

*Full Length Research Paper*

## Foliar tissue, grain yield and economic return by surface application of gypsum and different number of soybean plants in precision seed drill

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The gypsum has elevated calcium and sulfur in the soil, and there are reports of increased grain yield of soybean with reduced number of plants, being necessary in conjunction with economic return on investment. This study investigated the effect of application superficial of gypsum and different numbers of plants in precision seed drill in the nutritional aspect of the leaf tissue, grain yield of soybean cultivated in clayey Rhodic Hapludox and economic return on investment. Used in the experiment was a randomized block design in scheme tracks (4 × 4), with four doses of gypsum (0, 800, 1600 and 2400 kg ha<sup>-1</sup>) applied at the V4 stage of soybean Vmax RR (SYN 7059RR) and four variations in the number of plants (12, 14, 16 and 18 plants per meter), with four replications. Samples of leaf tissue were collected in the flowering stage of soybean in the 2011/2012 crop, and then determined the levels of Ca, Mg, K, P, S, Cu, Zn, Mn and Fe. At maturity the yield assessment was performed. The number of plants per meter with precision seed drill and superficial application of gypsum at the V4 stage do not affect the content of macro-and micronutrients leaf tissue of soybean cultivar SYN 7059RR. The application of gypsum at the V4 stage and reducing the number of plants per meter statistically do not affect the grain yield. Recommend lower number of plant (12 plants m<sup>-1</sup>) on soybean cultivar for SYN 7059RR. The economic returns using higher amount of seed (14, 16 and 18 plants m<sup>-1</sup>) is -283, -260 and -271% with investment of US\$ 13.76, 29.24 and 44.72. Use of gypsum focused costs to only two cultures (soybeans and wheat) during the crop season provides residual soil of 104.43 kg ha<sup>-1</sup> of S. Application 800 kg ha<sup>-1</sup> gypsum provides US\$ 14.56 profit with 44% economic return to payment half investment (US\$ 33.32).

**Key words:** No-till, fertilization, plant population, seeding rate, investment return.

### INTRODUCTION

The no-tillage system became indispensable practice in Brazil, reducing the impacts of intensive agricultural

activity on the environment and increasing the competitiveness of the agricultural commodities in the

international market by grains demands, increasing grain yield and reducing need to use pastures and forests. No-till system requires proper management to maintain soil fertility and provide adequate nutrition to plants (Caires et al., 2011) and adequate number of plants (Tourino et al., 2002; Mauad et al., 2010) to increase grain yield.

One factor that may limit soybean grain yield is soil acidity in surface and subsurface (Gelain et al., 2011). The limestone application is effective in controlling surface acidity, but shows little mobility in the ground, so it has less action in the subsurface layers. Alternatively can be use the gypsum that although minimally alter the pH, it is efficient to reduce the exchangeable  $Al^{3+}$  toxicity to plants, reducing the activity of this element in the soil solution, especially in subsurface layers, in addition to providing nutrients for plants by sulfur (S) and calcium (Ca) (Neis et al., 2010; Elrashidi et al., 2010).

The gypsum can increase crop yields due to increased Ca and sulfate ( $SO_4^{2-}$ ) available to plants (Caires et al., 2002, 2004). Caires et al. (2003) studied the application of limestone and gypsum on the surface and embedded reported that gypsum improved the environment for root growth in the subsoil, but did not cause improvement in the production of soybeans in long time by no-till. Different crop responses to gypsum have been observed in several field studies gypsum application increased corn production (Farina et al., 2000; Caires et al., 2004) but did not increase statistically grain yield of soybean (Oliveira and Pavan, 1996; Caires et al., 2003). However, in Brazilian cerrado (low pH surface and subsurface) in in Red Latosol the application gypsum has promoted increased yield of soybeans in low time by no-till (Broch et al., 2011), by providing S to plants, which plays a fundamental role as a component of some amino acids found in high content in soybean (Novais et al., 2007), intensifying the demand of S in legumes to accumulate protein (Brochi et al., 2011). In fact, Sávio et al. (2011), Motta et al. (2013) and Pauletti et al. (2014) identify responses with lower doses of gypsum in soybean ( $800$  at  $1500 \text{ kg ha}^{-1}$ ).

Moreover, among the cultural practices used to obtain higher production of plant species has to choose the best arrangement of plants is important per favoring weed control and increases the efficiency for the utilization of environmental resources such as light, water and nutrients (Albuquerque et al., 2012), reducing pressure by the increase in crop area expansion. Thus, cultural management or precision seeding aims to obtain optimum plant population and optimal spatial distribution of plants between and within-row, maximizing crop performance at no additional cost (Coelho et al., 2002).

Crops with elevated plant population increase cost with seeds, can lead to lodging of plants rather than providing

increased yield. Low populations favor the development of weeds per increasing distance between plants and can result in lower yield (Vasquez et al., 2008). So much so that studies with population of soybean plants have shown no effect on grain yield, which is associated with phenotypic plasticity of the crop. The plants compensate for the reduction in the number of plants, by increasing the individual legumes production, contributing to increased tolerance of this variation (Mauad et al., 2010).

Density of plants effects highlight the importance of uniformity of plants from increase number of plants to achieve greater yield potential. Gypsum efficiency in correcting soil acidity with problems in subsuperficial layers and increase nutrients. Therefore, need for economic evaluation to use new and different technologies together in the crop system. One of fundamental importance to assess the economic level of the input in order to avoid over or under dosing consequently ensure economic return. Thus, it is appropriate to identify the return on investment for each technology used and highlight the point of greatest return on investment.

In addition, use of technologies such as gypsum fertilizer and management of soybean identify adequate number of plants per meter can interfere grain yield, being necessary to know the economic return on investment with these interferences in the crop system. In this sense, the objective of this study was to evaluate the effect of surface application doses of gypsum and different numbers of plants in precision seed drill in nutritional aspect of leaf tissue, grain yield of soybean in clayey Rhodic Hapludox and economic return on investment.

