Soil management and application of agricultural gypsum in a Planosol for soybean cultivation

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ABSTRACT: *This study investigated the effects of soil management systems, tillage, and application of gypsum agricultural to soil, on soybean development in lowland areas. The experiment was carried out on an Alfisol in a randomized complete block design in a factorial arrangement. The two soil tillage practices were without deep tillage and with deep tillage. Gypsum treatments were no gypsum application, 500kg of gypsum ha⁻¹, 1000kg of gypsum ha⁻¹, and 1500kg of gypsum ha⁻¹. Deep tillage resulted in less soil resistance to root penetration during ryegrass cultivation during the soybean offseason, 11 months after applying the management treatments, resulting in higher dry mass of ryegrass in the offseason and higher soybean yield in the following year.*
Key words: *Glycine max L., deep tillage, nodulation, grain yield.*

Manejo do solo e aplicação de gesso agrícola em Planossolo para o cultivo de soja

RESUMO: *O trabalho visou identificar o efeito de dois sistemas de manejo do solo, com e sem escarificação, associado à aplicação de gesso agrícola no desenvolvimento de plantas de soja em áreas de terras baixas. O trabalho foi realizado a campo, em Planossolo Háplico Eutrófico arênico, em esquema bifatorial (2x4) no delineamento experimental de blocos ao acaso composto por dois sistemas de manejo do solo: sistema sem escarificação do solo e sistema com escarificação do solo. Os tratamentos com gesso agrícola foram: testemunha sem aplicação de gesso agrícola, 500kg ha⁻¹ de gesso agrícola, 1000kg ha⁻¹ de gesso agrícola e 1500kg ha⁻¹ de gesso agrícola. A escarificação do solo proporciona maior rendimento de grãos de soja em áreas de terras baixas com presença de camada compactada, independente do uso de gesso agrícola. Os efeitos da escarificação do solo resultam na menor resistência à penetração de raízes no final do cultivo do azevém na entressafra da soja, 11 meses após o manejo, resultando em maior massa seca do azevém em sucessão e produtividade da soja no ano seguinte.*
Palavras-chave: *Glycine max L., escarificação, nodulação, rendimento de grãos.*

INTRODUCTION

Rotation and/or succession planting in lowland areas presents a challenge for irrigated rice cultivation. One of the major benefits of rotation or succession planting is the breaking up of cycles of pests, diseases, and hard-to-control weeds, especially weedy rice. In this context, soybean crops present a promising option. However, lowland areas present a limitation for cultivation of leguminous crops and their development.

In lowland areas, soil compaction and the low natural fertility levels are some of the soil characteristics restricting cultivation of dry or offseason crops. Soil compaction results in macroporosity reduction and greater density and resistance against penetration, which restrict root growth in addition to reducing water and nutrient availability for plants (CABRAL et al., 2012), compromising productivity due to higher stress susceptibility caused by the excess or deficit of water.

Regarding chemical characteristics, soils in lowland areas are characterized by low natural fertility and reduced organic matter, phosphorus, and potassium contents. Furthermore, VEDELAGO et al. (2012) reported that approximately 40% of the soils planted with irrigated rice crops in Rio Grande do Sul, Brazil, showed aluminum saturation

higher than 10%, and 30% of the soils also showed exchangeable calcium content under 2cmol$_c$ dm^{-3} in the 0-0.2m layer, which aggravates stress on plants such as soybean. Thus, the association of physical and chemical limitations in these soils may not only impair the absorption of water and nutrients by plants but also result in growth depth restriction for plant roots and impair the biological nitrogen fixation process (CALONEGO et al., 2011).

According to DALLA NORA et al. (2014), agricultural gypsum may be used as an environment enhancer for roots in sub-superficial layers with high aluminum content. In general, agricultural gypsum has greater solubility in water (150 times) compared with limestone, which enables better mobility and consequently better effects throughout the soil depth. Sulfate anions present in gypsum combines with Ca^{2+} and moves to the surface where they dissociate, release Ca^2, and combine with Al^{3+} composing an insoluble ionic pair ($AlSO_4^+$) (ZANDONA et al., 2015). This process removes aluminum from the CEC and permits roots to explore deeper soil layers throughout the soil profile.

