

Chiseling and gypsum application affecting soil physical attributes, root growth and soybean yield¹

Escarificação e gessagem influenciando atributos físicos do solo, crescimento de raízes e produtividade da soja

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ABSTRACT - This study aimed to evaluate the effect of chiseling and gypsum application on soil physical properties, soybean root growth and grain yield. An experiment was carried out in Londrina, Paraná state, Brazil, under a randomized complete block design, with six replications. The soil in the experimental area is classified as a dystroferic Red Latosol (Oxisol), containing 720 g kg⁻¹ of clay. The experiment comprised four treatments: (1) continuous no-tillage (CNT) system without gypsum application, (2) CNT with gypsum application at 3.5 Mg ha⁻¹, (3) chiseled soil without gypsum, and (4) chiseled soil with gypsum application. Regardless of gypsum application, chiseling increased water infiltration rate in soil and reduced penetration resistance. Gypsum application affected neither water infiltration nor soil penetration resistance in both no-tillage (NT) and chiseled soil systems. Moreover, gypsum application improved soybean root development at a depth range of 0.20-0.40 m in NT system. Chiseling increased root growth in the surface layer (0-0.20 m depth). Either isolated or combined, chiseling and gypsum application had no impact on soybean grain yield throughout one cropping season.

Key words: No-tillage. Soil penetration resistance. Infiltration rate. Soil compaction.

RESUMO - O objetivo desse estudo foi avaliar o efeito da escarificação e da gessagem em atributos físicos do solo, crescimento de raízes e produtividade de grãos de soja. O experimento foi conduzido em Londrina, PR, em delineamento de blocos completos casualizados, com seis repetições. O solo da área experimental foi classificado como Latossolo Vermelho Distroférico, o qual apresenta 720 g kg⁻¹ de argila. Foram avaliados quatro tratamentos: Sistema Plantio Direto (SPD) contínuo, sem gesso (1) e com gesso, 3,5 Mg ha⁻¹ (2), solo escarificado sem gesso (3) e com gesso (4). A escarificação, independentemente da aplicação de gesso agrícola, aumentou a taxa de infiltração de água no solo e reduziu o escoamento superficial e a resistência à penetração. O gesso agrícola, tanto no SPD quanto no solo escarificado, não alterou a taxa de infiltração de água no solo, o escoamento superficial e a resistência à penetração. O gesso promoveu aumento do crescimento de raízes da soja na camada de 0,20-0,40 m no SPD. A escarificação promoveu aumento do crescimento de raízes de soja na camada superficial (0-0,20 m). A escarificação e a gessagem, de forma isolada ou combinadas, não influenciaram a produtividade de grãos da soja em uma safra.

Palavras-chave: Sistema Plantio Direto. Resistência do solo à penetração. Taxa de infiltração. Compactação.

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INTRODUCTION

Agricultural soil management is a set of practices that, if rationally used, increase crop yield, being financially worthwhile to farmers. On the other hand, improper management may cause soil physical, chemical, and biological degradation and gradually decrease its production potential (DEBIASI *et al.*, 2010).

No-tillage (NT) system has been recognized as fundamental for sustainable soil management in Brazilian agroecosystems (FRANCHINI *et al.*, 2012). The main problem of unsuitable tillage practices is the formation of highly compacted layer, often between 0.10 and 0.20 m deep. Moreover, this compaction can reduce root development and crop yield (DEBIASI *et al.*, 2010). In this regard, chiseling has often been advised as alternative to reduce soil physical impediments (KLEIN; CAMARA, 2007) since its effects persist for one year or less (VEIGA *et al.*, 2007). However, this practice only breaks the compacted layer, not rebuilding the damaged soil structure, as it does not act on causes of compaction. In addition, it should be noted that there is still a lack of information about the effect of soil chiseling on root growth and crop yield.

Agricultural gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) has been used to complement liming, decreasing aluminum (Al) toxicity and increasing calcium (Ca) and sulfur (S) concentrations in depth (SORATTO; CRUSCIOL; MELLO, 2010; TIECHER *et al.*, 2018). Moreover, gypsum application improves chemical properties in surface soil layers. Acidic soils are unfavorable for root growth in surface layers. Gypsum can also act as soil structure conditioning agent, facilitating particle aggregation and reducing soil mechanical resistance to penetration (NUERNBERG; RECH; BASSO, 2005). Therefore, gypsum is likely to speed up soil restructuring after chiseling, and their synergistic effect could provide relevant agronomic advantages.