## MATERIALS AND METHODS

### Description of study

The study was conducted in Guaíra, western Paraná with the following coordinates  $24^{\circ} 21' S$  and  $54^{\circ} 12' W$ , with an altitude of 266 m. The area is grown in the crop sequence and tillage system 25 years ago, in the summer using soybean and wheat in the winter. The soil was classified of clayey Rhodic Hapludox (Eutroferic Red Latosol in the Brazilian classification) (Embrapa, 2013a), and the particle size and chemical soil characteristics are presented in Table 1. This soil develops high Ca/Mg (4.9) and mid-level S to soil with clay  $>400 \text{ g kg}^{-1}$  in 0 to 0.20 m depth, being recommended application of S to increase S levels and for maintenance fertilizer (Embrapa, 2013b).

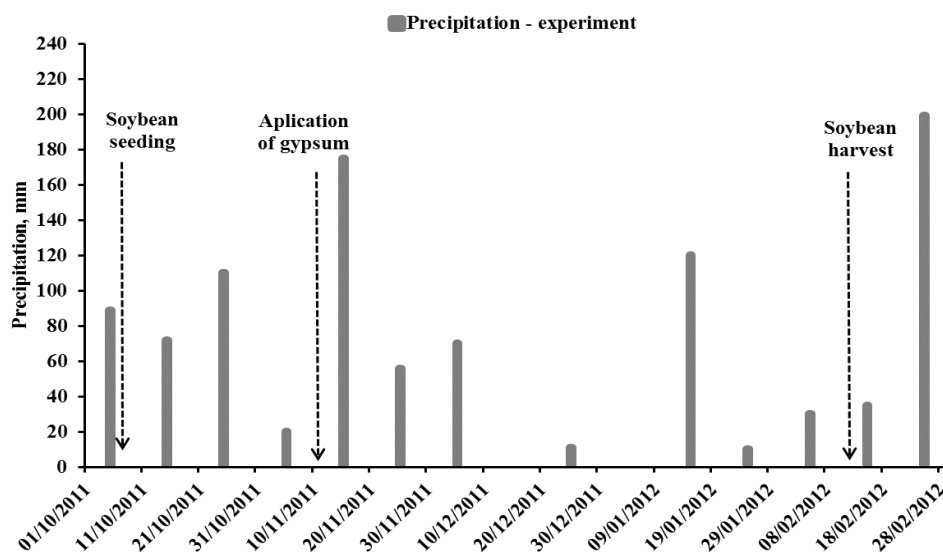
According to Koppen's classification, the climate of the region is of type Cfa, subtropical with rains well distributed throughout the year and hot summers (Caviglione et al., 2000). The rainfall recorded during the conduct of the experiment, between October 2011 and February 2012 was 997 mm (Figure 1), yet the greater volume of rainfall concentrated in the month of November and the

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**Table 1.** Granulometric and chemical attributes of clayey Rhodic Hapludox collected in layer of 0 - 0.2 m deep. Guaira, Paraná, Brazil, 2011.

pH <sup>(1)</sup>	Ca g dm <sup>-3</sup>	P <sup>(4)</sup> mg dm <sup>-3</sup>	Ca <sup>+2(2)</sup>	Mg <sup>+2(2)</sup>	K <sup>+(4)</sup>	Al <sup>+3(2)</sup>	H+Al <sup>(3)</sup>	SB	CTC
						cmol <sub>c</sub> dm <sup>-3</sup>			
5.40	19.09	9.70	7.85	1.60	0.71	0.00	4.28	10.16	14.44
Cu <sup>(4)</sup>	Zn <sup>(4)</sup>	Fe <sup>(4)</sup> mg dm <sup>-3</sup>	Mn <sup>(4)</sup>	S <sup>(5)</sup>	V	Clay <sup>(6)</sup>	Silt <sup>(6)</sup>	Sand <sup>(6)</sup>	
						g kg <sup>-1</sup>			
12.30	4.50	28.00	274	10.00	70.36	660	200	140	

<sup>(1)</sup>pH in CaCl<sub>2</sub> the ratio 1:2.5, <sup>(2)</sup>Extractor KCl 1 mol L<sup>-1</sup>, <sup>(3)</sup>Extractor calcium acetate 0.5 mol L<sup>-1</sup> pH 7.0, <sup>(4)</sup>puller Mehlich-1, <sup>(5)</sup>Extractor Ca (H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub> 500 mg L<sup>-1</sup> of P in HOAc 2 mol L<sup>-1</sup> (Embrapa, 2009), <sup>(6)</sup>hydrometer method (Embrapa, 1997).



**Figure 1.** Precipitation (mm) in the experimental area during the period of driving between 10/01/2011 to 03/01/2012 in cumulative 15 days.

end of February, after harvest and lower values in the months of December 2011 and January 2012.

#### Experimental design, treatments and conduction

The experimental design was randomized blocks, in scheme of tracks (4 × 4), with four repetitions, totaling 64 experimental plots. The first factor was composed of increasing agricultural gypsum doses (0, 800, 1,600 and 2,400 kg ha<sup>-1</sup> agricultural gypsum with 17% of Ca, 15% S-SO<sub>4</sub><sup>2-</sup>, 5% S). The second factor was constituted of the variation in the number of plants per meter (12, 14, 16 and 18 plants of soybean per meter). The application of gypsum was conducted to haul in 11 November 2011, during the vegetative stage V4 soybean culture. Gypsum application used low doses to provide S to cultures in crop system (soybean and wheat), thus, first dose limit by uniform distribution by equipment's, that is 800 to 1000 kg ha<sup>-1</sup> (Raij, 2008).

The cultivation of soybeans was conducted after the wheat harvest in no-tillage system. The sowing of culture was conducted on 7 October 2011, using the transgenic cultivar Vmax RR (SYN 7059RR), 197 g by thousand seed weight (Syngenta, 2015) and 90% germination index recommended for the region, as agroclimatic zoning for the state of Paraná (Mapa, 2011). The plots had five meters in length, and width with six lines of culture, being

the spacing between rows of 0.45 m. Thus, each installment had a total area of 13.50 m<sup>2</sup> and floor area of 5.40 m<sup>2</sup>, disregarding 0.5 m on each side that make up the length of parcel and a line of culture on each side that make up the width of the parcel.