However, chemical correction alone may not be sufficient to enable proper development of the soybean root system in these areas. Deep tillage may be an alternative for loosening the region where most roots and nodes are concentrated, enabling greater water storage in the soil (SARTORI et al., 2015). Therefore, this study aimed to evaluate the effects of two soil management systems, with and without deep tillage, and agricultural gypsum application in lowland areas on soybean crops.

MATERIALS AND METHODS

The experiment was conducted during the 2012/13 and 2013/14 cropping seasons on an Alfisol (EMBRAPA, 2013). Regional climate of the study area is classified as humid subtropical (Cfa) according to the Köppen's classification system, with approximately 1,616mm average yearly rainfall.

The experimental design was a 2×4 bifactorial model with randomized blocks in four replications. The first factor comprised two soil management systems, No Tillage System (NTS; without soil preparation), and Deep Tillage System (DTS; 0.30m depth), 30 days before soybean sowing using a five-shank chisel plow with shanks spaced 0.35m apart.

The second factor consisted of agricultural gypsum doses as follows: T1: control, without gypsum application, T2: 500kg ha^{-1}, T3: 1,000kg ha^{-1}, and T4: 1,500kg ha^{-1} of gypsum. Agricultural gypsum

was composed of 18% calcium and 26% sulfur, and was spread on the soybean sowing day in the first year. Each experimental unit consisted of 21m^2 of usable area. The BMX Potência soybean variety was selected for the experiment, and 30 seeds were sown per m^2. Seeds were treated with Pyraclostrobin (25g L^{-1}), methyl thiophanate (225g L^{-1}), and fipronil (250g L^{-1}), at a rate of 200mL per 100 seed kg^{-1}, and inoculated with *Bradyrhizobium japonicum* strains.

In the 2012/13 cropping season, soybean sowing occurred on November 4, 2012, and basal dressing fertilization was performed using 40kg N ha^{-1}, 90kg P$_2$O$_5$ ha^{-1}, and 135kg K$_2$O ha^{-1}. Planting was performed using the MF 407 (Massey Ferguson) pantographic seed driller composed of six lines equipped with straw cutting discs and 22" fertilizer applicator discs with a 0.08m working depth. Soil samples were collected from the 0-0.15 and 0.16-0.3m depths 30 days before soybean sowing for physical and chemical analyses, presented in table 1.

Initial plant population evaluation was performed 10 days after emergence by counting the plants from three meters of the sowed line. The aerial part dry mass and length, in addition to root dry mass and length, viable node dry mass, and number of viable nodes per plant, were evaluated during the R2 phenological stage (FEHR & CAVINESS, 1977), using 10 plants collected from the second sowed line.

Aerial part length and dry mass evaluations were performed by cutting the plants at the ground level and measuring these parts using a graduated ruler. Thereafter, plants were stored in paper bags for aerial part dry mass estimation. Roots were collected through 0.4 m deep and 0.5m wide trenches established perpendicularly to the sowed line. They were rinsed with running water, posteriorly measured using a graduated ruler, and stored for dry mass determination.

Node viability was determined following the methodology described by NETO et al. (2008). The same roots collected for length and dry mass determination were used, and the nodes were classified according to their diameters. Nodes larger than 2mm were transversally sectioned for internal color evaluation. Pinkish colored nodes (active legoglobins) were considered viable, while dark or greenish colored nodes (inactive legoglobins) were considered non-viable. Node dry mass, and aerial part and root dry masses were determined using a forced-ventilation oven at 65°C until constant mass, with posterior weighing using a precision scale.

Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S)

Table 1 - Chemical analysis of the 0-15 and 16-30cm soil layers performed 30 days before sowing the soybean crop harvested in 2012/13.

---0-15cm depth---					
pH (H$_2$O) (1:1)	K	Ca	Mg	Effective CEC	pH 7 CEC
---Cmol$_c$ dm^{-3}---					
4.9	72.0	3.6	2.9	6.9	12.2
P	S	Al	m (%)[1]	V (%)[2]	OM
--------------------mg dm^{-3}--------------------		mmol$_c$ dm^{-3}	-------------------------------%-------------------------------		g dm^{-3}
7.6	12.0	0.2	2.9	54.7	2.0
--16-30cm depth--					
pH (H$_2$O) (1:1)	K	Ca	Mg	Effective CEC	pH 7 CEC
---Cmol$_c$ dm^{-3}---					
4.3	24.0	1.7	1.3	5.6	14.0
P	S	Al	m (%)	V (%)	OM
--------------------mg dm^{-3}--------------------		mmol$_c$ dm^{-3}	-------------------------------%-------------------------------		g dm^{-3}
3.0	13.0	2.5	44.6	54.7	1.3

[1]aluminum saturation; [2]base saturation.

contents in soybean leaves were determined using the third fully expanded leaves, from the apex to the bottom, of 20 plants per experimental unit during the R2 phenological stage. Thereafter, samples were transferred to the Forest Ecology Laboratory of the Universidade Federal de Santa Maria (UFSM) where analyses were performed. Soil mechanical resistance was determined during the R2 stage, using a Falker PLG 1020 digital penetrometer, with five measurements performed per experimental unit at the 0.40m depth in the sowed line.

Grain productivity was determined through manual harvesting from a 7.5m^2 area. Numbers of pods and grains per plant were determined for 10 plants, sequentially collected from the second sowed line of each experimental unit.

The ryegrass seed was spread while the soybean crop was at the R7/R8 phenological stage (April 3, 2013) at a rate of 40kg of seed ha^{-1}. Fertilization was performed using two 40kg N ha^{-1} applications on the 40th and 75th days after sowing. Three 0.50m^2 subsamples were collected from each experimental unit for ryegrass dry mass determination: on June 10, August 13, and September 25, 2013, for the first, second, and third subsamples, respectively. The samples were dried using a forced ventilation oven at 65°C. Soil mechanical penetration resistance was measured on August 27, 2013.

Ryegrass harvesting and soybean sowing were performed on November 26, 2013, using the same experimental units of the 2012/13 cropping season, but without the implementation of soil management

systems and agricultural gypsum application. Basal dressing fertilization included 40kg N ha^{-1}, 90kg P$_2$O$_5$ ha^{-1}, and 135kg K$_2$O ha^{-1}. The variables evaluated during the second year included number plants per square meter, number of pods per plant, number of grains per plant, and grain productivity, using the procedures described above.

