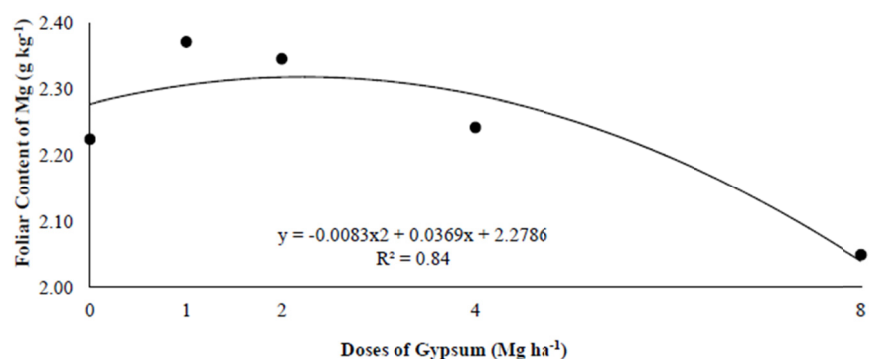

Figure 3. Mg^{2+} foliar content of corn crop as a function of gypsum doses

Caires, Kusman, Barth, Garbuio, and Padilha (2004) and Raij et al. (1998) also found a decrease in the Mg foliar content in corn due to gypsum. This reduction of Mg in corn due to high doses of gypsum shows that leaching of exchangeable Mg in the soil related to the use of large amounts of gypsum can impair the absorption of the nutrient by plants. In the literature there are also reports of the same thing having occurred in soybean crops (*Glycine max*) (Oliveira & Pavan, 1996; Caires et al., 1998; 1999).

Other factors may also influence the decrease of Mg^{2+} content through the use of gypsum. The Ca:Mg ratio is antagonistic, that is, the increase in the concentration of an ion causes a generally partial and reversible decrease in the absorption of another element, which combines to the carrier to cross the membrane in the same way (Malavolta, 2006; Prado, 2008). The absence of a response in the foliar content of P as a function of phosphate fertilization (Table 4) can be explained by the fact that water stress occurs when the second harvest corn crop is in most need of water.

The summary of the variance analysis (Test F) for the foliar content of micronutrients and crude protein (PB%) in the studied corn hybrid is shown in Table 5. It was observed that there was no interaction between the factors for any of the studied variables. By evaluating in isolation the dose variations of P_2O_5, it was verified that there was no significance for any of the foliar micronutrient content studied (Table 5).

Table 5. Summary of the variance analysis (F test) for: block, gypsum, phosphorus and their interactions for the micronutrients: zinc (Zn), manganese (Mn), iron (Fe) copper (Cu) and crude protein (PB%) of the foliar analysis, determined at the full flowering stage of the corn crop

Variation Causes	Zn	Mn	Fe	Cu	PB%
Block	10.19[**]	9.42[**]	1.60[ns]	6.71[**]	0.72[ns]
Gypsum (G)	2.64[¨]	0.60[¨]	1.57[¨]	1.63[¨]	1.07[¨]
Phosphorus (P)	1.03[ns]	0.12[ns]	1.00[ns]	1.14[ns]	0.04[ns]
G × P	2.21[ns]	1.09[ns]	1.15[ns]	0.23[ns]	0.79[ns]
Polinomail Regression					
Linear Reg.	10.33[**]	0.49[ns]	0.51[ns]	0.43[ns]	1.02[ns]
Quadratic Reg.	0.25[ns]	1.25[ns]	5.01[ns]	2.83[ns]	0.01[ns]

Note. [¨] Polinomial Regression. F Test does not apply. [**] significant at 1% probability ($p < 0.01$). [*] significant at 5% probability ($0.01 \leq p < 0.05$). [ns] not significant ($p \geq 0.05$).