In the treatment of the seeds was used the fungicide Maxim XL (25 g L<sup>-1</sup> of fludioxonil and 10 g L<sup>-1</sup> of metalaxyl-M) at the dosage of 100 ml for 100 kg of soya beans. For the chemical fertilization of sowing was used 250 kg ha<sup>-1</sup> of the commercial formulation with 20% phosphorus and 20% potassium. Monitoring of pests, diseases and weeds and the need for control was carried out in accordance with the recommendations for the culture of soybean (Embrapa, 2010).

#### Measurements and field management

In the culture of soybean foliar tissue samples were collected in full bloom, as recommended procedures regarding time and leaves sampled by Malavolta et al. (1997), for the determination of the levels of Ca, Mg, K, P, S, Cu, Zn, Mn and Fe (Embrapa, 2009). At the point of harvest, was conducted the collection of aerial part of plants of the crop of soybeans, thrashing in thresher Winning B-150 for the obtaining of the beans, which were heavy for determination of yield, with subsequent standardization of 14% of the samples for moisture in soybean culture.

## Economic return on investment

Investment, grain yield return and economic return on investment calculation was performed through the costs to acquire used amount of seed or gypsum, together with income grain yield related to the treatment of 12 plants per meter or absence gypsum application. Cost of gypsum was divided equally between soybean and wheat used in crop system. Also calculated S residual after two crops (soybean and wheat) in crop system and was considered export of S by cultures.

Equations used for available investment, grain yield return and economic return with different number of plants:

$$i) \text{ Costs seeds (US\$ ha}^{-1}\text{)} = \text{"Use seeds (kg ha}^{-1}\text{)}^{(1)} * \text{"Costs seeds (US\$ kg}^{-1}\text{)}^{(2)}$$

<sup>(1)</sup> considered 90% of emergence and 197 g for mass 1000 grains;

<sup>(2)</sup> Costs seed in fev 2015.

$$ii) \text{ Costs seeds 12/14/16 (US\$ ha}^{-1}\text{)} = \text{Costs seeds '14/16/18 plants' (US\$ ha}^{-1}\text{)} - \text{Costs seeds '12 plants' (US\$ ha}^{-1}\text{)}$$

$$iii) \text{ Variation grain soybean 14/16/18 (kg ha}^{-1}\text{)} = \text{"Grain yield '14/16/18 plants' (kg ha}^{-1}\text{)} - \text{"Grain yield '12 plants' (kg ha}^{-1}\text{)}$$

$$iv) \text{ Income soybean (US\$ ha}^{-1}\text{)} = \text{"Variation grain soybean 14/16/18 (kg ha}^{-1}\text{)} * \text{"Soybean price (US\$ kg}^{-1}\text{)}$$

$$v) \text{ Profit or Prejudice (US\$ ha}^{-1}\text{)} = \text{"Income soybean (US\$ ha}^{-1}\text{)} - \text{"Costs seed (US\$ ha}^{-1}\text{)} |;$$

$$vi) \text{ Investment return} = \text{"Prejudice (US\$ ha}^{-1}\text{)} - \text{"Costs seed (US\$ ha}^{-1}\text{)} | / \text{"Costs seed (US\$ ha}^{-1}\text{)} |$$

$$vii) \text{ Investment return (\%)} = \text{"Prejudice (US\$ ha}^{-1}\text{)} - \text{"Costs seed (US\$ ha}^{-1}\text{)} | / \text{"Costs seed (US\$ ha}^{-1}\text{)} | * 100.$$

Equations used for available investment (costs gypsum), grain return and economic return with doses of gypsum:

$$i) \text{ Costs doses applied (US\$ ha}^{-1}\text{)} = \text{"Doses of gypsum (kg ha}^{-1}\text{)} * \text{"Costs product applied (US\$ kg}^{-1}\text{)}^{(1)}$$

$$ii) \text{ Total Costs gypsum (US\$ ha}^{-1}\text{)} = \text{"Costs doses applied (US\$ ha}^{-1}\text{)} * \text{"Costs application (US\$ ha}^{-1}\text{)}^{(1)}$$

<sup>(1)</sup> Costs gypsum and application in fev 2015.

$$iii) \text{ Costs gypsum 'soybean crop' (US\$ ha}^{-1}\text{)} = \text{"Total Costs gypsum 'doses' (US\$ ha}^{-1}\text{)} - \text{"Total Costs gypsum 'absence gypsum' (US\$ ha}^{-1}\text{)}$$

$$iv) \text{ Variation grain soybean 'doses gypsum' (kg ha}^{-1}\text{)} = \text{"Grain yield 'doses gypsum' (kg ha}^{-1}\text{)} - \text{"Grain yield 'absence gypsum' (kg ha}^{-1}\text{)}$$

$$v) \text{ Income soybean (US\$ ha}^{-1}\text{)} = \text{"Variation grain soybean 'doses gypsum' (kg ha}^{-1}\text{)} * \text{"Soybean price (US\$ kg}^{-1}\text{)}$$

$$vi) \text{ Profit or Prejudice (US\$ ha}^{-1}\text{)} = \text{"Income soybean (US\$ ha}^{-1}\text{)} - \text{"Costs gypsum 'soybean crop' (US\$ ha}^{-1}\text{)} |;$$

$$vii) \text{ Investment return} = \text{"Profit or Prejudice (US\$ ha}^{-1}\text{)} - \text{"Costs gypsum 'soybean crop' (US\$ ha}^{-1}\text{)} | / \text{"Costs gypsum 'soybean crop' (US\$ ha}^{-1}\text{)} |$$

$$viii) \text{ Investment return (\%)} = \text{"Profit or Prejudice (US\$ ha}^{-1}\text{)} - \text{"Costs gypsum 'soybean crop' (US\$ ha}^{-1}\text{)} | / \text{"Costs gypsum 'soybean crop' (US\$ ha}^{-1}\text{)} | * 100.$$

Equation used to describe S residual by gypsum in soil after two crops (soybean and wheat) in crop system:

$$S \text{ residual gypsum (kg ha}^{-1}\text{)} = \text{"Input S (kg ha}^{-1}\text{)} - \text{"S grain exported soybean (kg ha}^{-1}\text{)} - \text{"S grain exported second crop - wheat (kg ha}^{-1}\text{)}$$

## Statistical analysis

The data were subjected to analysis of variance at the 5% level of significance and in the event of a significant effect for the effect of gypsum and number of plants, regression analysis was performed using the SAEG 8.0 Program (Saeg, 1999). After, describing the

economic return on investment for the effect of gypsum and number of plants with grain yield and costs.