This study aimed to evaluate the effect of chiseling and gypsum application on soil physical properties, and on soybean root growth and grain yield.

MATERIAL AND METHODS

The experiment was conducted in an experimental area at Universidade Filadélfia de Londrina (UNIFIL), in Londrina, Paraná state, Brazil ($23^{\circ}23'11''$ S, $51^{\circ}13'06''$ W, and 552 m altitude). This experimental area had been grown with annual crops under NT for 15 years. Its soil is classified as dystroferric Red Latosol (Oxisol). The experiment was carried out under a randomized complete block design, with four treatments and six repetitions. The treatments consisted of: (1) continuous no-tillage (CNT) system without gypsum application, (2) CNT system with gypsum application at 3.5 Mg ha^{-1} , (3) chiseled soil without gypsum application, and (4) chiseled soil with gypsum application. Each plot had 50 m^2 ($5 \times 10 \text{ m}$) and a useful area of 24 m^2 ($3 \times 8 \text{ m}$).

The Table 1 displays the soil chemical properties in the experimental area, which were determined by the method proposed by Tedesco *et al.* (1995). Agricultural gypsum was hand-broadcast onto the soil before chiseling, in May 2014, following method recommended by Embrapa (2013). Clay content ($> 700 \text{ g kg}^{-1}$) was used to estimate the applied dose, which was 3.5 Mg ha^{-1} .

Table 2 defines crop sequence and the times when gypsum application, chiseling, and physical soil analyses were performed. Chiseling was performed using a chiseling plow equipped with fixed shanks mounted on a three-point hitch tool holder frame. Shanks were spaced 0.5 m apart. The operation was performed at a working depth of 0.25-0.30 m when the soil was friable.

Soil water infiltration was assessed in October 2015. At that time, the high risk of erosion increased due to heavy rainfall events. Measurements were made at three sites per plot, using the Cornell sprinkle infiltrometer (SANTI *et al.*, 2012). This equipment simulates high-intensity rainfall, and surface runoff was measured by collecting surplus water, using a hose set at the bottom of the infiltrometer ring. Runoff volume was read every three minutes. Rainfall intensity was simulated at 300 mm h^{-1} , controlled by differences in reservoir water-volume

Table 1 - Soil chemical properties in three soil layers at implementation of the experiment

Soil layers (m)	pH CaCl	Al ³⁺ H+AL			CEC pH 7.0	P	K	Organic matter	Ca ²⁺	Mg ²⁺	S	BS %
		cmol _c dm ⁻³	m	%								
0.00-0.10	4.2	0.68	7.5	15.3	11.2	13.3	0.24	20.6	2.4	1.05	4.7	33.4
0.10-0.20	4.5	0.44	6.2	9.9	10.2	9.6	0.07	15.6	3.0	0.92	6.0	29.3
0.20-0.40	4.3	0.94	6.4	28.6	8.8	3.0	0.04	10.0	1.6	0.68	6.4	26.7

m (%) = aluminum saturation. CEC = cation exchange capacity. BS (%) = base saturation

Table 2 - Sequence of crops used in the experiment and the times when gypsum application, chiseling, and physical soil analyses were performed

Soil management	Gypsum application and Chiseling		Infiltration and runoff assessment		Evaluation of penetration resistance		
	Cropping seasons						
	2014		2015				
	↓	Winter	Summer	Winter	↓	Summer	↓
Continuous no-tillage		Wheat	Soybean	Wheat		Soybean	
Chiseled soil		Wheat	Soybean	Wheat		Soybean	

Gypsum application and chiseling were performed at May 2014

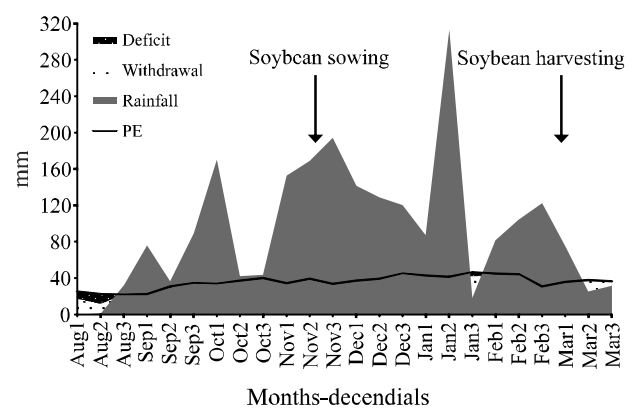
readings every three minutes. Rain intensity and surface runoff were measured simultaneously. Finally, infiltration rate was estimated as the difference between applied rain and runoff. Each measurement lasted about 36 minutes.

