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Soil physical and phenological attributes of soybean in different management systems and gypsum

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ABSTRACT

The objective of this work was to evaluate the physical attributes of the soil as well as the components of soy production in the different frequencies of soil scarification with and without the use of agricultural gypsum. The experiment was carried out during the 2011/12 and 2012/13 agricultural years in succession of corn crops in the winter and soybean in the summer in Cerrado experimental area, in Selvíria - MS. The experimental design was a randomized block design, in a 3 x 2 factorial scheme (soil management x gypsum), with four replications. The management systems were: no-till system continuous (SPDC), no-till system with scarified every twelve months (SPDE 12), no-till system with scarified every six months (SPDE 6), with or without the use of gypsum. The soil physical attributes were evaluated at depths of 0.0-0.10 and 0.10-0.20 m, as well as the agronomic characteristics of the soybean crop. The no-till system continuous (SPDC) over time with the application of gypsum provided continuous values of soil physical attributes in the two layers and years of cultivation. It was also the system that provided higher values of final population and of the mass of one hundred grains, with no increase in soybean yield.

Key words: soil scarification; agricultural gypsum; *Glycine max*

Atributos físicos do solo e fenológicos da soja em diferentes sistemas de manejo e gesso

RESUMO

O objetivo do trabalho foi avaliar os atributos físicos do solo, bem como os componentes de produção da soja nas diferentes frequências de escarificação do solo com e sem o uso do gesso agrícola. O experimento foi realizado durante os anos agrícolas 2011/12 e 2012/13 em sucessão das culturas de milho no inverno e soja no verão em área experimental de Cerrado, em Selvíria - MS. O delineamento experimental foi o de blocos ao acaso, em esquema fatorial 3 x 2 (manejo do solo x gesso), com quatro repetições. Os sistemas de manejo foram: Plantio Direto Contínuo (SPDC), Plantio Direto Escarificado a cada doze meses (SPDE 12), Plantio Direto Escarificado a cada seis meses (SPDE 6), com ou sem o uso de gesso. Foram avaliados os atributos físicos do solo, nas profundidades de 0,0-0,10 e 0,10-0,20m, bem como as características agronômicas da cultura da soja. O sistema de plantio direto contínuo (SPDC) ao longo do tempo junto à aplicação do gesso proporcionou valores contínuos dos atributos físicos do solo nas duas camadas e anos de cultivo. Também foi o sistema que proporcionou maiores valores de população final e da massa de cem grãos, contudo sem incremento na produtividade da soja.

Palavras-chave: escarificação do solo; gesso agrícola; *Glycine max*

Introduction

The direct sowing system has been recognized as an important practice in the sustainability of environmental agro-systems. This fact is directly related to the characteristics of the system because it has a greater quantity of straw on the surface, which provides the increase of organic matter, maintenance of soil aggregates, lower temperature variations and soil moisture, as well as the greater cycling of nutrients and erosion control (Moraes, 2013).

However, the no-tillage system has not been well established in the country, so that many areas have difficulty maintaining the amount of organic matter in the soil, in which crop succession has been wrongly used instead of rotation, with plants that do not have a high potential of phytomass production, with high C/N ratio and abundant and deep root systems. In this way, the system ends up in a process of soil degradation and compaction. Debiasi et al. (2013) state that the maintenance of organic matter in soil management and tillage systems can affect the physical, chemical and biological attributes, and consequently the viability of the production.

Several authors have observed the occurrence of a compacted layer in direct sowing at a 0.10-0.20m depth (Franchini et al., 2011; Bottega et al., 2011; Debiasi et al., 2013). Embrapa, in its surveys, have indicated that the degree of compaction in the 0.10-0.20m layer is limiting to growth and development of plants in approximately 45% of the areas cultivated with summer soybean and autumn/winter maize in clay soils (Franchini et al., 2009; Franchini et al., 2011).

One of the measures to recommend and improve the physical quality of the soil and to reduce compaction is the adoption of soil scarification mechanisms over time, or the use of conditioners that have soil aggregation properties, such as agricultural gypsum. The use of a scarification mechanism leads to the breaking of compacted layers, thus improving the physical attributes of the soil, with greater aeration and water movement in the profile.

In this sense, starting from the assumption that the predominant soils in the Cerrado are very weathered, with high levels of toxic Al, which characterizes an important chemical barrier for the satisfactory root development of the crops, in depth, the scarification added to the application of soil gypsum to the soil, besides improving the physical conditions, can promote improvements in the chemical conditions of the subsoil. This, according to Araújo et al. (2017), contributes to an adequate root development in the soil profile, since the plastering promotes the increase of the Ca and S content in depth, decreases the saturation by Al and its absorption by the roots due to the formation of the $AlSO_{4+}$ ion pair, which is not toxic to the plants (Vitti et al., 2008; Vitti & Priori, 2009) Several authors (Rosa Junior & Vitorino, 1994; Rosa Junior et al., 2006) propose that gypsum acts as a conditioner of the soil structures favoring the aggregation of the particles and consequently in the improvement of its structure, with greater aeration and hydraulic conductivity. Thus, soil physical attributes, such as density and porosity, can be altered by the combination of the management system and the plaster (Costa et al., 2007).