## RESULTS AND DISCUSSION

### Leaf tissue

The addition of gypsum to the soil to haul in soybean, specifically in the vegetative stage until the dose of 2400 kg ha<sup>-1</sup>, as well as different numbers of plants did not influence foliar concentrations of macro and micronutrients in soybean (Table 2 and 3). In order that the average levels found were 6.65, 23.98, 2.30, 13.30 g kg<sup>-1</sup> and 28.22, 33.08, 72.78 and 171.09 mg kg<sup>-1</sup> of P, K, S, Ca, Cu, Zn, Mn and Fe, respectively, considered adequate (Embrapa, 2010).

The average content of 2.40 g kg<sup>-1</sup> of Mg seen in Table 1, face down sufficiency range between 2.5 and 10 g kg<sup>-1</sup> of Embrapa (2010), may be related to elevated levels of Ca and K in soil (Table 1), mainly caused by the imbalance between cations in the soil, which may adversely affect the development of plants (Marschner, 2012). Prochnow et al (2010) and Salvador et al. (2011) highlighted the importance of the relationship between Ca:Mg:K in Brazilian agriculture, and Oliveira Júnior et al. (2013) guides to evaluate the relationship between these cations together with bands of sufficiency to recommend the application of lime and fertilizer. Also noteworthy, the average leaf P content of 6.87 g kg<sup>-1</sup>, as to Embrapa (2010), the P content in leaf sufficient in soybeans is in the range from 2.5 to 5.0 g kg<sup>-1</sup>. Thus, it can be seen that the leaf P content was found high above the sufficiency range. However, in relation to the effect of treatments on leaf P content, Nogueira and Melo (2003) and Quaggio et al. (1998) also found no increase in foliar P concentration with application of gypsum preceding the cultivation of annual crops. For K, Ca and S levels of 23.98, 13.30 and 2.30 g kg<sup>-1</sup> were found in leaf tissue of soybean, respectively (Table 2), the point was not that we found a significant effect levels foliar Ca and S, which are added to the soil with the application of gypsum. This fact is probably due to the sufficient level of these nutrients in the soil (Raij, 2008), as shown in Table 1. Moreover, Souza et al. (2012) found an increase in the accumulation of nutrients in the soybean shoot with the use of gypsum, but the elevation of levels of compaction reduced the accumulation of nutrients, and have found that the bulk density remained high for the development of roots, even with the other Poacea in prior to the deployment of soybean cultivation.

Generally, use of lower doses to supply S to cultures, tested in this work, becomes more interesting because the Mg leaching, provided by surface layer of gypsum, accumulates in 40 to 80 cm layers of soil (Zambrosi et al., 2007). Thus, lower doses of gypsum allows reuse Mg leaching, because gypsum facilitates root growth in subsurface layers, recycling Mg by these layers

**Table 2.** F values, coefficient of variation (CV) and phosphorus (P), potassium (K), sulfur (S), calcium (Ca) and magnesium (Mg) in the leaf tissue of soybean, arising from the use of different number of plants per meter with precision plants drill (Number plants) and surface application of gypsum in soybean. Guaíra, Paraná, Brazil, 2012.

Treatments	----- g kg <sup>-1</sup> -----									
	P		K		S		Ca		Mg	
Number plants m <sup>-1</sup>										
12	6.80		23.43		2.24		13.07		2.50	
14	6.43		26.10		2.20		13.95		2.39	
16	6.67		21.84		2.41		12.47		2.48	
18	6.69		24.56		2.35		13.72		2.23	
Gypsum --- kg ha <sup>-1</sup> ---										
0	6.87		24.84		2.34		14.85		2.37	
800	6.90		26.29		2.19		12.25		2.39	
1600	6.22		24.04		2.27		12.72		2.22	
2400	6.60		20.77		2.39		13.38		2.61	
	<b>Medium value</b>									
	6.65		23.98		2.30		13.30		2.40	
	<b>F value</b>									
N <sup>o</sup> plants	0.21	ns	1.66	ns	1.02	ns	0.62	ns	1.75	ns
Gypsum	1.34	ns	0.62	ns	0.10	ns	0.50	ns	0.49	ns
N <sup>o</sup> plants x Gypsum	1.12	ns	0.58	ns	1.67	ns	0.97	ns	1.39	ns
C.V. N <sup>o</sup> plants (%)	14.00		22.56		30.84		22.91		18.65	
C.V. Gypsum (%)	19.91		50.70		42.97		47.72		37.14	
C.V. N <sup>o</sup> plants x Gypsum (%)	13.19		31.72		25.72		15.56		22.53	

ns: not significant at the 5% level of probability by F test.

(Zambrosi et al., 2007).

However, Caires et al. (1998) and Soratto and Crusciol (2008) observed an increase in the sulfur content in the leaves in the use of gypsum before planting. In studies with low fertility soils, interference has been observed in chemical soil with gypsum application, being favorable to the development of soybean plants. Zapparoli et al. (2013) observed a reduction of Al<sup>+3</sup>, Ca and P increased with gypsum application in Typic aluminic sandy texture, as well as increase in the dry matter of the area.

Thus, it is advisable to carefully evaluate the use of gypsum in soils with high fertility, especially in relation to Ca and S, it becomes unnecessary investment, especially when Ca levels are elevated (Table 1), may interfere with the balance between Ca:Mg:K, impairing the uptake of cations by roots of soybean (Fonseca and Meurer, 1997; Watanabe et al., 2005; Novais et al., 2007). Nava et al. (2012) evaluated a cultivar of apple sensitive to calcium deficiency in soil with high fertility, found that the annual use of gypsum for eight years has magnesium deficiency in plants.

