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Marco Segalla Prazeres
Universidade do Estado de Santa Catarina
marcosegalla@hotmail.com

Fabrício Tondello Barbosa
Universidade Estadual de Ponta Grossa
fabriciotondello@gmail.com

Ildegardis Bertol
Universidade do Estado de Santa Catarina
ildegardis.bertol@udesc.br

Tercio Vaisnava Fehlauer
Universidade do Estado de Santa Catarina
tercioagro@gmail.com

Gustavo Ferreira de Oliveira
Universidade do Estado de Santa Catarina
gustavo.fdo@edu.udesc.br

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SOIL WATER INFILTRATION IN NO-TILLAGE AFTER SCARIFICATION AND CULTIVATION OF VEGETABLE SPECIES

ABSTRACT: Soil water infiltration is influenced by management, especially by the type of soil tillage, among other factors, and its knowledge is important for conservation planning. Scarification can improve physical and water conditions and increase soil water infiltration. The aim of this study was to evaluate some physical properties and the water infiltration into the soil in the presence and absence of scarification in no-tillage, in a silty clay texture *Cambissolo Húmico*. For this, the following treatments were tested: no-tillage and no-tillage subjected to scarification, both combined with the crops of black oats/corn, black oats/beans, wheat/corn, wheat/beans, forage turnip/corn and forage turnip/beans. Soil sample collection and water infiltration tests were carried out at the beginning and at the end of the experiment. Scarification positively affected the physical properties of the soil only in the 0-5 cm surface layer, whose effect persisted for a period of one year for most attributes, resulting in greater water infiltration compared to treatment without scarification.

KEYWORDS: Soil conservation, Soil management, Water movement in soil.

INFILTRAÇÃO DE ÁGUA NO SOLO EM SEMEADURA DIRETA APÓS ESCARIFICAÇÃO E CULTIVO DE ESPÉCIES VEGETAIS

RESUMO: A infiltração de água no solo é influenciada pelo tipo de preparo mecânico, dentre outros fatores, e seu conhecimento é importante para o planejamento conservacionista. A escarificação pode melhorar as condições físicas e hídricas e aumentar a infiltração de água no solo. O objetivo deste trabalho foi avaliar algumas propriedades físicas e a infiltração de água no solo na presença e ausência de uma escarificação em semeadura direta, em um Cambissolo Húmico de textura argilo siltosa. Para isso, testaram-se os seguintes tratamentos: semeadura direta e semeadura direta submetida a uma escarificação, ambos combinados com os cultivos de aveia preta/milho, aveia preta/feijão, trigo/milho, trigo/feijão, nabo forrageiro/milho e nabo forrageiro/feijão. Coleta de amostras de solo e testes de infiltração de água foram realizados no início e ao final do experimento. A escarificação afetou positivamente as propriedades físicas do solo apenas na camada superficial de 0-5 cm, cujo efeito persistiu pelo período de um ano para a maioria dos atributos, resultando em maior infiltração de água em relação ao tratamento sem escarificação.

PALAVRAS-CHAVE: Conservação do solo, Manejo do solo, Movimento de água no solo.

INFILTRACIÓN DE AGUA EN EL SUELO EN SIEMBRA DIRECTA DESPUÉS DE ESCARIFICACIÓN Y CULTIVO DE ESPECIES VEGETALES

RESUMEN: La infiltración de agua en el suelo está influenciada por el tipo de preparación mecánica, entre otros factores, y su conocimiento es importante para la planificación de la conservación. La escarificación puede mejorar las condiciones físicas y del agua y aumentar la infiltración de agua en el suelo. Este estudio tuvo como objetivo evaluar algunas propiedades físicas y la infiltración de agua en el suelo en presencia y ausencia de escarificación en la siembra directa, en un *Cambissolo Húmico* con textura arcillo limosa. Para esto, se probaron los siguientes tratamientos: siembra directa y siembra directa sometidas a una escarificación, ambas combinadas con el cultivo de avena negra/maíz, avena negra/frijoles, trigo/maíz, trigo/frijoles, nabo forrajero/maíz y nabo forrajero/frijoles. Se recogieron muestras de suelo y se realizaron pruebas de infiltración de agua al principio y al final de la investigación. La escarificación del suelo afectó positivamente las propiedades físicas del suelo solo en la capa superficial de 0-5 cm, cuyo efecto persistió durante un año para la mayoría de los atributos, lo que resultó en una mayor infiltración de agua en el suelo en comparación con el tratamiento sin escarificación.

PALABRAS CLAVES: Conservación del suelo, Manejo del suelo, Movimiento del agua del suelo.