When evaluating the dose variations of gypsum in isolation, there was only significance for the Zn^{2+} foliar content, adjusting the negative linear regression equation (Figure 4), that is, there was a reduction of Zn^{2+} foliar content as a function of increasing the doses of gypsum. This result can be explained by the increase in the Ca^{2+}

foliar content due to the increasing doses of gypsum (Figure 2), since high levels of Ca^{2+} in the soil provide an inhibitory effect for the absorption of Zn^{2+} (Malavolta, 2006).
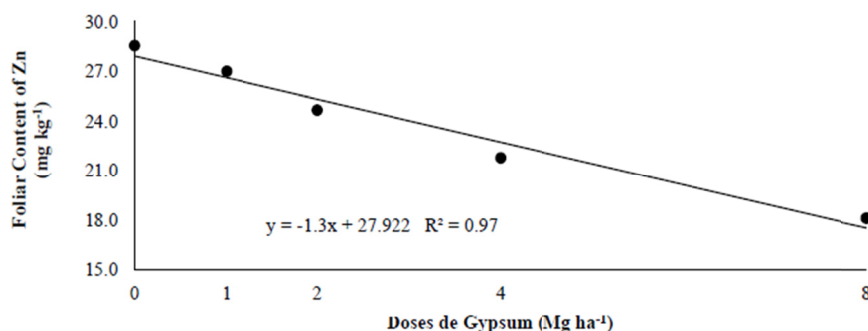

Figure 4. Zn^{2+} leaf content of corn crop due to gypsum doses

The variance analysis (F-test) of the dry root mass of the studied corn (DRM) in the 0-20 and 20-40 cm soil layers is shown in Table 6. It can be observed that there was interaction between the studied factors only in the 20-40 cm layer of soil. The corn DRM averages were not altered with the applied gypsum doses for any soil layer studied.

Table 6. Summary of variance analysis (Test F) for: block, gypsum, phosphorus and their interactions for dry root mass (DRM)

Variance Causes	DRM	
	0-20 cm	20-40 cm
Block	2.26 [ns]	0.36 [ns]
Gypsum (G)	0.72 [¨]	0.66 [¨]
Phosphorus (P)	3.23 [*]	1.54 [ns]
G × P	1.42 [ns]	0.90 [*]
Polinomial Regression		
Linear Reg.	0.04 [ns]	0.73 [ns]
Quadratic Reg.	2.79 [ns]	0.18 [ns]

Note. [¨] Polinomial Regression. [**] significant at 1% probability ($p < 0.01$). [*] significant at 5% probability ($0.01 \leq p < 0.05$). [ns] not significant ($p \geq 0.05$).

Evaluating, in isolation, the doses of P, only the dry roots mass in the 0-20 cm layer of soil presented different results among the evaluated doses (Table 7). As P_2O_5 doses increased, there was a reduction in dry root mass, where plants grown in plots that received 80 kg ha^{-1} of P_2O_5 showed a reduction in root mass when compared to plants that did not receive phosphate fertilization.

The low values of DRM obtained possibly occurred due to modifications in root growth and architecture since they are variables that directly interfere in the DRM. Which were pointed out by several authors as a response to low availability of P (Alves et al., 2002).

Table 7. Dry root mass (DRM) of corn in the 0-20 cm layer of soil when evaluating the phosphorus doses in isolation

Doses of P_2O_5 (kg ha^{-1})	DRM (g dm^{-3})
0	8.31 a
40	7.89 ab
80	7.01 b
CV%	21.93

Note. The averages followed by the same letter do not differ statistically from each other, according to the Tukey test at 5% probability.

Pereira (2007), evaluating the DRM in many soil layers noted that in the presence of gypsum the dry root mass values tend to decrease in the 0-10 cm layer of soil and increase in layers deeper than 10 cm. Different results were found by Rosolem e Marcello (1998), who observed that the low availability of P, induces root growth in terms of length with a consequent increase in surface area of the root, but without increasing dry root mass.

In the interaction between gypsum and phosphorus there was an increase in the dry root mass of corn with the increase in the availability of P only in the 20 to 40 cm layer of soil and only for the dose of 8, 0 Mg ha^{-1} of gypsum (Table 8).

Table 8. The result of the interaction between gypsum and phosphorus for the dry root mass of corn of the 20-40 cm layer

P_2O_5 doses (kg ha^{-1})	Gypsum doses (Mg ha^{-1})				
	0	1	2	4	8
	--- g dm^{-3} ---				
0	4.23 a	4.44 a	4.20 a	3.87 a	3.63 b
40	4.65 a	4.25 a	4.70 a	3.49 a	3.66 b
80	3.84 a	4.46 a	4.06 a	4.22 a	5.25 a
CV %	16.29				

Note. The averages followed by the same letter in the column do not differ statistically from each other. The Tukey test was applied at 5% probability.

The summary of the variance analysis (F-Test) for corn production components is shown in Table 9. There was no interaction between the factors studied (G × P) for any of the evaluated production components. For the P_2O_5 dose variation factor, only ear diameter and number of rows presented different behavior out of the doses evaluated (Table 9).