In the 2015/2016 cropping season, the experimental area was grown with soybean, cultivar NA 5909 RG, sown on 13 October 2015. Row spacing was 0.45 m, and plant density was 300 thousand plants per hectare. Fertilization consisted of applying 350 kg ha⁻¹ NPK (04-14-08) fertilizer. Soybean seeds were previously treated with Standak (200mL 100 kg⁻¹ seeds) and Gelfix 5[®] liquid inoculant (100mL 50 kg⁻¹ seeds). Pest, disease, and weed controls were carried out according to technical recommendations for the crop. A ten-day water balance was calculated during the 2015/2016 cropping season (Figure 1), using meteorological data from the Instituto Agronômico do Paraná (IAPAR, 2016).

At full flowering soybean stage, the root system was evaluated by the monolith method, opening one trench per plot. From each trench, monolith samples were taken at five depth layers (0.00-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.40, and 0.40-0.60 m). Monolith width was 0.30 m, and its central point was placed below the soybean row. Plant roots were separated from soil by water washing and 2-mm mesh sieving. After washing and separating, root samples were scanned and images were processed by the Safira software (JORGE; RODRIGUES, 2008) for root length measurement. For this purpose, the following equation was used:

$$\text{Root length (cm cm}^3\text{)} = \frac{\sum \text{digitized lengths} \times \text{total dry mass}}{\text{Digitalized root dry mass} / \text{collected volume (cm}^3\text{)}}$$

Penetration resistance (PR) measurements in each plot were performed in two times: during experiment setup (May 2014) and during soybean full flowering (January 2016). Measurements were made up to a depth of 0.50 m by an automated penetrometer (Falker, Solo Track model), equipped with a cone with a 30° angle and 12.83 mm diameter. Along with this, samples were collected at

Figure 1 - Sequential water balance during the 2015/2016 cropping season. PE = Potential evapotranspiration

the depth layers of 0.00-0.10 m and 0.10-0.20 m, for soil moisture determination. Moisture contents were adjusted for comparing PR measures of both evaluations, according to Moraes *et al.* (2014).

At full bloom stage, SPAD index was determined in ten plants per plot, and measured in the central leaflet (avoiding the leaf midrib) of the third fully expanded leaf, in a basipetal direction. These measurements were made using a SPAD chlorophyll meter (SPAD-502; Konica Minolta, Japan). This equipment uses the absorbance within red (widely absorbed by chlorophyll) and infrared (low or zero absorption) light spectra to estimate relative chlorophyll content.

At full bloom stage, leaf area index (LAI) was also measured using an LI-COR LAI-2200 Plant Canopy Analyzer (LI-COR Biosciences, Nebraska, USA), which has fisheye lens for solar radiation capture, equipped with a cone with a 90° opening angle. Measurements were performed in the rows (under plant canopy) and between rows (near ground surface). These were carried out on days with clear sky conditions and under full sun to avoid under and overestimation.

Soybean plants were harvested from two 5-m rows (plot useful area) to estimate grain yield. The plants were threshed and grain yield adjusted to 13% moisture. In addition, ten plants per plot were used for height measurements.

Data were submitted to normality (Shapiro-Wilk) and homoscedasticity (Hartley) tests. After this, an analysis of variance and F test ($p < 0.05$) were performed. The averages of treatments were compared by the Tukey test ($p < 0.05$). The statistical analyses were performed using the Sisvar 5.3 software (FERREIRA, 2008).

RESULTS AND DISCUSSION

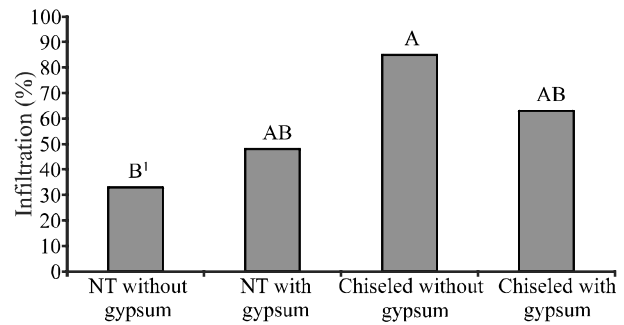
If compared to the NT system, the chiseled soils presented higher water infiltration rates (IR) and lower surface runoff intensity (SR) (Table 3). However, gypsum application had no effect either on soils under NT nor on the chiseled soil. The results showed that the chiseling effect on water infiltration remained 18 months after its application.