The obtained data was analyzed using the mathematic model presupposition test. The variance was determined using the F test. Because the investigated parameters did not show interactive effects, evaluation for the main effects was performed separately for each factor and significant means were compared using the Tukey's test at 5% error probability.
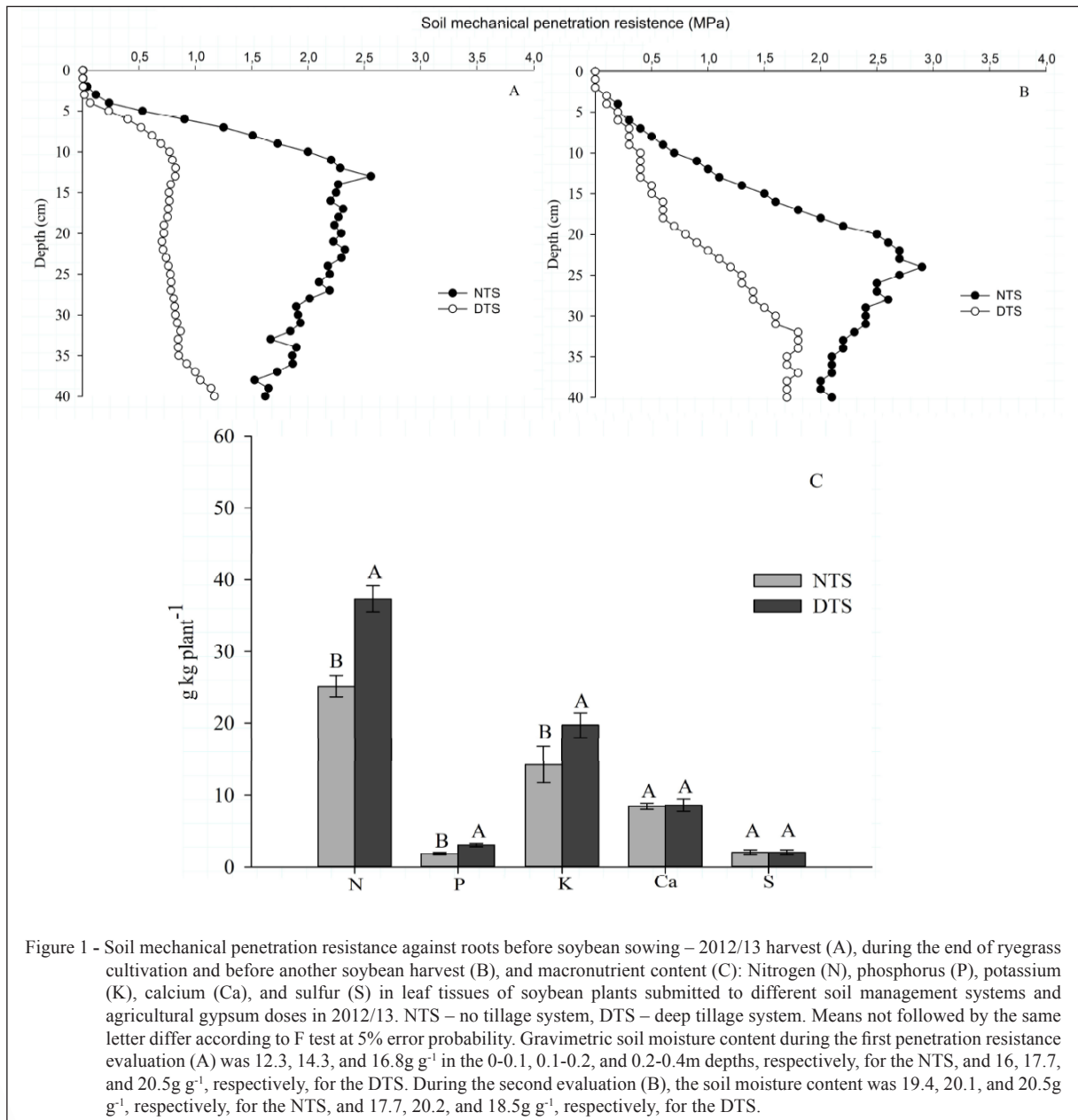
RESULTS AND DISCUSSION

The plant population and productivity components, as well as the plant growth characteristics such as aerial part and root lengths and aerial part, root, and node dry masses, were not affected by application of gypsum. Consequently, the use of agricultural gypsum did not affect the soybean grain productivity (Table 2). Among the soil management systems, a 24% difference in grain productivity was observed: the deep tilled area presented 3,643kg ha^{-1} productivity, while the non-tilled area presented 2,774kg ha^{-1} productivity. This difference may be partly associated with alterations in the root environment, which was verified through the root penetration mechanical resistance (Figure 1A), with the presence of a compacted layer at the 0.1m depth

Table 2 - Ryegrass dry mass and soybean plant population, number of pods per plantk, number of grains per plant, grain productivity, aerial part length (APL), root system length (RSL), aerial part dry mass (APDM), root system dry mass (RSDM), number of viable nodes (NVNP), and viable node dry mass (VNDM) under different soil management systems and agricultural gypsum (GP) doses.