For ear diameter, the treatment that did not receive phosphate fertilization presented lower values in relation to the others. For the number of rows per ear, there was a significant difference only between treatments 0 and 80 kg ha^{-1} of P_2O_5 (Table 10). These components exhibit a relationship of dependency with each other, since the increase in the number of rows usually results in ears with larger diameter.

Table 9. Summary of variance analysis (Test F) for: block, gypsum, phosphorus and their interactions for the production components in corn

Variation Causes	Ear Diameter	Cob Diameter	Grain Length	Ear Length	Number of Rows	1000 Grains
Block	2.09 ns	2.88 *	11.79 **	4.68 **	0.71 ns	12.67 **
Gypsum (G)	0.85 ¨	0.26 ¨	0.25 ¨	1.52 ¨	1.64 ¨	0.81 ¨
Phosphorus (P)	4.22 *	1.29 ns	2.37 ns	1.84 ns	3.32 *	1.36 ns
G × P	0.40 ns	0.32 ns	0.38 ns	0.54 ns	0.72 ns	0.44 ns
Polinomial Regression						
Linear Reg.	0.13 ns	0.21 ns	0.64 ns	0.36 ns	0.50 ns	0.41 ns
Quadratic Reg.	2.24 ns	0.16 ns	0.32 ns	5.46 *	2.76 ns	2.22 ns

Note. ¨ Polinomial Regression. ** significant at 1% probability ($p < 0.01$). * significant at 5% probability ($0.01 \leq p < 0.05$). ns not significant ($p \geq 0.05$).

Table 10. Average ear diameter, number of rows and productivity, evaluating the doses of phosphorus in isolation

Doses of P_2O_5 (kg ha^{-1})	Ear Diameter (cm)	Number of Rows (un)
0	4.46 b	14.27 b
40	4.56 a	14.39 ab
80	4.56 a	14.64 a
CV%	2.96	2.93

Note. The averages followed by the same letter do not differ statistically from each other using the Tukey test at 5% probability.

The increase in ear diameter and number of rows per ear, provided by the treatments with phosphorus, is due to the higher demand for this nutrient during the V6 stage, which positively affects with the number of grain rows in the V8 stage, length of ears in the V12 stage and consequently in productivity (Fancelli & Dourado Neto, 2000).

Evaluating, in isolation, the dose variations of gypsum (Table 9), there was only significance for the the length of ear component. It is noteworthy that the averages adjusted better to the quadratic regression equation model due to the increase of the gypsum doses (Figure 5), where the highest ear length of 14.01 cm was obtained with application of 3.28 Mg ha^{-1} of gypsum.

Amaral et al. (2017) evaluating the length of corn ears cultivated in the second harvest crop observed an increase due to increasing doses of gypsum (0, 1, 2, 3 and 4 Mg ha^{-1}), which obtained the highest values of ear length at the dose of 4 Mg ha^{-1}. A different result was obtained by Soares (2016), who did not observe any effect of agricultural gypsum on the length of ears from the second corn crop, however for this author rainfall distribution was abundant and uniform during the conduction of the experiment.
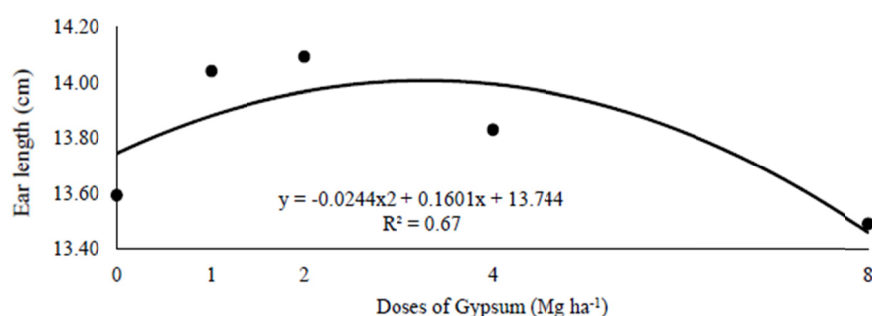

Figure 5. Ear length of the corn crop due to doses of agricultural gypsum

The summary of the variance analysis (Test F) for corn grain yield is shown in Table 11. There was no interaction between the different sources studied. However, it is possible to notice that there was an isolated significant effect for the doses of gypsum and P.