It can also be used to increase Ca/Mg ratio, for low ratio affect the absorption of Ca, with priority Mg absorption, which enhances vegetative growth of plants, however, with lower Ca does not confer increased

tolerance of plants to water adversity. Elrashidi et al. (2010) observed that the physiological effects of large amount additions of Ca<sup>2+</sup> and S-SO<sub>4</sub><sup>2-</sup> in the region of nutrient uptake by the roots may reduce crop yields after gypsum application. Caires et al. (2011b) found the following response decreasing order of crops the gypsum application: wheat>maize>soybean, and demand for Ca<sup>2+</sup> and S-SO<sub>4</sub><sup>2-</sup> followed the reverse order: soybean>maize>wheat.

The number of plants did not influence the nutrient content in the leaves of soybean (Table 2 and 3). So that morphological changes in the number of plants for planting soybeans have been common, restricted to the reduction in plant height (Marchiori, 1999), increase in the number of branches (Marchiori, 1999; Heiffig, 2002), increase in the number of pods per plant (Tourino et al., 2002) and number of seeds per pod (Tourino et al., 2002; Heiffig, 2002), providing similar yield, regardless of the number of plants.

### Grain yield

By analyzing the data in Table 3, there was significant interaction between seed number and of gypsum with

**Table 3.** F values, coefficient of variation (CV) and copper (Cu), zinc (Zn), manganese (Mn), iron (Fe) in leaf tissue and grain yield of soybean from the use of different number of plants per meter with seeder precision (Number plants) and surface application of gypsum in soybean. Guaíra, Paraná, Brazil, 2012.

Treatments	Cu		Zn		Mn		Fe		Grain yield	
	----- mg kg <sup>-1</sup> -----		----- mg kg <sup>-1</sup> -----		----- mg kg <sup>-1</sup> -----		----- mg kg <sup>-1</sup> -----		--- kg ha <sup>-1</sup> ---	
Number plants m <sup>-1</sup>										
12	33.07		32.06		70.42		161.11		2710.80	
14	23.39		34.85		72.07		170.34		2679.93	
16	30.14		34.84		81.19		173.71		2663.27	
18	26.26		30.57		67.46		179.22		2625.30	
Gypsum										
--- kg ha <sup>-1</sup> ---										
0	33.07		32.10		76.55		169.52		2640.43	
800	23.21		37.91		81.50		180.55		2768.82	
1600	29.02		27.48		64.86		176.39		2704.93	
2400	27.56		34.82		68.24		157.91		2565.12	
	<b>Medium value</b>									
	28.22		33.08		72.78		171.09		2669.83	
	<b>F value</b>									
Nº plants	2.97	ns	1.25	ns	2.39	ns	0.97	ns	0.17	ns
Gypsum	0.49	ns	2.05	ns	3.17	ns	0.42	ns	1.01	ns
Nº plants x Gypsum	1.96	ns	0.50	ns	0.71	ns	2.00	ns	2.20	*
C.V. Nº plants (%)	35.15		22.92		20.79		17.97		12.94	
C.V. Gypsum (%)	82.56		37.39		23.53		35.61		13.01	
C.V. Nº plants x Gypsum (%)	47.17		42.38		23.98		17.75		10.94	

\*: significant at 1% level of probability by F test, however the regression equations were not significant; ns: not significant at 5% level of probability by F test.

respect to yield variable indicating the use of a linear equation, but there was no significant for any of the possible equations to represent the effect the number of plants and effect of gypsum on yield of soybean. Accordingly, Neis et al. (2010) also observed no increase in soybean yield with application of gypsum, similar fact was detected by Oliveira and Pavan (1996) and Caires et al. (2003) with other annual crops.

Regarding the use of gypsum, there was no benefit from its application to soybean yield, a fact that should be associated with no presence of Al<sup>+3</sup> in the 0 to 0.02 m layer, and soil fertility limitation not present development of culture (Table 1). Moreover, opportunities to use gypsum as providing Ca in corn, with linear response in the yield of the application of gypsum even in fertile soils has been verified (Ferreira et al., 2013). Caires et al. (2011) also noted an increase in corn yield and increase of P and S in the leaf tissue both in corn and in soybeans when using gypsum dystrophic Oxisol. Another situation in response to gypsum was to reduce the alkalinity of the soil, to minimize the availability of sodium and chlorine ions in Cambissolo Saline Sodic (Santos et al., 2013).

On the other hand, same test in this research with adequate levels by Ca<sup>+2</sup> and absence Al<sup>+3</sup> in clayey

Rhodic Hapludox soil, soybean has not responded to high doses of gypsum probably due affinity divalent cations by the roots (Caires et al., 2011b). Differently from beans, wheat and corn, and with responses at doses up to 18000 kg ha<sup>-1</sup> gypsum (Nuernberg et al., 2005). However, there is the possibility of using gypsum to replace nutrients in conditions where there is no pronounced subsurface acidity problems at lower doses, particularly as a source of S (Caires et al., 2011a, b).

### Three recent research

Sávio et al. (2011) identified increase of Ca and S in leaf tissue and increase of 21% in grain yield of soybean with 1095 kg ha<sup>-1</sup> of gypsum and maximum number of pods with dose of 751 kg ha<sup>-1</sup> of gypsum by studying doses of 500, 1000 and 1500 kg ha<sup>-1</sup> compared absence of gypsum (dose 0) in Oxisol dystrophic come from degraded pasture with pH 4.5, 26 of V%, 0.4, 0.3 and 0.24 cmolc dm<sup>-3</sup> de Ca, Mg and K, respectively.

By observing the average yield values with 12 plants per meter was obtained 2710.8 kg ha<sup>-1</sup> of grain and 18 plants per meter was obtained 2625.30 kg ha<sup>-1</sup>,

**Table 4.** Investment by use seed in treatments with costs of seeds, grain return with grain yield and economic return to different number of plants. Guaira, Paraná, Brazil, 2012.