In view of the above and considering the importance of the interaction of different soil management with the application of gypsum, this work was carried out with the objective of evaluating the soil physical attributes variation and the agronomic performance of the soybean crop for two years of cultivation, in a low altitude cerrado area.

Materials and Methods

The experiment was developed during the agricultural years 2011/12 and 2012/13 in succession of corn crops in winter and soybean in the summer, in an experimental area of the Research, Teaching and Extension Farm (FEPE) belonging to the Faculty of Engineering of Unesp, Campus of Ilha Solteira, located in the municipality of Selvíria - MS, presenting as geographical coordinates 20°20'51.44" S and 51°24'11.10" W and average altitude around 335 m. The soil was classified as a dystroferric Red Latosol, with clayey texture (Embrapa, 2013). The climate of the region is Aw, defined as tropical humid with rainy season in summer and dry in winter, according to the international classification of Köeppen, presenting temperature, precipitation and average annual relative humidity of 24.5° C, 1370 mm and 64.8%, respectively (Hernandez, 1995). In November 2010, the physical and chemical characterization of the soil of the area was performed, according to Tables 1 and 2.

Before the installation of the experiment, the area was kept fallow for a year. From the beginning of the research after the physical and chemical characterization of the area only in November 2010, the application of dolomitic limestone (26% CaO and 19% MgO) with 80% of PRNT was carried out, in the amount of 2.5 t ha^{-1} in the whole experimental area, according to the results of soil analyzes, in order to reach 70% base saturation. In the plots that received the agricultural gypsum ($CaSO_4.2H_2O$) as treatment, it was applied moments after the limestone, manually, in the dose of 700 ha^{-1}.

Before soybean, corn was planted on the dates of 04/03/2011 (first harvest) and 04/14/2012 (second harvest). The plots consisted of 325 m^2 (25 m x 13 m). For the installation and conduction of the experiment a tractor (4 x 2) with TDA was used, with maximum power of 100 KW in the engine and five-borer scarifier with dozer engaged.

For the desiccation of the weeds present in the area before corn and soybean cultivation, sprays were performed in the

Table 1. Initial physical characterization of the soil of the experimental area, prior to the installation of the experiment, Selvíria, MS, Brazil.

Depth (m)	Macroporosity	Microporosity	Porosity	Density ($kg\ dm^{-3}$)
	($m^3\ m^{-3}$)			
0.0 - 0.10	0.10	0.32	0.42	1.52
0.10 - 0.20	0.07	0.31	0.38	1.61

Table 2. Initial chemical characterization of the soil of the experimental area, prior to the installation of the experiment, Selvíria, MS, Brazil.

Depth (m)	P-resin mg dm^{-3}	O.M. g dm^{-3}	pH CaCl	K	Ca	Mg	H+Al	Al	SB	CTC	V	m
				mmolc dm^{-3}							%	
0.0 - 0.15	16	23	4.7	2.5	18	16	36	5	36.5	72.5	50	5
0.15 - 0.30	14	17	4.3	1.7	8	7	42	11	16.7	58.7	28	40

two harvests using 0.75mL ha^{-1} of ethyl carfentrazone (i.a) and 1.5 kg ha^{-1} of glyphosate (i.a).

For the two soybean crops (11/15/2011 and 11/21/2012), the cultivar MSOY 7908 RR with 80% germinative power and 98% purity were used. The sowing density adopted for the two agricultural years was 17 seeds m^{-1}, with 0.45m line spacing, with an approximate population of 250 thousand plants ha^{-1}. Soil fertilization for the two years of cultivation was 250 kg ha^{-1} of the commercial formulation 08-28-16 and inoculation of the seeds with peaty inoculant with *Bradyrhizobium* spp.

As a crop handling, in the two years of cultivation, three sprays were used to control the caterpillars, with methomyl (i.a) at the dose of 0.6 L ha^{-1} and endosuflan (i.a) at a dose of 1,25L ha^{-1} of the active ingredient, and for the control of soybean rust, 25 g ha^{-1} of epoxiconazole (i.a) + 66.5 g ha^{-1} of pyraclostrobin (i.a) were applied.