INTRODUCTION

The rate of water infiltration into the soil is one of the properties that best represents the physical conditions of the soil, its quality and structural stability (PANACHUKI et al., 2011; SANTOS et al., 2016), in addition to being important to define conservation practices of soil, to plan, and design irrigation and drainage systems (BERTOL et al., 2015).

Different management and cultivation practices alter the physical properties of the soil, which can manifest themselves in different ways, influencing plant development (BERTOL et al., 2001). Thus, the original structure of the soil can be changed by breaking up the aggregates into smaller units. As a result, there is a reduction in the volume of macropores and an increase in soil density, with a consequent decrease in the rate of water infiltration into the soil.

Water infiltration in soil differs significantly with management (BERTOL et al., 2015), that is why its increase has been used as an argument for scarification in no-till areas (GIRARDELLO et al., 2011). In no-tillage, soil mobilization restricted to the seeding line associated with the pressure exerted by agricultural machines results in the compaction of surface layers (TORMENA et al., 1998). Compaction hinders root growth, reduces the infiltration, the soil water redistribution and the gas exchange, resulting in decreased production (POTT et al., 2018). Nicoloso et al. (2008) consider mechanical scarification as an efficient alternative to improve the physical conditions of very clayey soils only when associated with biological scarification, using plants with a well-developed root system.

Soil attributes related to water transport, such as infiltration rate, are sensitive to assess the duration of mechanical decompaction in the soil (DRESCHER et al., 2016). In clayey Latossolo Vermelho, Vieira and Klein (2007) evaluated the effect of scarification on the decompaction of an area under no-tillage, observing an increase in the rate of water infiltration into the soil 24 months after this practice, proving a residual effect.

Even with the positive effects of scarification, there is high variability regarding its persistence in the soil (TWONLOW et al., 1994). Busscher et al. (2002), found that the effect of scarification has a tendency to reduce its effects over time, depending on the soil wetting and drying cycles, resulting in the reconsolidation process.

For Prando et al. (2010), scarification in a clayey-textured *Nitossolo Vermelho*, provides greater water infiltration into the soil only in the first year of cultivation. Some authors claim that mechanical intervention in soil managed with no-tillage, through scarification, showed a transitory potential to mitigate soil compaction (DRESCHER et al., 2011).

There is a lack of studies on the effect of scarification in areas managed under no-tillage in a subtropical environment and located in plateau regions. In this áreas, in many situations predominate shallow clayey soils with high levels of silt, high acidity and high levels of organic matter, such as *Cambissolos Húmicos* derived from sedimentary rocks, which occur in the Santa Catarina Plateau. These soils have limited water infiltration capacity (BERTOL et al., 2015). When cultivated they generally present physical restrictions to plant growth and development, mainly due to low macro porosity and high soil density and penetration resistance values (BORTOLINI et al., 2016).

The aim of this study was to evaluate the physical properties and water infiltration in a silty clayey *Cambissolo Húmico* after no-tillage scarification and its residual effect after cultivation, in a succession of different plant species.

MATERIAL AND METHODS

The experiment was carried out between June 2015 and June 2016, in an experimental field located at the Centro de Ciências Agroveterinárias, of the University of the State of Santa Catarina, located in the municipality of Lages, in the Planalto Sul region of

Santa Catarina. The climate of the place, according to criteria established by the Köeppen classification (ALVARES et al., 2013), is of the Cfb type (humid subtropical, rainy and with cool summers), with an average annual precipitation of 1,533 mm (SCHICK et al., 2014).

The soil of the area is a *Cambissolo Húmico alumínico léptico* (420 g kg^{-1} of clay, 440 g kg^{-1} of silt and 140 g kg^{-1} of sand in the 0-0.2 m layer), located at coordinates 27º 47' S and 50° 19' W with 937 m of average altitude.

The treatments consisted of two types of soil management: no-tillage (NT), characterized by soil mobilization restricted to the sowing line, and no-tillage subjected to scarification (NTS), both combined with the cultivation of six sequences of vegetable species, which are: black oats/corn (O/C), black oats/beans (O/B), wheat/corn (W/C), wheat/beans (W/B), forage turnip/corn (R/C) and forage turnip/beans (T/B). The experimental design was of randomized blocks with three replications, in a split-plot scheme, totaling 36 experimental units. The plots had dimensions of 6 x 10 m (60 m^2) and constituted the types of soil management (NT and NTS). The subplots had dimensions of 2 x 10 m (20 m^2) and constituted the winter crops (black oats, wheat, and forage turnip), while the subplots had dimensions of 2 x 5 m (10 m^2) and constituted the crops of the species of summer (corn and beans). For this, after the first period under winter crops, each subplot was divided in half, in length, for the implantation of corn and bean crops.