---Soybean 2012/13 harvest---			
Gypsum doses (kg ha^{-1})	Plants (m^{-2})	Pods plant^{-1}	Grains plant^{-1}	GP (kg ha^{-1})
0	25^{ns}	48^{ns}	116^{ns}	3.210^{ns}
500	24	49	121	3.204
1000	25	49	120	3.206
1500	24	49	116	3.226
---Soil management---				
NTS	25^{ns}	44b*	108b	2.774b
DTS	25	53a	128a	3.643a
CV %	6.2	6.7	7.4	2.3
Gypsum doses (kg ha^{-1})	APL (cm)	RSL (cm)	APDM (g)	RSDM (g)	NVNP	VNDM(g)
0	80.9^{ns}	18.5^{ns}	24.3^{ns}	4.2^{ns}	29^{ns}	1.6^{ns}
500	80.3	18.4	23.9	4.3	31	1.6
1000	81.6	18.8	24.8	4.2	30	1.6
1500	77.5	19.3	23.2	4.4	30	1.6
---Soil management---						
NTS	73.1b	15.9b	17.1b	3.9b	27b	1.3b
DTS	86.9a	21.8a	31.1a	4.7a	32a	1.9a
CV %	5.1	8.5	5.5	10.1	5.6	2.8
---Offseason (ryegrass)---						
Gypsum doses (kg ha^{-1})	1st harvest (kg ha^{-1})		2nd harvest (kg ha^{-1})		3rd harvest (kg ha^{-1})	
0	1.031^{ns}		2.261^{ns}		2.625^{ns}	
500	1.124		2.330		2.732	
1000	1.050		2.174		2.721	
1500	1.109		2.225		2.621	
---Soil management---						
NTS	893b*		2.053^{ns}		2.293b	
DTS	1.259a		2.441		3.056a	
CV %	10.2		12.5		9.5	
---Soybean 2013/14 harvest---						
Gypsum doses (kg ha^{-1})	Plants (m^{-2})		Pods plant^{-1}		Grains plant^{-1}	GP (kg ha^{-1})
0	25^{ns}		58^{ns}		133^{ns}	3.486^{ns}
500	24		56		131	3.552
1000	24		57		131	3.519
1500	24		57		136	3.523
---Soil management---						
NTS	25^{ns}		54b*		126b	3.267b
DTS	25		60a		139a	3.764a
CV %	4.8		11.4		6.2	5.6

*Means not followed by the same letter differ according to Tukey's test at 5% probability, ^{ns}not significant according to Tukey's test at 5% probability, NTS - no tillage system, DTS - deep tillage system.

Figure 1 - Soil mechanical penetration resistance against roots before soybean sowing – 2012/13 harvest (A), during the end of ryegrass cultivation and before another soybean harvest (B), and macronutrient content (C): Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and sulfur (S) in leaf tissues of soybean plants submitted to different soil management systems and agricultural gypsum doses in 2012/13. NTS – no tillage system, DTS – deep tillage system. Means not followed by the same letter differ according to F test at 5% error probability. Gravimetric soil moisture content during the first penetration resistance evaluation (A) was 12.3, 14.3, and 16.8g g^{-1} in the 0-0.1, 0.1-0.2, and 0.2-0.4m depths, respectively, for the NTS, and 16, 17.7, and 20.5g g^{-1}, respectively, for the DTS. During the second evaluation (B), the soil moisture content was 19.4, 20.1, and 20.5g g^{-1}, respectively, for the NTS, and 17.7, 20.2, and 18.5g g^{-1}, respectively, for the DTS.

for the non-tilled system, which was significantly reduced by the deep tillage process. Penetration resistance is one of the soil physical attributes used as indicators of compaction, and penetration resistance values higher than 2MPa are considered limiting for the plant root system (SUZUKI et al., 2007). Deep tilled soil presented ≤2MPa penetration resistance up to the 0.40m deep layer.