The smallest IR and largest SR in NT system may be related to compaction within the first few centimeters of the soil profile. This compaction is due to the cumulative effect of traffic on the soil and natural settlement of particles (CUNHA; CASCÃO; REIS, 2009). On the other hand, chiseling breaks the compacted layer and split it into parts of different sizes, creating fissures where water can easily percolate.

In the soil under NT without gypsum application (Figure 2), SR started already 4.32 minutes after rainfall initiation, whereas in the chiseled soil without gypsum, it started after 13.53 minutes. In these both treatments, total infiltration values represented 40 and 80% of the simulated rains, respectively. This may represent significant changes in the practices used for erosion control. According to Carlesso *et al.* (2011), increasing runoff rates can result in higher risks of soil

loss, regardless of surface conditions. Using the same equipment (Cornell infiltrometer), Santi *et al.* (2012) evaluated infiltration in a typical clayey dystrophic Red Latosol under NT and observed that runoff started between 3 and 6 min after rainfall initiation (300 mm h^{-1}), which corroborates our results.

Figure 2 - Soil water infiltration in relation to simulated precipitation by Cornell infiltrometer in different soil management systems and time necessary to start the runoff (No-tillage without gypsum = 4'32"; No-tillage with gypsum = 5'56"; Chiseled soil without gypsum = 9'55" and Chiseled soil with gypsum = 13'53")



¹Means followed by the same letters do not differ from each other by the Tukey test at 5% probability

At the beginning of the experiment (May 2014), PR values in the experimental area were close to 3,000 kPa (Figure 3A), with no clear differences among treatments. After 20 months, the second evaluation showed higher PR values, within a range of 2.500 kPa (Figure 3B). In this case, there is a compaction trend within soil surface layer in NT due to machinery traffic (DRESCHER *et al.*, 2012).

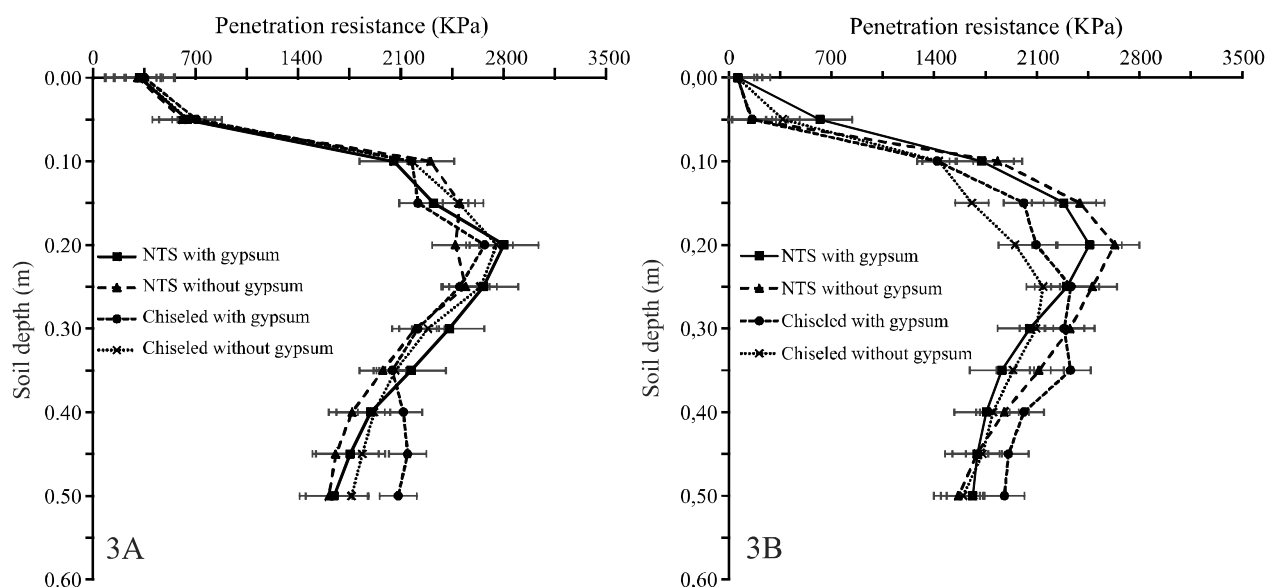
All treatments showed a decrease in PR throughout the experiment. This may be due to absence of machinery traffic in the plots, once several operations were manually