The experiment area had been cultivated for two decades with different yearly crops and types of management. In May 2011, soil acidity correction was carried out with limestone incorporation using a scarifier and light harrow. From this moment on, the area was conducted without interruption under no-tillage.

In June 2015, one month before the sowing of the winter species, a scarification operation was carried out on the plots that received such treatment. Scarification was carried out in the soil with moisture in a friable consistency and covered with plant residues from the previous crop. The scarifier contained two rows of mismatched rods, the front line being composed of seven rods and the rear row consisting of six rods, with a distance of 0.5 m between them. Thus, the scarification resulted in furrows spaced 0.25 m apart, with an actuation of 0.25 m in depth.

The sowing of winter crops took place in July 2015, using 80 and 20 kg ha^{-1} of seeds in the treatments of black oat (*Avena strigosa*) and forage turnip (*Raphanus sativus*) respectively. For the treatment with wheat (*Triticum aestivum*) 330 viable seeds/m^2 were used. The sowing was done with an experimental plot seeder with 0.20 m spacing between rows, making a total of 10 rows per plot.

In December 2015, after managing the winter crops by uniformly distributing their plant biomass on the ground with the use of a mower, corn (*Zea mays*) and common black bean (*Phaseolus vulgaris*) crops were implanted. Row spacing was 0.50 m and density was 80,000 and 300,000 plants ha^{-1} of corn and beans, respectively. Sowing was done with a manual seeder. The fertilization of the crops was carried out according to the recommendations of the CQFS RS/SC (2016) and the control of weeds was carried out manually during the winter crops and with the application of herbicides in the summer crops.

The determinations of water infiltration and the soil physical properties were carried out in two periods, the first after soil preparation and before the sowing of winter crops, in June 2015, and the second, in May 2016, after the summer crop development cycle.

Trenches were opened to collect soil samples with preserved structure in volumetric rings of 141.3 cm^3 in the layers of 0-5, 5-10, 10-20 and 20-30 cm. Soil density (Sd), total porosity

(Tp), macropores (Ma) and micropores (Mi) were determined according to the methodology described in EMBRAPA (2011). For this, the rings were saturated in water, submitted to a sand tension table with a suction of 6 kPa and then dried in an oven at 105 °C, for 48 hours.

The soil water infiltration tests were carried out using the concentric double cylinder method (FORSYTHE, 1975), to obtain the final soil water infiltration rate (FIR) and the total infiltrated water layer (accumulated I). The inner and outer cylinders were respectively 0.3 and 0.6 m in diameter, and each treatment repetition received a test lasting 90 minutes.

The data were subjected to analysis of variance and, when significant by the F test at the 5% level ($p<0.05$), the treatment means were compared by the Tukey test ($p<0.05$). Correlations between variables were performed using Pearson's linear model.

RESULTS AND DISCUSSION

INITIAL PERIOD OF THE EXPERIMENT, AFTER THE SCARIFICATION THE SOIL

The final soil water infiltration rate (FIR) was respectively 8.8 and 6.0 cm h^{-1} for NTS and NT, representing a numerical increase of 47% provided by scarification. The total layer of infiltrated water (accumulated I) was respectively 22.4 and 14.3 cm for NTS and NT, which represented a value 57% higher in NTS (Table 1). Although quantitative differences are evident, there was no statistical difference between the managements due to the high variability observed in the field of water infiltration into the soil, as observed by Vieira and Klein (2007). The increase in water infiltration is associated with the mobilization of the soil caused by the scarifier, which causes changes in its structure (GASSEN et al., 2014), such as an increase in the pore space, especially the macroporosity on the soil surface (TORMENA et al., 2002).

Table 1. Final soil water infiltration rate (FIR) and total layer of infiltrated water (accumulated I), in the initial period of the experiment, in the different managements.

Management			
NTS	NT	NTS	NT
FIR (cm h^{-1})		accumulated I (cm)	
8.8±1.7 ^{ns}	6.0±1.8 ^{ns}	22.4±7.4 ^{ns}	14.3±4.6 ^{ns}

Where: NTS: no-tillage subjected to scarification; NT: no-tillage. Mean ± standard deviation. ^{ns} Not significant by analysis of variance.

The physical properties of the soil were influenced by scarification in the surface layer, with no effect between treatments in the other layers (Table 2). Soil density (Sd) was numerically reduced by scarification by 11% at a depth of 0-5 cm, with no significant difference between managements. These results are in agreement with those obtained by Araújo et al. (2004), who observed alterations caused by scarification only in the first layer of soil sampled.