The experimental design used was randomized blocks in a 3 x 2 factorial scheme (soil management x with or without the use of gypsum), with four replications. The management systems were always carried out at each harvest before sowing of autumn/winter or summer soybeans, defined as: Continuous Direct Seeding (CDS), Scarified Direct Seeding at each 12 months (SDS12), Scarified Direct Seeding at each six months (SDS6), with and without the use of gypsum. It is important to note that limestone and gypsum were only applied in the first harvest, in November 2010.

The soil physical attributes were evaluated at the end of the soybean crop in the two agricultural years on 03/15/2012 and 03/25/2013. In order to determine the soil physical attributes, three undisturbed samples of soil were collected per plot at each depth of 0.0-0.10 and 0.10-0.20 m, with steel rings of 100 cm³ volume.

Soil density (SD) was determined by the volumetric ring method, after which, in the laboratory, the total porosity (TP) was determined by the saturation percentage by water of the soil. Microporosity (MI) and soil macroporosity (MA) were determined with the use of the tension table (Embrapa, 1997).

In order to characterize the soil fertility, an initial sampling of the area before the installation of the experiment was carried out on 11/15/2010, so that it was done in total area according to Table 2. At the end of soybean cultivation in the second crop on 03/25/2013, the chemical attributes of the soil were also evaluated, and three sub-samples were collected in each plot, generating a composite sample. For that, two profiles of tractoring were determined, using screw thread in the depths of 0.0-0.10 and 0.10-0.20 m (Raij et al., 2001).

In the useful area of each plot, composed of three 5-meter length central lines, the morphological and production components of soybean were evaluated. The evaluated attributes were: the initial and final population of plants, by counting the plants in three 5-meter central lines of each plot, respectively. The values obtained were extrapolated to the number of plants ha^{-1}. Thus, the survival rate was calculated by the ratio between the values of the initial and final booth, multiplied by one hundred. The mean heights of the plants and the insertion of the first pod of the soybean were determined by measuring with a centimeter-graduated ruler the distance between the plant collar until the insertion of the first pod and until the apical end of the plant, in ten plants per plot, respectively. Then, the number of pods per plant was subsequently obtained. After the mechanical track of the plants of the useful area of the plot, the mass of 100 grains in eight replicates of 100 grains was determined by weighting (Brazil, 2009), and for grain yield, the values were corrected for the 13% degree of humidity on wet basis and transformed for kg ha^{-1}.

The results were submitted to the test for homogeneity of variance by the Bartlett test and normality by the Lilliefors test. When these conditions were met, the ANOVA was performed and the complementary test of comparison of means by the Tukey test was performed at 5% probability, with the aid of the statistical program Assitat version 7.7 Beta (Silva & Azevedo, 2016).

Results and Discussion

In general, Table 3 shows that the use of limestone in the two depths neutralized the toxic aluminum and provided nutrients in the profile. It is important to note that, with the use of gypsum, the soil presented lower phosphorus (P), potassium

Table 3. Mean values obtained for phosphorus (P), organic matter (OM), potential hydrogen (pH), potassium (K), calcium (Ca), magnesium (Mg), potential acidity (H + Al), aluminum (Al) and base saturation (V%) regarding soil and gypsum management in the 2012/2013 soybean crop, at depths of 0.0-0.15 and 0.15-0.30 m.

Causes of variation		P # mg dm^{-3}	O.M. g dm^{-3}	pH $CaCl_2$	k #	Ca #	Mg #	H+Al #	AL #	V # %
					mmol dm^{-3}					
						0.0 - 0.15 m				
Management	SDS6	25.8	20.7	4.9	2.9	21	14.1	32.5	2	53.6
	CDSS	21.7	21.2	5.1	2.8	24	15.6	29.5	1.2	59.1
	SDS12	22.3	21.2	5	3.4	22.5	14.7	30.7	1.5	56.5
Plaster	With	29.7	21	5	3.2	21.7	14.7	30.43	1.7	56.4
	Without	20.62	21.3	5	2.9	23.3	15	31.31	1.4	56.5
Average overall		25.18	21.15	5.04	13.5	22.56	14.87	30.87	82.76	56.46
CV (%)		27.94	6.56	4.19	3.13	10	7.71	5.3	37.4	11.39
IC		16	23	4.7	2.5	18	16	36	5	50
						0.15 - 0.30 m				
Management	SDS6	29.2 a	21.0	5.0	3.7	20.8	14.2	31.3	1.7	55.2 a
	CDSS	27.8 a	20.6	4.9	2.8	21.7	13.8	32.8	2.3	54.6 ab
	SDS12	20.3 b	21.3	4.9	3	21.1	13.1	32.8	2.5	54.5 ab
Plaster	With	19.12 b	21.0	4.9	2.9 b	19.3 b	13	32.8	2.5	51.5 b
	Without	32.3 a	20.9	5.0	3.4 a	22.2 a	14.2	32.1	1.8	55.5 a
Average overall		25.71	20.96	4.97	3.18	6.29	9.20	4.40	2.18	53.5
CV (%)		8.10	7.33	4.44	9.81	20.81	13.62	32.50	20.80	7.67
IC		14	17	4.3	1.7	8	7	42	11	28

SDS12 = Scarified Direct Seeding at each 12 months; SDS6 = Scarified Direct Seeding at each six months; CDSS = Continuous Direct Seeding System; IC = initial chemical characterization of the soil of the experimental area. Means followed by same letter, lowercase in columns do not differ from each other by Tukey's test (p <0.05).