Treatments (Factor 1)		Investment			Grain return			Economic return			
Number of plants	Use of seed <sup>(1)</sup>	Costs seed	Costs seed ha <sup>-1(2)</sup>	Costs seed <sup>(3)</sup>	Grain yield <sup>(4)</sup>	Variation: grain soybean <sup>(3)</sup>	Soybean price <sup>(5)</sup>	Income soybean <sup>(3)</sup>	Profit or Prejudice <sup>(3,6)</sup>	Investment return <sup>(3,7)</sup>	
plants m <sup>-1</sup>	kg ha <sup>-1</sup>	US\$ kg <sup>-1</sup>	US\$ ha <sup>-1</sup>	US\$ ha <sup>-1</sup>	kg ha <sup>-1</sup>	kg ha <sup>-1</sup>	US\$ kg <sup>-1</sup>	US\$ ha <sup>-1</sup>	US\$ ha <sup>-1</sup>	-----	%
12	53.00	1.72	91.16	0.00	2710.80	0.00	0.37	0.00	0.00	0	0
14	61.00	1.72	104.92	- 13.76	2679.93	- 30.87	0.37	-11.51	- 25.27	- 2.83	- 283
16	70.00	1.72	120.40	- 29.24	2663.27	- 47.53	0.37	-17.73	- 46.97	- 2.60	- 260
18	79.00	1.72	135.88	- 44.72	2625.30	- 85.50	0.37	-31.89	- 76.61	- 2.71	- 271

<sup>(1)</sup> considered 90% of emergence, and 197 g for mass 1000 grains (Syngenta, 2015); <sup>(2)</sup> Costs seed (Copagril, 2015); <sup>(3)</sup> Other treatments compared treatment "12 plants"; <sup>(4)</sup> obtained in experiment; <sup>(5)</sup> by Chicago Board (Cmegroup, 2015); <sup>(6)</sup> Profit or Prejudice = "Income soybean US\$ ha<sup>-1</sup>" - | "Costs seed US\$ ha<sup>-1</sup>" |; <sup>(7)</sup> Investment return = ("Prejudice US\$ ha<sup>-1</sup>" - | "Costs seed US\$ ha<sup>-1</sup>" |) / | "Costs seed US\$ ha<sup>-1</sup>" | or Investment return (%) = ("Prejudice US\$ ha<sup>-1</sup>" - | "Costs seed US\$ ha<sup>-1</sup>" |) / | "Costs seed US\$ ha<sup>-1</sup>" | \* 100.

particularly statistically similar (Table 3). Within this context, Oz (2008) reports that higher plant population did not affect grain yield in soybean. Indeed, several studies have highlighted the lack of effect of the number of plants on yield of soybean, by varying the number of plants per meter between 9.9 to 15.3 (Vasquez et al., 2008) and 5.4 to 16 (Souza et al., 2010), probably due to favorable changes in yield components (Marchiori, 1999; Heiffig, 2002; Tourino et al., 2002).

A similar yield of the number of plants assessed can be explained by the greater number of pods and seeds per pod for treatments with fewer compensating for lower plants number of plants (Mauad et al., 2010). Indeed, Heiffig et al. (2006) also observed no significant effect by altering the number of plants in soybean.

Moreover, Peixoto et al. (2000) and Tourinho et al. (2012) observed an increase in yield due to the increase in the number of plants with achieving proper operation and uniform seeding. In work done by Cortez et al. (2011) found that the use of number of plants between 15 and 20 plants per

meter did not alter the yield of soybean, allowing used fewer plants to reduce spending on seeds for sowing. For Hörbe et al. (2013), the plant arrangement is a cultural practice that affects the yield of crops, the most important being the regular distribution of seeds, eliminating spaces between plants, the number of plants, especially in precision agriculture systems.

#### Economic return of investment

According to Table 4, the statistical difference between the grain yield of soybeans to increase from 12 to 18 plants per meter was not detected, even occurring grain yield 2710.80 and 2625.30 kg ha<sup>-1</sup>, respectively. However, when assessing the costs to acquire the seeds together with the income provided with different number of plants, it was found prejudice with more plants. Over 12 plants per meter showed a negative economic results, with values of \$ -25.27, -46.97 and -76.61 for the use of 14, 16 and 18 plants per meter,

respectively; in fact, to evaluate the economic return on investment when purchasing higher amount of seeds, the values were between -283, -260 and -271% for their treatments. The use of seeds to achieve 12 plants per meter is more efficient, since by increasing the number of plants the farmer will have prejudice to the other number of plants tested, interfering in the economic performance for soybean cultivar SYN 7059RR.

Other researchers, Tourinho et al. (2012), Heiffig et al. (2006), Oz (2008), Vasquez et al. (2008) and Souza et al. (2010) highlight the need for uniformity of plants in the area of cultivation, the distribution of plants is more important to increase grain yield of soybean than change number of plants. In addition, higher cost was observed to acquire higher amount of seeds affect income. In the economic return on investment was demonstrated that culture with fewer plants, together with the use of high quality seeds and sowing in suitable soil moisture conditions (Hörbe et al., 2013) has more uniform cultivation of culture (Tourinho et al., 2012) and better

**Table 5.** Investment, cost by doses of gypsum applied, cost just soybean crop (divided by two crops: soybean and wheat), grain return with grain yield, economic return with profit or prejudice with investment and investment return to soybean crop. Guaira, Paraná, Brazil, 2012.