The total porosity (Tp) ranged between 0.45 and 0.57 m^3 m^{-3} and was significantly influenced by the preparation in the 0-5 cm layer, and the NTS treatment increased Tp by 0.07 m^3 m^{-3}, when compared to NT. Werner et al. (2016) observed a similar behavior when evaluating the effect of scarification on natural field in a clayey *Nitossolo Bruno* (Nitisol).

Scarification resulted in a greater volume of macropores (Ma) in the 0-5 cm layer, with a value of 0.21 m^3 m^{-3}, differing significantly from NT with 0.09 m^3 m^{-3} (Table 2).

Table 2. Soil density (Sd), total porosity (Tp), macroporosity (Ma) e microporosity (Mi) of the soil, in the initial period of the experiment, in different managements and in four layers.

Management	Sd (kg dm^{-3})	Tp (m^3 m^{-3})	Ma (m^3 m^{-3})	Mi (m^3 m^{-3})
		Layer (cm)		
		0-5		
NTS	1.09±0.03 ^{ns}	0.57±0.01 A	0.21±0.01 A	0.36±0.01 B
NT	1.22±0.08 ^{ns}	0.50±0.04 B	0.09±0.04 B	0.40±0.02 A
		5-10		
NTS	1.32±0.08 ^{ns}	0.48±0.03 ^{ns}	0.07±0.04 ^{ns}	0.41±0.02 ^{ns}
NT	1.29±0.05 ^{ns}	0.47±0.01 ^{ns}	0.06±0.01 ^{ns}	0.41±0.01 ^{ns}
		10-20		
NTS	1.19±0.21 ^{ns}	0.53±0.08 ^{ns}	0.13±0.08 ^{ns}	0.40±0.01 ^{ns}
NT	1.28±0.06 ^{ns}	0.48±0.02 ^{ns}	0.09±0.05 ^{ns}	0.39±0.03 ^{ns}
		20-30		
NTS	1.40±0.04 ^{ns}	0.45±0.02 ^{ns}	0.04±0.03 ^{ns}	0.40±0.01 ^{ns}
NT	1.37±0.01 ^{ns}	0.45±0.01 ^{ns}	0.03±0.01 ^{ns}	0.42±0.01 ^{ns}

Where: NTS: no-tillage subjected to scarification; NT: no-tillage. Mean ± standard deviation. ^{ns} Not significant by analysis of variance. ($p<0,05$). Means preceded by the same capital letter, in the column, do not differ significantly by the Tukey test ($p<0.05$).

The NTS treatment had the most significant variation in depth of Ma values, with a reduction of 81% in the 20-30 cm layer compared to the surface layer. The higher surface Ma value in the NTS is due to the action of the scarifier rods, which resulted in the fracturing of the aggregates and the development of pores, especially the macropores.

Considering the critical limit of Ma equal to 0.10 m^3 m^{-3}, where lower values suggest aeration problems to plant roots (XU et al., 1992), there was a limitation in NT in all soil layers. We attribute this behavior to the minimum disturbance and machine traffic (DRESCHER et al., 2011). When considering the critical value of Ma, NTS was efficient in overcoming such limitation in the 0-5 cm (0.21 m^3 m^{-3})

and 10-20 cm (0.13 m^3 m^{-3}) layers, which can interfere with the growth of the plant root system and the water flow along the soil profile.

The micropores values (Mi) ranged between 0.36 and 0.42 m^3 m^{-3}. In the superficial layer (0-5 cm), scarification (NTS) provided a significant reduction of 4% in the volume of Mi compared to NT (Table 2). In general, it was possible to observe that there was a more accentuated change in Ma than in Sd, Tp and Mi. This behavior occurred because part of the volume of Mi was converted into Ma by the action of the implement during the mechanical soil preparation, in agreement with Werner et al. (2016).

FINAL PERIOD OF THE EXPERIMENT, AFTER THE CULTIVATION OF VEGETABLE SUCCESSIONS

The effects of scarification on soil water infiltration persisted for a period of twelve months. The FIR was respectively 11.3 and 8.1 cm h^{-1} in NTS and NT, in the average of the cultures, representing a numerical difference of 39.5% between the managements (Table 3). Compared to the beginning of the experiment, the NTS and NT treatments increased the final infiltration rate by 28.4 and 35%. Vieira and Klein (2007), evaluating the effect of no-tillage scarification in a Latossolo Vermelho, concluded that it had an effect on water infiltration for a period of 24 months. Among winter crops and in the average of managements, black oat had a FIR of 11.3 cm h^{-1}, being 25 and 29% higher, respectively, than forage turnip (FIR: 9.0 cm h^{-1}) and wheat (FIR: 8.8 cm h-1), while in summer crops, corn (FIR: 10.4 cm h^{-1}) was 15% higher than beans (FIR: 9.0 cm h^{-1}). Like corn, mentioned above, black oats, for having a high phytomass production, protect the soil, and due to its dense and fasciculated root system, it promotes the formation of aggregates, improving the structure of the soil, making it more porous and airy. Although quantitative differences occurred, there was no significant difference between the succession of plant species, due to the high variability observed in the field.