Table 3 - Water infiltration rate and runoff in soil as a result of simulated precipitation by Cornell infiltrometer in different soil management systems

Soil management	Water infiltration rate (mm h^{-1})	Runoff (mm)
No-tillage without gypsum	31.8 b ¹	222 a
No-tillage with gypsum	73.2 b	186 a
Chiseled soil with gypsum	100.0 a	116 b
Chiseled soil without gypsum	139.2 a	56 b
CV (%)	29.6	38.0

¹Means followed by the same letters, comparing the same variable, do not differ from each other by the Tukey test at 5% probability

Figure 3 - Penetration resistance (PR) evaluated up to 0.50 m at the beginning of the experiment (May/2014) (3A) and January/2016 (3B), under different soil management systems



performed. Moreover, the studied soil has shrinking-swelling properties, presenting natural cracks within the compacted volume, and hence particle binding and PR reductions (VIANA; FERNANDES FILHO; SCHAEFER, 2004).

In the second evaluation, greater differences were observed for PR among treatments, mainly at the depth range of 0.15-0.20 m. Treatments under NT showed higher values than those under chiseled soil, showing peaks close to 0.20 m in depth. Under NT and without gypsum application, soils were the most resistant to penetration. Despite not having PR peaks, chiseled soils also showed the highest values at the 0.20 m depth layer when gypsum was not applied. These results coincide with the high IR values of the same treatments. Lower PR values may be due to soil adhesion reduction after chisel breaking and increased porosity, which is responsible for a faster water flow throughout the soil profile.

A PR range from 2,000 to 4,000 kPa has been proposed as critical to root development in annual crops, especially in low humidity soils (SUZUKI *et al.*, 2007). In studying soil compaction effect on a dystrophic Red Latosol, Secco (2009) found that a PR range of 2,650-3,260 kPa decreased yield of wheat (18.3%), corn (34.0%), and soybean (24.3%). Likewise, Beutler *et al.* (2006) observed that PR values from 2,240 kPa decreased soybean yield by 32%, in a Red Latosol with a clay content of 330g kg⁻¹.

Gypsum in chiseled soils had no influence on root length in all studied layers (Figure 4A). In this case, lower

PR might have favored root penetration rather than the ideal Ca or harmful Al levels. After chiseling, roots were clearly concentrated within the 0.05-0.10 m depth layer. Conversely, under continuous NT, lower root growth was found within the surface layer but higher in the 0.20-0.40 m depth layer, after breaking the layer with high PR peaks. In such case, gypsum increased root growth in the 0.20-0.40 m depth layer (Figure 4B).

By comparing continuous NT and chiseled soil, we observed that root growth pattern was close to normal in chiseled soils. In continuous NT, root growth was limited up to 0.20 m depth, which was recovered when more favorable conditions were found at greater depths. In this Latosol type, the lower part of A horizon, in the transition to AB or BA horizons, there is a reduction in soil adhesion and resistance levels, with an increase in macro-porosity due to its grain structure.

Root growth depends on several factors such as available oxygen and water (KOLB; JOLY, 2009), soil density, penetration resistance, and chemical properties, as well as calcium availability and toxic aluminum presence. In this sense, once can assume that chiseling practice provided more favorable conditions for soybean root growth in the surface layer when to soil under continuous NT system, which provided suitable conditions at depths greater than 0.20 m.

Leaf area index (LAI) at full flowering was lower for plants grown in the chiseled soil without gypsum when compared to the other treatments (Table 4). SPAD index and plant height were not influenced by the treatments.

Figura 4 - Soybean root length (cm cm⁻³) in the 0.0-0.60 m layers in continuous no-tillage system (SPD) and scarified soil, with and without gypsum