(K), and calcium (Ca) contents, reflecting lower basal saturation (V%) in the depth of 0.15-0.30m. When comparing the initial Ca/Mg ratio of the soil with the values of the same relation at the end, there was an increase of its contents.

The average values for the physical attributes of the soil in relation to the management and use of gypsum in the 2011/12 and 2012/13 harvests in the layers of 0.0-0.10m and 0.10-0.20m are presented in Tables 4 and 5, respectively. Regarding the 2011/12 harvest, only the effect of soil management did not present a significant difference for all soil physical attributes in the 0.0-0.10 m layer. However, the highest values of macroporosity (MA 20) and total porosity (TP 20) in the continuous direct seeding system (CDSS) were observed in the subsurface (Table 4).

In general, only the use of gypsum has not provided a difference to the physical attributes of the soil in the two layers evaluated in the 2011/12 harvest, except for the total porosity (TP 20) in the 0.10-0.20 m layer, where the use of this input presented higher values (Table 4). However, in the second harvest (2012/13), the values of (TP10) increased while those of (SD10) decreased with the use of gypsum (Table 6).

This result is related to the characteristics of the applied inputs (limestone and gypsum), promoting the increase of the Ca/Mg ratio, increasing the root growth with greater accumulation of organic matter in the system, thus improving the structure, aeration and retention of water in the soil, as well as physical attributes over time. Souza et al. (2010) studied conventional and direct seeding systems, with and without the use of gypsum, and found greater plant height in the presence of the residual effect of gypsum. This attribute may have been more pronounced due to the lower degree of soil densification in the presence of this conditioner, due to the greater aggregation of the soil, consequently improving the structure, or also due to the chemical favoring with the

Table 4. Mean values of macroporosity (MA), microporosity (MI), total porosity (TP) and soil density (SD) in the layers of 0.0-0.10 and 0.10-0.20 m, after soybean harvest regarding the handling and plaster in (2011/2012), Selvíria, MS, Brazil.

Causes of variation		MA 10	MA 20	MI 10	MI 20	TP 10	TP 20	SD 10	SD 20
		(m^3 m^{-3})						(kg dm^{-3})	
Management (M)	SDS12	0.10	0.05 b	0.30	0.31	0.40	0.37 b	1.54	1.65
	CDSS	0.08	0.09 a	0.31	0.31	0.40	0.40 a	1.58	1.57
	SDS6	0.12	0.08 ab	0.33	0.31	0.45	0.39 ab	1.43	1.60
Plaster (P)	With	0.10	0.08	0.30	0.31	0.41	0.39 a	1.54	1.60
	Without	0.10	0.06	0.32	0.31	0.42	0.38 b	1.50	1.64
Value of F	M	$0.789^{n.s}$	3.938*	$0.800^{n.s}$	$0.493^{n.s}$	$2.42^{n.s}$	3.806*	$1.850^{n.s}$	$2.647^{n.s}$
	P	$0.001^{n.s}$	$3.118^{n.s}$	$0.826^{n.s}$	$0.781^{n.s}$	$0.597^{n.s}$	4.993*	$0.616^{n.s}$	$2.832^{n.s}$
	M*P	$1.615^{n.s}$	2.100*	$0.384^{n.s}$	$5.249^{n.s}$	2.312*	0.853*	3.059*	1.129*
Average overall		0.10	0.07	0.31	0.31	0.41	0.39	1.52	1.62
CV (%)		51	33	15	2	10	5	8	4

SDS12 = Scarified Direct Seeding at each 12 months; SDS6 = Scarified Direct Seeding at each six months; CDSS = Continuous Direct Seeding System. Means followed by same letter, lowercase in columns do not differ from each other by Tukey's test (p <0.05).

Table 5. Development of the interaction between soil management systems and the use of gypsum for total porosity (TP), Macroporosity (MA) and Soil Density (SD) in the 2011/12 crop, at the two depths evaluated, Selvíria, MS, Brazil.