Table 3. Final soil water infiltration rate (FIR) and total layer of infiltrated water (accumulated I), at the end of the cultivations, in the different treatments.

Plant succession	Management			
	NTS	NT	NTS	NT
	FIR (cm h^{-1})		accumulated I (cm)	
O/B	11.5±7.2 aA	8.3±0.9 aA	24.7±15.5 aA	17.0±2.1 aA
O/C	11.9±9.2 aA	13.4±3.0 aA	26.0±21.8 aA	26.2±4.4 aA
W/B	8.4±3.6 aA	7.9±4.2 aA	18.9±7.0 aA	17.2±8.3 aA
W/C	14.5±2.6 aA	5.2±0.9 aB	30.0±3.7 aA	10.8±1.7 aB
T/B	13.1±5.9 aA	4.8±2.8 aB	26.0±10.2 aA	11.9±6.8 aA
R/C	8.5±2.0 aA	8.6±3.9 aA	17.1±4.5 aA	20.3±5.9 aA
Mean	11.3±2.2 A	8.1±0.6 B	23.8±5.1 A	17.2±0.9 B

Where: NTS: no-tillage subjected to scarification; NT: no-tillage; O: black oats; W: wheat; R: forage turnip; B: bean; C: corn. Mean ± standard deviation. Means followed by the same lowercase letter in the column and uppercase in the row do not differ by the Tukey test ($p < 0.05$).

The total amount of infiltrated water (accumulated I) followed the same behavior as the final infiltration rate. The NTS resulted in an accumulated I 38% higher than the NT, in the average of the cultures (Table 3). For this variable, oat and corn crops were 23 and 13% higher than the other winter crops (turnip and wheat) and summer (beans), respectively. Girardello et al. (2011), in a clayey Latossolo Vermelho tested soil scarification and obtained an increase in water infiltration four times higher than in the non-scarified area, but found that this effect was annulled seven months after preparation.

At the end of the cultivation, the Sd ranged between 1.05 and 1.46 kg dm^{-3}, with statistical influence of scarification only in the 0-5 cm layer (Table 4). This result demonstrates that after twelve months of soil mobilization in the NTS treatment, the Sd was 16.5% lower than in NT. Similar results were obtained by Tormena et al. (2002) and Araújo et al. (2004), indicating that the persistence of scarification effects are probably associated with greater structural stability of the soil in the surface layer, which is due to the effect of root development.

In the 0-5 cm layer, the turnip/bean, wheat/bean and turnip/corn successions in NTS presented lower Sd values compared to the same successions in NT (Table 4). In the lower layers, there was no interaction between management and succession. In the 5-10 cm layer in NT, the observed value exceeded the critical limit of 1.40 kg dm^{-3} for clayey soils (REICHERT et al., 2003), indicating possible subsurface compaction due to the effect of machine traffic associated with the minimum disturbance. On the other hand, in the NTS, in the 20-30 cm layer, the mean value of Sd was equal to the critical value, indicating possible compaction by the base of the scarifier rods.

Tp ranged between 0.40 and 0.58 m^3 m-3, with a significant effect between treatments in the 0-5 and 20-30 cm layers (Table 4). On the surface, the NTS management was superior to the NT, following the opposite behavior of the Sd, being higher in the turnip/bean, wheat/bean and turnip/corn successions compared to the same successions in NT. In the 20-30 cm layer, the NTS management resulted in lower Tp than in the NT.

Table 4. Soil density (Sd) and total porosity (Tp), at the end of cultivation, in different treatments and in four layers.