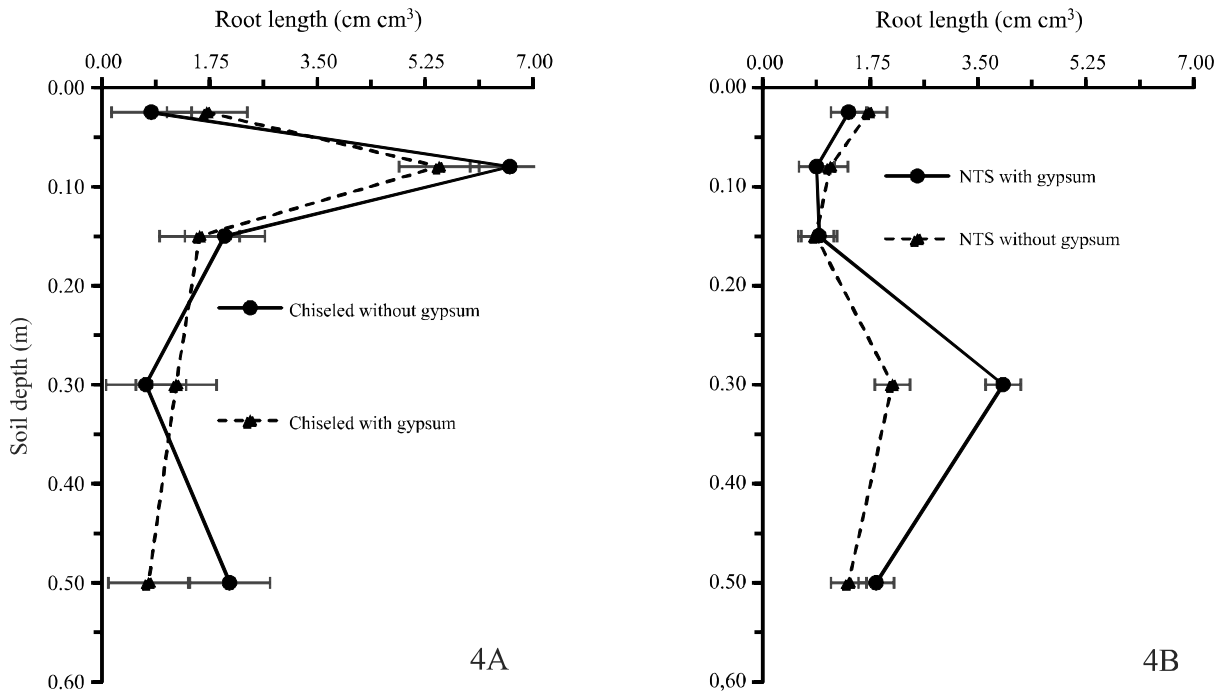


Table 4 - Variables related to soybean crop as a function of chiseling and gypsum application, Londrina, Paraná state, Brazil

Soil management	LAI ¹	Spad index	Plant height (m)	Yield (kg ha ⁻¹)
No-tillage without gypsum	3.74 a ²	28.1 a	60.3 a	3,096 a
No-tillage with gypsum	3.83 a	29.0 a	61.9 a	3,374 a
Chiseled soil with gypsum	3.86 a	28.5 a	67.7 a	2,947 a
Chiseled soil without gypsum	2.87 b	26.7 a	64.1 a	2,555 b
CV (%)	8.8	3.6	3.8	4.6

¹Leaf area index. ²Means followed by the same letters, comparing the same variable, do not differ from each other by the Tukey test at 5% probability

However, grain yield was inferior in chiseled soil without gypsum, as in LAI results. Despite water surpluses during most of the soybean cycle, a critical deficit occurred on the third ten-day period of January, when crop was in grain filling stage. According to Santos *et al.*, (2014), water deficits during reproductive stages increase harvest losses if compared to shortfalls in vegetative growth stages. The absence or minimum soil tillage in NT raise water contents compared to traditional tillage systems. This is mainly due to crop residue maintenance on the soil surface, which reduces evaporation and maintains mild soil temperatures (FRANCHINI *et al.*, 2012). The opposite was observed when chiseling practice was conducted, in which IR increased (Figures 2) and soil residue cover decreased

(KLEIN; CAMARA, 2007). Additionally, in chiseled soils, soybean root growth was higher in surface than in subsurface layers when compared to NT treatments.

CONCLUSIONS

1. Regardless of gypsum application, chiseling increased water infiltration and reduced surface runoff and penetration resistance;
2. Both in no-tillage and in chiseled soils, gypsum application had no influence on water infiltration rate, surface runoff, and penetration resistance;

3. Gypsum increased soybean root growth in the depth range of 20-40 cm in the no-tillage system, but had no influence on plants grown in the chiseled soil;
4. Chiseling improved soybean root growth in surface layer compared to subsurface layers;
5. Either isolated or in combination, chiseling and gypsum application had no effect on soybean grain yield compared to the no-tillage system without gypsum application.

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