Soil management	TP		MA		SD	
	Plaster					
	With	Without	With	Without	With	Without
			0.0 - 0.10 m			
SDS12	0.39 aA	0.41 abA	0.08 aA	0.11 aA	1.57 aA	1.51 abA
CDSS	0.43 aA	0.37 bA	0.11 aA	0.08 aA	1.48 aA	1.67 aA
SDS6	0.42 aA	0.48 aA	0.11 aA	0.13 aA	1.53 aA	1.33 bB
			0.10 - 0.20 m			
SDS12	0.38 aA	0.36 aA	0.06 aA	0.05 aA	1.64 aA	1.67 aA
CDSS	0.42 aA	0.39 aB	0.11 aA	0.07 aB	1.51 aB	1.63 aA
SDS6	0.39 aA	0.39 aA	0.07 aA	0.08 aA	1.61 aA	1.60 aA

SDS12 = Scarified Direct Seeding at each 12 months; SDS6 = Scarified Direct Seeding at each six months; CDSS = Continuous Direct Seeding System. Means followed by same letter, lowercase in columns do not differ from each other by Tukey's test (p <0.05).

Table 6. Mean values of macroporosity (MA), microporosity (MI), total porosity (TP) and soil density (SD) in the layers of 0.0-0.10 and 0.10-0.20 m, after soybean harvest regarding the handling and plaster in (2012/2013), Selvíria, MS.

Causes of variation		MA 10	MA 20	MI 10	MI 20	TP 10	TP 20	SD 10	SD 20
		(m^3 m^{-3})						(kg dm^{-3})	
Management (M)	SDS12	0.08	0.13	0.40	0.31	0.48	0.45	1.48	1.52
	CDSS	0.13	0.09	0.31	0.39	0.44	0.46	1.54	1.59
	SDS6	0.09	0.13	0.37	0.31	0.46	0.45	1.45	1.48
Plaster (P)	With	0.2	0.12	0.38	0.32	0.49 a	0.44	1.43 b	1.51
	Without	0.18	0.11	0.34	0.35	0.43 b	0.46	1.54 a	1.54
Value of F	M	$1.162^{n.s}$	$1.887^{n.s}$	$0.428^{n.s}$	$1.150^{n.s}$	$0.321^{n.s}$	$0.116^{n.s}$	$1.159^{n.s}$	$1.153^{n.s}$
	P	$0.063^{n.s}$	$0.250^{n.s}$	$0.695^{n.s}$	$1.189^{n.s}$	5.187*	$0.94^{n.s}$	8.781**	$0.461^{n.s}$
	M*P	$0.231^{n.s}$	$2.891^{n.s}$	$1.711^{n.s}$	$0.466^{n.s}$	$0.574^{n.s}$	$1.55^{n.s}$	$0.698^{n.s}$	$1.443^{n.s}$
Average overall		0.197	0.123	0.362	0.338	0.463	0.457	1.489	1.53
CV (%)		36	35	41	28	16	13	6	8

SDS12 = Scarified Direct Seeding at each 12 months; SDS6 = Scarified Direct Seeding at each six months; CDSS = Continuous Direct Seeding System. Means followed by same letter, lowercase in columns do not differ from each other by Tukey's test (p <0.05).

presence of calcium, which provides better development and distribution of the root system.

In the 2011/12 harvest (Table 5), in the 0.0-0.10 m layer, a significant difference was observed without the use of gypsum, with the highest values of total porosity (TP 10) and the lowest values for (SD 10) in SDS6. Probably this effect was due to the greater number of soil scarification, however the sporadic scarification of the soil every six months in clayey Red Latosol was inefficient, since the maintenance period with the best physical characteristics of the soil (TP 10 and SD 10) was less than twelve months. This fact was observed in the second year of cultivation (2012/13), in which it did not remain for the same soil layer (Table 6).

The small period of efficiency of scarification is related to the form of action of the subsoiler rods, which have the function of breaking the compacted blocks of the soil at their points of weakness, however, between the stems there is permanence of compacted aggregates, besides high clay content, which favors the return to the original conditions already in the first year, agreeing with Moraes (2013), who, in a study with soil management conducted in a very clayey dystroferric Red Latosol for 24 years, observed that the period of the effect of soil scarification remained less than 10 months. According to Reichert et al. (2011), there is a larger amount of reduced size particles with high contact surface in clayey soils, which benefits the rearrangement of the particles between the porous spaces of the soil.