Plant succession	Management			
	NTS	NT	NTS	NT
	Sd (Kg dm^{-3})		Tp (m^3 m^{-3})	
	Layer 0-5 (cm)			
O/B	1.12±0.17 aA	1.27±0.11 aA	0.56±0.07 aA	0.50±0.05 aA
O/C	1.10±0.15 aA	1.24±0.01 aA	0.57±0.06 aA	0,50±0.01 aA
W/B	1.06±0.14 aB	1.29±0.08 aA	0.58±0.05 aA	0.49±0.03 aB
W/C	1.15±0.16 aA	1.23±0.10 aA	0.54±0.07 aA	0.51±0.04 aA
T/B	1.05±0.08 aB	1.35±0.04 aA	0.58±0.03 aA	0.46±0.01 aB
R/C	1.07±0.09 aB	1.26±0.14 aA	0.57±0.04 aA	0.48±0.09 aB
Mean	1.09±0.10 B	1.27±0.03 A	0.56±0.04 A	0.49±0.02 B
	Layer 5-10 (cm)			
O/B	1.45±0.03 ^{ns}	1.43±0.05 ^{ns}	0.42±0.03 ^{ns}	0.42±0.04 ^{ns}
O/C	1.40±0.07 ^{ns}	1.44±0.03 ^{ns}	0.43±0.05 ^{ns}	0.41±0.05 ^{ns}
W/B	1.36±0.13 ^{ns}	1.39±0.08 ^{ns}	0.47±0.05 ^{ns}	0.45±0.04 ^{ns}
W/C	1.39±0.08 ^{ns}	1.37±0.13 ^{ns}	0.44±0.04 ^{ns}	0.45±0.05 ^{ns}
T/B	1.36±0.05 ^{ns}	1.46±0.01 ^{ns}	0.46±0.02 ^{ns}	0.40±0.03 ^{ns}
R/C	1.38±0.10 ^{ns}	1.42±0.06 ^{ns}	0.45±0.04 ^{ns}	0.43±0.03 ^{ns}
Mean	1.39±0.02 ^{ns}	1.42±0.02 ^{ns}	0.44±0.02 ^{ns}	0.43±0.01 ^{ns}
	Layer 10-20 (cm)			
O/B	1.37±0.07 ^{ns}	1.41±0.05 ^{ns}	0.46±0.03 ^{ns}	0.43±0.03 ^{ns}
O/C	1.39±0.05 ^{ns}	1.36±0.07 ^{ns}	0.43±0.03 ^{ns}	0.46±0.03 ^{ns}
W/B	1.39±0.04 ^{ns}	1.34±0.11 ^{ns}	0.45±0.02 ^{ns}	0.45±0.08 ^{ns}
W/C	1.37±0.06 ^{ns}	1.37±0.09 ^{ns}	0.46±0.02 ^{ns}	0.45±0.04 ^{ns}
T/B	1.42±0.06 ^{ns}	1.35±0.11 ^{ns}	0.43±0.04 ^{ns}	0.46±0.05 ^{ns}
R/C	1.32±0.10 ^{ns}	1.25±0.06 ^{ns}	0.48±0.04 ^{ns}	0.50±0.02 ^{ns}
Mean	1.38±0.02 ^{ns}	1.35±0.04 ^{ns}	0.45±0.02 ^{ns}	0.46±0.02 ^{ns}
	Layer 20-30 (cm)			
O/B	1.42±0.04 ^{ns}	1.34±0.12 ^{ns}	0.43±0.03 aA	0.47±0.05 aA
O/C	1.41±0.09 ^{ns}	1.31±0.06 ^{ns}	0.44±0.05 aA	0.48±0.03 aA
W/B	1.35±0.09 ^{ns}	1.34±0.03 ^{ns}	0.46±0.03 aA	0.47±0.02 aA
W/C	1.38±0.02 ^{ns}	1.37±0.07 ^{ns}	0.45±0.01 aA	0.46±0.03 aA
T/B	1.47±0.01 ^{ns}	1.35±0.08 ^{ns}	0.40±0.01 aB	0.47±0.04 aA
R/C	1.39±0.07 ^{ns}	1.29±0.02 ^{ns}	0.44±0.04 aA	0.49±0.01 aA
Mean	1.40±0.03 ^{ns}	1.33±0.02 ^{ns}	0.44±0.01 B	0.47±0.01 A

Where: NTS: no-tillage subjected to scarification; NT: no-tillage; O: black oats; W: wheat; R: forage turnip; B: bean; C: corn. Mean ± standard deviation. Not significant by analysis of variance ($p < 0.05$). Means followed by the same lowercase letter in the column and uppercase in the row do not differ by the Tukey test ($p < 0.05$).

These results suggest that scarification acts positively to reduce Sd and increase Tp on the surface, on the other hand, it negatively affects these variables in depth below the action of the scarifier rods. As for the Ma values of the soil, there was a statistical difference between treatments in the 0-5 and 10-20 cm layers (Table 5). The soil mobilization, through scarification, maintained, after twelve months of preparation, a 90% higher Ma volume in the NTS compared to the NT in the 0-5 cm layer. Regarding plant successions, scarification positively affected Ma in the wheat/bean and turnip/bean sequences in this same layer. Probably, the roots of the plants that developed during the period of conducting the experiment in the NTS management prevented the reconsolidation of the soil and prevented its return to the initial state of surface compaction (NICOLOSO et al., 2008). In these successions, there was a significant reduction in Ma values at the end of the NT growing. This may have occurred due to the low root development characteristic of the bean crop, associated with the high Sd in that layer.