Soil compaction reduced the plant aerial part and root lengths (Table 2). In agreement with

this result, GIACOMELI et al. (2016) reported that deep tillage contributes to increasing the soil porosity and consequently, reduces soil bulk density by breaking the compacted layer. This soil management procedure tends to positively affect plant development, because it enables roots to explore a larger area. Root development in compacted soils is limited, which impairs nutrient exploitation and water absorption by plants (VOLTAN et al., 2000). Soil compaction effects, reflected on the aerial

part and root lengths, may also be reflected in the root and aerial part dry mass reductions. Use of agricultural gypsum did not affect the parameters investigated in this study, which may be related to the low aluminum saturation (Table 1) in the soil layer where the plants root system is concentrated (0-0.2m depth).

The deep tilled soil presented a large number of viable nodes and higher node dry mass per plant (Table 2). This may be associated with the effects of deep tillage, which tends to provide better aeration in the plant root region and improves drainage in the soil profile affecting nodulation, which is very sensitive to water excess (SARTORI et al., 2015). Plants with satisfactory root development show better usage of sucrose, which is produced by photosynthesis and transported to the nodes, turning into alpha-keto acid and participating in the nitrogenase metabolism (COKER & SCHUBEL, 1981), which enables the maintenance of symbiosis in bacterial colonies and positively affects the symbiotic nitrogen fixation process and consequently grain productivity.

The nitrogen, phosphorus, and potassium macronutrient contents in plant tissues increased under the deep tillage system (Figure 1C) irrespective of the doses of agricultural gypsum. This behavior may be related to the greater development of the root system observed in the area under deep tillage, due to the lower mechanical penetration resistance. SILVA & ROSOLEM (2001) associated the higher absorption of nitrogen, phosphorus, and potassium by soybean plants with less dense soils, a parameter which directly affects the soil penetration resistance. Calcium and sulfur contents were not affected by the management systems and agricultural gypsum applications, indicating that the contents of these nutrients were sufficient for the crop needs for high grain productivity (URANO et al., 2007).

Ryegrass planted following the soybean crop in the same area (Table 2) did not show the effects of agricultural gypsum application on dry mass production. However, deep tillage performed before soybean sowing provided higher dry mass production in two of the three evaluations, with a 23% increment at the last quantification time point. This may be related to the persistence of the effects of deep tillage of the soil, represented by the soil mechanical penetration resistance: lower penetration resistance values were observed up to 0.4m depth, 11 months after implementation of deep tillage, compared with the no-tillage system. Furthermore, the use of ryegrass during the offseason may have contributed to the maintenance of this effect, because plants with

an extensive root system promote the aggregation of soil particles over time (DEBIASI et al., 2010).

In the same area, the soybean grain productivity components in the 2013/14 season, after the ryegrass cultivation season, were not affected by gypsum application during that period. However, deep tillage of the soil performed during the previous year provided higher grain productivity compared with the non-tilled area. This result suggested that part of the soil alterations resulting from the tillage effect remained during the subsequent cultivation periods. A study conducted by DRESCHER et al. (2016) reported that alterations in the physical and water properties caused by tillage in Latosols persist in the subsequent periods, varying from six months for properties such as density, porosity, and macro porosity; and up to 24 months for parameters such as penetration resistance, water conductivity, and soil water infiltration rate.

CONCLUSION

Deep tillage resulted in higher grain productivity of soybean plants cultivated in lowland areas with a compacted layer present close to the surface, independent of agricultural gypsum application. For the achieved productivity levels of soybean in lowland areas, there was no performance response to the application of agricultural gypsum under sufficient calcium and sulfur availability in the soil. Benefits of deep tillage of the soil, such as low penetration resistance, are sustained during the second cultivation season, favoring offseason ryegrass and succession soybean crops.

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