At higher depth (0.10-0.20 m), there was a difference in CDSS for (TP 20) and (MA 20), with higher values using gypsum, and lower values for (SD 20) (Table 5). This behavior is understandable due to the different soil management systems and the characteristics of the gypsum. Since in the 0.0-0.10 m layer, in the SDS6 system, soil scarification occurs every six months, there is a greater mobilization of the soil, which provides the increase in the number of pores and decrease in density, whereas in CDSS this does not occur. When the aggregates remain stable, canaliculi are formed by the death of the root system, which have as function to increase the percolation of water and nutrients in the profile, allowing the greater aeration of the soil. Richard et al. (2001) report that management systems that provide the preservation and stability of pores in the profile can favor the upward flow of water, allowing it to be redistributed to the plants in a condition of scarcity of precipitation. Besides that, continuous pores allow the deepening of roots in the soil thus increasing the extraction of water in the profile (Reichert et al., 2011).

Combined to this effect, gypsum has characteristics of aggregation to clay minerals, as well as the greater percolation of free cations, increasing the amount of pores and aeration of the soil in profile. Raij (2008) proposes that the application of agricultural gypsum allows better ground conditions, and may act as soil decomposer in this environment, which is generally unfavorable to the roots. Also Rosa Junior & Vitorino (1994) and Rosa Junior et al. (2006) concluded that gypsum can act as a conditioner of soil structures (Ca^{2+} flocculating effect), favoring aggregation, and consequent improvement in soil structure. There are also other physical attributes such as soil density and porosity, which can be altered by the combination of the management system and the plaster (Costa et al., 2007).

In the second harvest, soil management did not present significant differences for soil physical attributes at the two depths evaluated (Table 6). However, when comparing the two harvests (2011/12 and 2012/13), it is observed that in the 0.0-0.10 m layer, in the continuous direct no-tillage system (CDSS), the values of MA10 and TP10 increased and SD10 decreased (Tables 4 and 6). Probably because the system is not fully consolidated, it cannot express all its characteristics as the greater maintenance and accumulation of the organic matter, as well as the formation of aggregates and of continuous pores formed over time. However, it can be noticed an improvement in the superficial layer due to greater the aeration of the soil, without its mobilization. Zotarelli et al. (2012) stated that for the maintenance of CDS over time, the presence of vegetal residues on the soil surface is essential to physically protect the soil against erosion, to control weeds and to preserve water in the soil.

The sporadic scarification of the soil made every six months resulted in less aeration of the soil in the 0.0-0.10 m layer. This fact is evident by the reduction of the values of MA10 and increase of SD10, from one year to the other. The same occurred in the scarification system at 12 months, also with increased soil density (SD10) (Tables 4 and 6). This fact is due to the greater traffic of machines made in the scarification and sowing, which even with the lower handling caused by the subsoiler rods and rollers, it still increases the mineralization of the organic matter in the area. Moraes (2013) also stated that soil scarification every three years in a no-tillage system on a very clayey dystrophic Red Latosol is an unnecessary practice and does not improve the physical quality of the soil, nor does it increase the yield of soybean grains and of wheat in relation to the continuous direct sowing system with 11 or 24 years.

In depth, the soil under CDSS presented higher values of TP 20 and SD 20, a fact that shows once again that this system is not yet fully consolidated, however values of (IM 20) increased from the first to the second year of evaluation, which evidences the greater storage and maintenance capacity of water in this layer. On the other hand, the values of the physical attributes in the treatments SDS6 and SDS12 obtained the highest values of MA 20 and TP 20, besides reduction in SD 20 (Tables 4 and 6). In this way, the effect of the mobilization and fragmentation of the soil aggregates conducted by the action of the subsoiling rods is evident. According to Moraes, (2013), over time, since well-managed, the tendency of the CDS is to result in the formation of stable aggregates, thus occurring increase in the quantity of pores, which provides a reduction in soil density, especially below 0.10 m, mainly related to aggregation by increasing the organic carbon content and the continuity and stability of pores, thus reducing to the degree of soil compaction.

In general, there was no significant difference in soybean agronomic attributes in the two years of cultivation (Tables 7 and 8). There was only significant difference for the initial (IP) and final (FP) population, with the highest values in the direct sowing system (CDSS), and in the survival index (SI) in the direct sowing system at 6 months (SDS 6) in the 2011/12 harvest (Table 7).

The highest survival rate (SI) in the scarified system every six months (SDS 6) is due to the lower initial population. This

Table 7. Mean values of initial population (IP), final population (FP), survival index (SI), plant height (PH), number of pods per plant (NPP), height of first pod insertion (HPI), mass of 100 grains (MG), dry mass (DM) and grain yield (GY), regarding soil management and the use of gypsum in the 2011/12 harvest, Selvíria, MS, Brazil.