Treatments (Factor 2)		Investment – Costs gypsum				Grain return				Economic return		
Doses of gypsum	Product applied <sup>(1)</sup>	Doses applied	Application	Total	Soybean crop <sup>(2)</sup>	Grain yield <sup>(3)</sup>	Variation: grain soybean <sup>(4)</sup>	Soybean price <sup>(5)</sup>	Variation: income soybean <sup>(4)</sup>	Profit or Prejudice <sup>(4,6)</sup>	Investment return <sup>(4,7)</sup>	
kg ha <sup>-1</sup>	US\$ kg <sup>-1</sup>	US\$ ha <sup>-1</sup>	US\$ ha <sup>-1</sup>	US\$ ha <sup>-1</sup>	US\$ ha <sup>-1</sup>	kg ha <sup>-1</sup>	kg ha <sup>-1</sup>	US\$ kg <sup>-1</sup>	US\$ ha <sup>-1</sup>	US\$ ha <sup>-1</sup>	-----	%
0	0.061	0	0	0	0	2640.43	0	0.37	0.00	0.00	0	0
800	0.061	48.80	17.85	66.65	- 33.32	2768.82	+ 128.39	0.37	+ 47.89	+ 14.56	+ 0.44	+ 44
1600	0.061	97.60	17.85	115.45	- 57.72	2704.93	+ 64.5	0.37	+ 24.06	- 36.67	- 0.58	- 58
2400	0.061	146.40	17.85	164.25	- 82.12	2565.12	- 75.31	0.37	- 28.09	- 110.22	- 1.34	- 134

<sup>(1)</sup> Costs seed (Copagril, 2015); <sup>(2)</sup> total costs by gypsum divided in two crops (soybean and wheat); <sup>(3)</sup> obtained in experiment; <sup>(4)</sup> Other treatments compared treatment "absence gypsum"; <sup>(5)</sup> by Chicago Board (Cmegroup, 2015); <sup>(6)</sup> Profit or Prejudice US\$ ha<sup>-1</sup> = "Income soybean US\$"- | Costs gypsum 'soybean crop' US\$ |; <sup>(7)</sup> Investment return = ( "Profit or Prejudice US\$ ha<sup>-1</sup>" - | Costs gypsum 'soybean crop' US\$ | ) / | Costs gypsum 'soybean crop' US\$ | or Investment return (%) = ( "Profit or Prejudice US\$ ha<sup>-1</sup>" - | Costs gypsum 'soybean crop' US\$ ha<sup>-1</sup> | ) / | Costs gypsum 'soybean crop' US\$ ha<sup>-1</sup> | \* 100.

performance of individual plants (Marchiori, 1999; Heiffig, 2002; Tourino et al., 2002; Vasquez et al., 2008; Mauad et al., 2010) providing similar grain yield to use of higher amount plants per meter, especially, greater economic return on investment in seeds.

Table 5 show costs gypsum to different doses, grain yield and gypsum price. Prado and Fernandes (2010) pointed out that the dimension of the economic return is sustained in crop yield, production costs and price of the product employed. Costs including product and application cost, with total costs of US\$ 66.65, 115.45 and 164.25 by 800, 1600 and 2400 kg ha<sup>-1</sup>, respectively. Costs gypsum by soybean crop US\$ 33.32, 57.12 and 82.12 superior to absence gypsum in the sequence, because divided by soybean and wheat. Although, grain yield soybean increase US\$ ha<sup>-1</sup> +47.89, +24.06 and -28.09.

Look just income soybean grain yield, treatments with 800 and 1600 kg ha<sup>-1</sup> of gypsum

highlighted from the others (Table 5). But, look to economic return, just treatment 800 kg ha<sup>-1</sup> provides profit US\$ +14.56, thus +44% by economic return investment (Table 5) to payment half investment by soybean (US\$ 33.32). Others treatments, prejudice US\$ -36.67 and -110.22 and -58% and -134% by economic return investment to 1600 and 2400 kg ha<sup>-1</sup> gypsum.

Others researchers to study economic return has been published in the literature. Prado and Fernandes (2010) also studied economics of slag of siderurgy application in the cultivation of cane sugar, highlighting doses with greater economic return. Fiorin et al. (2011) detected superiority of 9.2 to 13.7% when using precision farming system as application of appropriate amount of inputs into variable rate with the use of conventional system of fixed rate on soybeans.

Soybean culture exported 5.26, 5.14 and 4.87 kg ha<sup>-1</sup> S in grain (related grain yield in treatments) with 800, 1600 and 2400 kg ha<sup>-1</sup> by gypsum application, respectively (Table 6).

Estimate grain yield with wheat 2503 kg ha<sup>-1</sup> exported 5.51 kg ha<sup>-1</sup> of S in grain (Seab, 2015; Rampim, 2014). High doses of gypsum (1600 and 2400 kg ha<sup>-1</sup>) supply S in soil (80 and 120 kg ha<sup>-1</sup>) and S residual (69.35 and 109.62 kg ha<sup>-1</sup>) after two cultures (soybean-grain yield and wheat-estimate). Otherwise, absence gypsum application export 10.52 kg ha<sup>-1</sup> for both cultures, and didn't have reposition fertilization. This situation reduce S disponible in soil, that's approximate limit to medium class by S level in soil (10 mg dm<sup>-3</sup> S-SO<sub>4</sub><sup>-2</sup>).

High yield of soybean and wheat grains, need adequate nutrients levels in the soil, so the export S in soil with the middle class can reduce potential yield of next crops. Gypsum can be used to reset the nutrients exported S and Ca, and in this case, reset especially S (medium level in soil). Nutrients exported by crops can be reset using 800 kg ha<sup>-1</sup> gypsum in V4 stage of soybean, offering 20.23 kg ha<sup>-1</sup> of residual S in soil to the next crop season (soybean + wheat), related by economic return



**Table 6.** Input of S in treatments by gypsum, export of S in the soybean crop and estimate in second crop with wheat and residue of S by gypsum in soil before both crops. Guaíra, Paraná, Brazil, 2012.