Considering the critical value of Ma of 0.10 m^3 m^{-3}, the use of the corn crop was able to increase the Ma above this value in the treatments under NT (Table 5), compared to the beginning of the experiment (Table 2), with greater emphasis on the turnip/corn succession (Ma: 0.15 m^3 m^{-3}).

This result can be attributed to the combined effect of the roots used in this succession, since the forage radi has a well-developed taproot, with the ability to grow in compacted layers, form stable biopores and improve the physical properties of the soil (CUBILLA et al., 2002), while corn, although not having very developed roots, has a well-developed root system.

Table 5. Soil macroporosity (Ma) and microporosity (Mi) at the end of cultivation, in different treatments and in four layers.

Plant succession	Management			
	NTS	NT	NTS	NT
	Ma (m^3 m^{-3})		Mi (m^3 m^{-3})	
	Layer 0-5 (cm)			
O/B	0.18±0.12 aA	0.09±0.06 aA	0.38±0.06 ^{ns}	0.40±0.03 ^{ns}
O/C	0.19±0.11 aA	0.10±0.02 aA	0.38±0.06 ^{ns}	0.40±0.03 ^{ns}
W/B	0.22±0.07 aA	0.08±0.02 aB	0.35±0.03 ^{ns}	0.41±0.02 ^{ns}
W/C	0.15±0.10 aA	0.12±0.06 aA	0.39±0.04 ^{ns}	0.40±0.03 ^{ns}
T/B	0.21±0.03 aA	0.07±0.01 aB	0.36±0.04 ^{ns}	0.39±0.01 ^{ns}
R/C	0.20±0.09 aA	0.15±0.08 aA	0.37±0.05 ^{ns}	0.34±0.10 ^{ns}
Mean	0.19±0.07 A	0.10±0.02 B	0.37±0.04 ^{ns}	0.39±0.03 ^{ns}
	Layer 5-10 (cm)			
O/B	0.04±0.02 ^{ns}	0.05±0.02 ^{ns}	0.38±0.05 ^{ns}	0.37±0.03 ^{ns}
O/C	0.04±0.05 ^{ns}	0.02±0.01 ^{ns}	0.39±0.04 ^{ns}	0.39±0.05 ^{ns}
W/B	0.06±0.07 ^{ns}	0.12±0.09 ^{ns}	0.41±0.03 ^{ns}	0.32±0.10 ^{ns}
W/C	0.03±0.05 ^{ns}	0.07±0.04 ^{ns}	0.41±0.03 ^{ns}	0.38±0.02 ^{ns}
T/B	0.04±0.02 ^{ns}	0.03±0.03 ^{ns}	0.42±0.03 ^{ns}	0.37±0.04 ^{ns}
R/C	0.07±0.05 ^{ns}	0.04±0.03 ^{ns}	0.38±0.05 ^{ns}	0.39±0.01 ^{ns}
Mean	0.05±0.03 ^{ns}	0.06±0.01 ^{ns}	0.40±0.03 ^{ns}	0.37±0.02 ^{ns}
	Layer 10-20 (cm)			
O/B	0.04±0.04 aA	0.02±0.01 bA	0.41±0.02 ^{ns}	0.42±0.03 ^{ns}
O/C	0.02±0.01 aA	0.05±0.03 abA	0.40±0.03 ^{ns}	0.40±0.02 ^{ns}
W/B	0.04±0.01 aB	0.10±0.06 abA	0.41±0.02 ^{ns}	0.34±0.12 ^{ns}
W/C	0.03±0.02 aA	0.05±0.04 abA	0.43±0.03 ^{ns}	0.40±0.03 ^{ns}
T/B	0.05±0.01 aA	0.05±0.05 abA	0.39±0.05 ^{ns}	0.41±0.02 ^{ns}
R/C	0.09±0.08 aA	0.12±0.05 aA	0.39±0.03 ^{ns}	0.38±0.03 ^{ns}
Mean	0.05±0.01 ^{ns}	0.07±0.01 ^{ns}	0.41±0.01 ^{ns}	0.39±0.03 ^{ns}
	Layer 20-30 (cm)			
O/B	0.01±0.01 ^{ns}	0.05±0.06 ^{ns}	0.42±0.03 ^{ns}	0.41±0.02 ^{ns}
O/C	0.04±0.04 ^{ns}	0.06±0.06 ^{ns}	0.41±0.01 ^{ns}	0.42±0.04 ^{ns}
W/B	0.05±0.06 ^{ns}	0.04±0.04 ^{ns}	0.41±0.03 ^{ns}	0.43±0.03 ^{ns}
W/C	0.03±0.01 ^{ns}	0.02±0.02 ^{ns}	0.43±0.01 ^{ns}	0.45±0.04 ^{ns}
T/B	0.03±0.03 ^{ns}	0.02±0.01 ^{ns}	0.37±0.02 ^{ns}	0.45±0.04 ^{ns}
R/C	0.04±0.02 ^{ns}	0.08±0.03 ^{ns}	0.40±0.03 ^{ns}	0.41±0.02 ^{ns}
Mean	0.03±0.02 ^{ns}	0.04±0.02 ^{ns}	0.41±0.01 ^{ns}	0.43±0.02 ^{ns}