Causes of variation		IP	FP	SI	PH	NPP	HPI	MG	DM	GY
		(n^o ha^{-1})		(%)	(m)	(n^0)	(m)	(g)	kg ha^{-1}	
Management (M)	SDS12	228238 b	196572 b	84.5 ab	0.83	62.1	0.18	16.4	10323	3277
	CDSS	292219 a	225183 a	77.2 b	0.85	65.5	0.19	16.8	10379	3577
	SDS6	235738 b	205368 ab	87.2 a	0.81	65.7	0.2	16.4	9721	3403
Plaster (P)	With	248886	206849	83.8	0.81	64.0	0.19	16.9	9888	3371
	Without	243330	204998	85.3	0.84	65.3	0.18	16.7	10492	3397
Value of F	M	14.11**	5.79**	4.48*	$0.40^{n.s}$	$4.67^{n.s}$	$1.17^{n.s}$	$0.95^{n.s}$	$0.88^{n.s}$	$0.81^{n.s}$
	P	$0.40^{n.s}$	$0.10^{n.s}$	$0.39^{n.s}$	$1.52^{n.s}$	$0.39^{n.s}$	$1.05^{n.s}$	$0.11^{n.s}$	$2.28^{n.s}$	$0.02^{n.s}$
	M*P	0.09**	2.74**	$1.83^{n.s}$	$0.61^{n.s}$	10.11**	$0.005^{n.s}$	$1.52^{n.s}$	$0.74^{n.s}$	$0.96^{n.s}$
Average overall		246108	205923	0.84	0.83	64.7	0.19	16.82	10186.4	3384
CV (%)		10.01	8.02	8.35	9.08	9.08	13.47	8.72	11.24	13.06

* ($p < 0.05$);**($p < 0.01$); $^{n.s}$ (non-significant). Means followed by the same letter do not differ from each other by the Tukey test ($p < 0.05$).

Table 8. Mean values of initial population (IP), final population (FP), survival index (SI), plant height (PH), number of pods per plant (NPP), height of first pod insertion (HPI), mass of 100 grains (MG), dry mass (DM) and grain yield (GY), regarding soil management and the use of gypsum in the 2012/13 harvest, Selvíria, MS, Brazil.

Causes of variance		IP	FP	SI	PH	NPP	HPI	MG	DM	GY
		(n^0 ha^{-1})		(%)	(m)	(n^0)	(m)	(g)	(kg ha^{-1})	
Management (M)	SDS12	259627	220275 ab	88.9	0.75	49.7	0.25	20.7	10414	2823
	CDSS	269071	241108 a	90	0.75	45.5	0.26	20.2	10549	2923
	SDS6	245923	212220 b	90.1	0.72	47.6	0.26	20.0	10468	2766
Plaster (P)	With	253978	228608	89.9	0.75	44.7	0.26	20.9 a	10283	2827
	Without	253149	218331	87.8	0.72	50.5	0.24	19.6 b	10640	2849
Value of F	M	3.03*	7.31**	$1.86^{n.s}$	$0.51^{n.s}$	$1.95^{n.s}$	$1.24^{n.s}$	$0.51^{n.s}$	$0.029^{n.s}$	$0.27^{n.s}$
	P	$0.02^{n.s}$	$2.92^{n.s}$	$3.58^{n.s}$	$1.84^{n.s}$	$3.80^{n.s}$	$1.16^{n.s}$	7.50*	$0.593^{n.s}$	$0.02^{n.s}$
	M*P	$0.51^{n.s}$	1.75*	$3.69^{n.s}$	$0.45^{n.s}$	$1.92^{n.s}$	$0.01^{n.s}$	2.90*	$0.63^{n.s}$	$1.56^{n.s}$
Average overall		253562	223470	0.88	0.74	47.62	0.25	20.31	10461	2837
CV (%)		8.61	9.61	3.57	8.75	20.08	11.54	6.77	12.54	13.25

* ($p < 0.05$);**($p < 0.01$); $^{n.s}$ (non-significant). Means followed by the same letter do not differ from each other by the Tukey test ($p < 0.05$).

fact may be related to the properties of the scarification system, because with the greater soil turnover, greater straw degradation occurs, and with this, a lower soil cover by straw occurs, which has the functions of maintaining the temperature and humidity of the soil, and even with the rupture of compacted layers, the sowing after subsoiling can restructure the soil undesirably to the emergence of the seedlings.

Overall, in the 2012/13 harvest only the final population presented higher values in the CDSS. Regarding the use of gypsum, there was only significant difference for the mass of 100 grains (M.G) (Table 8).

The largest plant stands were obtained in the CDS system, with or without the use of gypsum for IP and only with the use of the corrective in FP (Table 9). In this system the best stabilization of the sowing occurs because there is a surface with greater amount of organic matter, and the cutting disks have the function of opening a small groove for the seed deposition. Thus, less surface rotation and lower water deficit conditions with the maintenance of the straw provide better conditions of germination and emergence of seedlings. In this way, the gypsum does not have participation in establishing plants at the beginning of the cultivation. However, with the correction of the physical and chemical attributes of the soil, as well as the soil profile with the use of plaster, there was the maintenance of live plants and, therefore, of the final stand.