Input - treatments by gypsum		First crop - Soybean			Estimate: Second crop - Wheat			Two crop - one year <sup>(5)</sup>	S residual by gypsum in soil <sup>(6)</sup>
Doses of gypsum <sup>(1)</sup>	Input S <sup>(1)</sup>	Grain Yield <sup>(2,4)</sup>	S exported <sup>(3)</sup>	S grain exported	Grain yield <sup>(4)</sup>	S exported <sup>(3)</sup>	S grain exported	S grain exported	kg ha <sup>-1</sup>
----- kg ha <sup>-1</sup> -----			1000kg (1000kg) <sup>-1</sup>	kg (1000kg) <sup>-1</sup>	kg ha <sup>-1</sup>	1000kg (1000kg) <sup>-1</sup>	----- kg (1000kg) <sup>-1</sup> -----		kg ha <sup>-1</sup>
0	0.00	2640.43	0.0019	5.02	2503.00	0.0022	5.51	10.52	-10.52
800	40.00	2768.82	0.0019	5.26	2503.00	0.0022	5.51	10.77	20.23
1600	80.00	2704.93	0.0019	5.14	2503.00	0.0022	5.51	10.65	69.35
2400	120.00	2565.12	0.0019	4.87	2503.00	0.0022	5.51	10.38	109.62

<sup>(1)</sup> Gypsum: 15% S-SO<sub>4</sub><sup>-2</sup> e 5% S; <sup>(3)</sup> obtained in experiment; <sup>(3)</sup> obtained in farm (Rampim, 2014); <sup>(4)</sup> grain yield average 2009-2014 in Parana State is 2958 kg ha<sup>-1</sup> and 2503 kg ha<sup>-1</sup> to soybean (just to compared) and wheat (used to estimate S exported), respectively (Seab, 2015); <sup>(5)</sup> S exported in two crops (soybean and wheat); <sup>(6)</sup> S residue after two crops used to paid the investment (soybean and wheat) and deficit S in treatment absence gypsum; S residual gypsum (kg ha<sup>-1</sup>) = "Input S (kg ha<sup>-1</sup>)" - "S grain exported soybean kg ha<sup>-1</sup>" - "S grain exported second crop - wheat kg ha<sup>-1</sup>"

(Table 5) by absorbing nutrients quickly solubilized gypsum with reduce mobilization to subsurface layers (Caires et al., 1998; Soratto and Crusciol, 2008; Caires et al., 2011; Nava et al., 2012; Michalovicz et al., 2014). In this dose of gypsum, grain yield and low costs income US\$ +47.89 and profit US\$ 14.56 (Table 5).

Similarly in recent research, in soils with inferiority fertility, identify low doses by gypsum increase grain yield. Motta et al. (2013) also worked with doses of gypsum (0 to 120 kg ha<sup>-1</sup> S; 5% S in product), in order to provide S to soybean in Oxisol, which found that the use of doses of 120 kg ha<sup>-1</sup> S with gypsum in soil with 0.26 cmol<sub>c</sub> dm<sup>-3</sup> K and 4 cmol<sub>c</sub> dm<sup>-3</sup> Ca, raises K and Ca in soybean leaf tissue in absence potassium fertilization, however without interfering in these levels nutrients by applying 60 kg ha<sup>-1</sup> K<sub>2</sub>O, nevertheless increase S both conditions, with and without potassium fertilization in no-till system. Other study, gypsum favored grain yield of corn, wheat and soybeans, when there was water deficiency. However, high doses of gypsum

(12000 kg ha<sup>-1</sup>) damaged the grain yield of soybeans by Mg deficiency induction in adequate water condition in Oxisol dystrophic typical, due to increase Ca/Mg ratio in soil, with added Ca; however, doses of 1500 and 3000 kg ha<sup>-1</sup> of gypsum favored grain yield independent of weather conditions for soybean and corn in the crop rotation system (Pauletti et al., 2014).

In other research, Raji (2008) identified application of soil conditioner, it is necessary doses above 800 to 1000 kg ha<sup>-1</sup> of gypsum, because lower doses do not provide uniform distribution of the throw by agricultural machines. In this condition, low dose of gypsum (800 kg ha<sup>-1</sup>) increase economic return and limit to adequate application.

### General considerations

For the number of plants can be indicated using 12 seeds per meter, because we obtain an equivalent yield, being relevant to reduce

production costs in the soybean system and elevate economic return of investment. However, it must be ensured operational efficiency during deployment of culture as a condition of adequate soil moisture for seed starting germination process as well as the culture does not deploy with excess moisture in the soil because it reduces soil layer deposited on the seed, also run the sowing operation at low speed, adequate depth of seed, seed quality, pay attention to the position of deposition of fertilizer in the seed, together with the seed distribution system regulated and/or selection of discs appropriate for each seed lot.

The broadcast application of 800 kg ha<sup>-1</sup> gypsum on soybeans in V4 stage possible to take advantage the nutrients released in the surface layers in the first crop, due to the high solubility (Raji, 2008), reducing intensive mobilization of Ca<sup>+2</sup> and S-SO<sub>4</sub><sup>-2</sup> the soil at high dose (Caires et al., 1998; Caires et al., 2002, 2004). Like this, use gypsum to provide nutrients Ca and S (Caires et al., 2003; Soratto and Crusciol, 2008; Sávio et al.,

2011; Zapparoli et al., 2013; Motta et al., 2013; Pauletti et al., 2014) with increase grain yield of soybean (Caires et al., 2011; Sávio et al., 2011; Broch et al., 2011; Ferreira et al., 2013; Santos et al., 2013; Motta et al., 2013; Pauletti et al., 2014), introducing more advantages to the crop system, due to the economic return on investment with product.

## Conclusion

The number of plants per meter with precision seed drill and superficial application of gypsum at the V4 stage do not affect the content of macro-and micronutrients leaf tissue of soybean cultivar SYN 7059RR. The application of gypsum at the V4 stage and reducing the number of plants per meter statistically do not affect the grain yield. Economic returns using higher amount of seed (14, 16 and 18 plants m<sup>-1</sup>) is -283, -260 and -271% with investment of US\$ 13.76, 29.24 and 44.72. Recommend lower number of plant (12 plants m<sup>-1</sup>) on soybean cultivar for SYN 7059RR. Soybean seeding in clayey Rhodic Hapludox with 10 mg dm<sup>-3</sup> S-SO<sub>4</sub><sup>2-</sup> level by absence gypsum reduce 10.52 kg ha<sup>-1</sup> of S by exported grain. Application of 800 kg ha<sup>-1</sup> gypsum provides US\$ 14.56 profit with 44% economic return to payment half investment by soybean (US\$ 33.32). Use of 800, 1600 and 2400 kg ha<sup>-1</sup> gypsum focused only on two cultures (soybeans and wheat) during the crop season provides residual soil of 20.23, 69.35 and 109.62 kg ha<sup>-1</sup> S, respectively.

## Conflict of Interest

The authors have not declared any conflict of interest.

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