Where: NTS: no-tillage subjected to scarification; NT: no-tillage; O: black oats; W: wheat; R: forage turnip; B: bean; C: corn. Mean ± standard deviation. ^{ns} Not significant by analysis of variance ($p<0.05$). Means followed by the same lowercase letter in the column and uppercase in the row do not differ by the Tukey test ($p<0.05$).

The turnip/corn succession resulted in the highest absolute values of Ma in the 10-20 cm layer, regardless of soil management, being higher than the bounding for the crops (0.10 m^3 m^{-3}). When observing the bounding value of Ma, this type of soil (Cambissolo Húmico with high silt content) has restrictions on root development, due to the low values observed in the lower layers, regardless of management and crops, in agreement with Bortolini et al. (2016).

Mi values ranged between 0.35 and 0.45 m^3 m^{-3} and did not show any significant difference twelve months after scarification and implantation of plant successions (Table 5).

CORRELATIONS BETWEEN VARIABLES

Pearson's correlation coefficients between the physical properties of the soil in the 0-5 cm layer and water infiltration are shown in Table 6. To interpret the results, the coefficient values were classified according to the degree of correlation (MUKAKA, 2012).

The variables of water infiltration FIR and accumulated I presented a very high (positive) correlation between them, and both presented low to moderate correlations with the properties Sd, Tp and Ma. Of these, Tp and Ma were correlated (positively) with FIR and accumulated I, while Sd had a (negative) correlation with the two infiltration variables. The Mi showed an insignificant correlation with FIR and accumulated I (Table 6). The results demonstrate that the reduction in Sd and the increase in Tp and Ma in the soil surface layer resulting from scarification effectively increase the final infiltration rate and the total amount of infiltrated water. It is through the Ma that the preferential paths for the entry of water into the soil go, and when it has a high moisture content, the maintenance of the water flow occurs in the larger pores, by gravitational effect (VIEIRA;

KLEIN, 2007). For this reason, a higher final water infiltration rate provides a greater total infiltration.

Table 6. Pearson linear correlation between physical properties of the *Cambissolo Húmico* (0-5 cm layer) and soil water infiltration.

Variables	Tp	Ma	Mi	FIR	I accumulated
Sd	-0.985 (p<0.01)	-0.941 (p<0.01)	0.557 (p<0.03)	-0.485 (p<0.07)	-0.514 (p<0.06)
Tp		0.921 (p<0.01)	-0.482 (p<0.08)	0.482 (p<0.08)	0.510 (p<0.06)
Ma			-0.771 (p<0.01)	0.412 (p<0.13)	0.480 (p<0.08)
Mi				-0.144 (p<0.62)	-0.254 (p<0.38)
RIF					0.972 (p<0.01)

Where: Sd: Soil density; Tp: total porosity; Ma: macroporosity; Mi: microporosity; TFI: final soil water infiltration rate; accumulated I: total layer of infiltrated water. Pearson's model coefficient followed by the correlation significance value (p-value). Degree of correlation (MUKAKA, 2012): negligible (<0.3), low (0.3 to 0.5), moderate (0.5 to 0.7), high (0.7 to 0.9) and very high (>0.9).

Thus, the increase in Sd provides lower Tp, an effect already expected, on the other hand, soil preparation also changes the pore size distribution, and part of the Mi were converted into Ma by scarification, in agreement with Werner et al. (2016). This justifies the high (negative) correlation between Ma and MI.

CONCLUSIONS

Scarification in soil managed under no-tillage positively affects the physical properties of the soil soon after tillage, with an effect restricted to the 0-5 cm surface layer, increasing total porosity and macroporosity.

The effects of scarification in a silty clayey *Cambissolo Húmico* persist for a period of one year, and result in greater water infiltration into the soil, as found in this research.

The physical properties of soil, density, total porosity and macropores. of the 0-5 cm surface layer are correlated with the final infiltration rate and the total depth of water infiltrated in the soil.

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