For the number of pods per plant (NPP), the highest values were obtained with the use of gypsum in SDS12, and without the use of gypsum in SDS6 (Table 9). However, in the six-month chiseling system, high soil spraying in conjunction with the application of gypsum leads to the transport of nutrients to the subsoil, as well as higher soil densities, demonstrating that for the attribute NPP, gypsum is beneficial to the system, however, the scarification time of the soil cannot be less than twelve months. Moreover, in scarified systems, for the lower plant populations, in the soybean crop there is the compensatory effect of higher number of pods per plant, due to less intraspecific competition.

The interaction between management and gypsum systems in soybean from the 2012/2013 harvest provided a better stand of plants (IP) and mass of 100 grains (MG) in CDSS, using gypsum (Table 10). Again, due to the higher soil aggregation in the CDSS, there was an increase in the number of plants (FP) and the advantage of higher grain filling due to the chemical corrections of the soil by the limestone with the gypsum, playing an aggregating role due to the Ca^{2+} and its chemical function of acting as a conditioner in the soil correction, providing a higher content of nutrients in subsurface. In this same line of research, Oliveira et al. (2009) stated that the agricultural gypsum acts as a decomposer of the soil, providing the reduction of the exchangeable Al toxicity, as well as the increase of calcium, magnesium and sulfur contents in the subsoil, crucial for the growth and productivity of agricultural crops.

In addition, gypsum is rich in sulfur (S), which is one of the most important nutrients in soybean yield, as it participates in amino acid synthesis (Marschner, 2012) and is one of the most requested nutrients by the soybean plant, equating to phosphorus and magnesium. Thus, the absence of S can limit grain yield (Crusciol et al., 2006), because its deficiency reduces the absorption of water and nutrients. Consequently, the plant becomes less tolerant to the effects of summer (Sousa

Table 9. Development of the interaction between soil management systems and use of plaster for the initial population (IP), final population (FP) and number of pods per plant (NPP) of soybean in the 2011/12 harvest, Selvíria, MS, Brazil.

Soil management	IP		FP		NPP	
	Plaster					
	With	Without	With	Without	With	Without
SDS12	229442 bA	227035 bA	191294 bA	201849 aA	72.5 aA	58.1 bB
CDSS	298886 aA	285553 aA	237034 aA	213331 aA	59.0 abA	66.0 abA
SDS6	237775 bA	233701 bA	207776 bA	202961 aA	52.2 bB	79.2 aA

SDS12 = Scarified Direct Seeding at each 12 months; SDS6 = Scarified Direct Seeding at each six months; CDSS = Continuous Direct Seeding System. Means followed by same letter, lowercase in columns do not differ from each other by Tukey's test (p <0.05).

Table 10. Development of the interaction between soil management systems and use of plaster for the initial population (IP) and final population (FP) of soybean in the 2011/12 harvest, Selvíria, MS, Brazil.

Soil management	IP		FP	
	Plaster			
	With	Without	With	Without
SDS12	223331 abA	217221 aA	21.42 aA	19.9 aA
CDSS	251849 aA	230368 aA	21.27 aA	18.42 aB
SDS6	215924 bA	208516 aA	19.81 aA	20.28 aA

SDS12 = Scarified Direct Seeding at each 12 months; SDS6 = Scarified Direct Seeding at each six months; CDSS = Continuous Direct Seeding System. Means followed by same letter, lowercase in columns do not differ from each other by Tukey's test (p <0.05).

et al. 2005), and with the lower absorption of the other nutrients there is a reduction in the production of photoassimilates and, therefore, of the productivity.

However, the higher number of plants and grain mass did not provide higher soybean yields in the two years of CDSS cultivation. This fact is related to the high phenotypic plasticity of soybean, that is, to the capacity of the crop to change its morphology and production components in order to adapt them to the conditions of the environment. In this way, it allows the lower sowing density to be compensated by the rearrangement of plants, allowing the maintenance of productivity in a wide difference in plant density per hectare. Balbinot Junior et al. (2015) reported that in several works with different soybean cultivars in the Paraná region, even with a large difference in plant density per hectare, most showed that the density had little influence on grain yield, which was explained by the fact that the crop presented spatial rearrangement capacity, thus obtaining the same productivity, even in a smaller plant stand.

Conclusions

The direct sowing system (CDSS) provided better soil physical conditions over time in the superficial layer. The application of gypsum contributed indirectly to the structuring and chemical conditioning of the soil in depth in the CDSS, allowing continuous values of the physical attributes of the soil.

The use of limestone along with gypsum associated with CDSS increased the final population and the grain mass of the soybean, however, there was no increase in grain yield in the two years of cultivation.

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