Table 11. Summary of variance analysis (Test F) for: block, gypsum, phosphorus and their interactions for corn grain yield

Causes of Variance	Produtivity (kg ha^{-1})
Block	2.39 [ns]
Gypsum (G)	4.34 [--]
Phosphorous (P)	4.05 [*]
G × P	2.10 [ns]
Polinomial Regression	
Linear Reg.	3.00 [ns]
Quadratic Reg.	10.86 [**]

Note. [--] Polinomial Regression. [**] significant at 1% probability ($p < 0.01$). [*] significant at 5% probability ($0.01 \leq p < 0.05$). [ns] not significant ($p \geq 0.05$).

Evaluating, in isolation, the P_2O_5 values against productivity, (Table 12), as well as, the two production components mentioned in Table 10, showed that there are increases in productivity due to the availability of P because of fertilization. The treatment that received 80 kg ha^{-1} of P_2O_5, was superior to the treatment with no phosphate fertilization (Table 12). These results can be explained by the increases observed in ear diameter and number of rows (Table 10), since both add to yield.

Table 12. Corn grain yield, with the variation factor P evaluated in isolation

Doses of P_2O_5 (kg ha^{-1})	Produtivity (kg ha^{-1})
0	1778.56 b
40	1886.44 ab
80	1935.49 a
CV%	9.56

Note. The averages followed by the same letter do not differ statistically from each other using the Tukey test at 5% probability.

Evaluating, in isolation, the grain productivity against the various gypsum doses, there is adjustment to the quadratic equation model as a function of the gypsum doses (Figure 6), where maximum productivity was obtained, 2,054.9 kg ha^{-1}, with an application of 4.38 Mg ha^{-1} of gypsum. Under conditions of water stress, as in this study, the corn grain yield responded to the application of agricultural gypsum beyond the dose recommended by the formula NG = 5 × g kg^{-1} of clay, which for this study is 2.93 Mg ha^{-1} of gypsum.
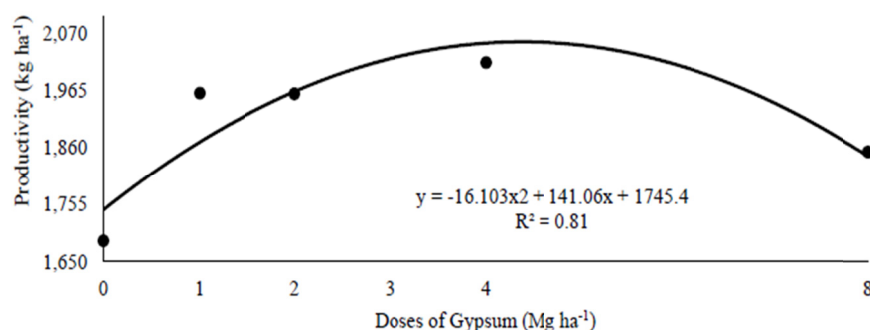

Figure 6. Corn productivity due to gypsum doses

The low yields of second corn crop found in this study are due to the long period of water stress, totaling 65 days with accumulated rainfall of 46.1 mm between the V6 and grain fill stages (Figure 1). Soares (2016) did not observe an effect of the agricultural gypsum on the soybean crop and the second harvest corn, in a year of good rainfall, unlike Amaral et al. (2017), which in the absence of water stress, observed in a test also conducted in Dystroferric Red Latosol during a year of good rainfall, evaluating the yield of corn grown in the second crop with increasing doses of gypsum (0, 1, 2, 3 and 4 Mg ha^{-1}) observed a linear increase in productivity, with a productivity of 6480 kg ha^{-1} at a dose of 4 Mg ha^{-1}.

Sousa, Lobato, and Rein (2005), observed the highest corn yield of 5525 kg ha^{-1} at the dose of 1 t ha^{-1} of gypsum, while Caires et al. (2004) found a higher increase in yield with 9 t ha^{-1} of gypsum in a Dystrophic Red Latosol (cited by Amaral et al., 2017).

4. Conclusion

The residual effect of the gypsum (16 months after its application) does not provide an increase in the efficiency of phosphate fertilization for the second corn crop.

Under water stress conditions, the yield of corn grains responds well to the application of agricultural gypsum above that of the recommended dose of the formula NG = 5 × g kg^{-1} of clay, which for this research is 2.93 Mg ha^{-1} of gypsum.

Phosphorus provides increases in corn grain yield only when 100% of the recommended dose is applied (80 kg ha^{-1} of P_2O_5).

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