Revista Ciência Agronômica, v. 54, e20218319, 2023
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Machinery traffic and cover crop effects on water infiltration rate in a Xanthic Hapludox[1]

Ernani Garcia Neto[2], Renan Caldas Umburanas[3,4], Vitor Hugo Outeiro[2], Marcelo Marques Lopes Müller[4], Leandro Rampim[4], Cassio Antonio Tormena[5], Cristiano Andre Pott[4*]

ABSTRACT - The effects of machinery traffic and cover crops on soil physical properties have been underexplored under no-till agricultural production in subtropical environments. The objective of this study was to quantify the soil water infiltration rate and related soil physical properties in response to tractor traffic levels (0, 2, 5, and 20 passes) and the presence or absence of cover crops in a Xanthic Hapludox soil over two growing seasons under no-till conditions. The experiment was carried out in a randomized block design arranged in a factorial scheme with four replications. The traffic factor was constituted by the number of passes with a 6 Mg weight tractor. The winter crop management practices factor consisted of the cover crops (i) black oat (*Avena strigosa*) in 2017 and turnip (*Raphanus sativus* var. *oleiferus*) in 2018 compared with (ii) fallow with spontaneous vegetation. The soil water infiltration rate increased with cover crops when compared to fallow. Regarding tractor traffic levels, shortly after soil compaction, there was a lower water infiltration rate at 20 passes, 45 mm h^{-1} lower than the absence of tractor traffic. The soil water infiltration rate was positively correlated with macroporosity and negatively correlated with soil bulk density. After 14 months of soil compaction caused by tractor traffic, an improvement in the soil physical properties and the water infiltration rate was found, which were enhanced by the inclusion of cover crops.

Key words: Green manure. Soil physical quality. Soil compaction. Double-ring pressure infiltrometer with constant load.

DOI: 10.5935/1806-6690.20230049
Editor-in-Chief: Prof. Alek Sandro Dutra - alekdutra@ufc.br
*Author for correspondence
Received for publication in 24/12/2021; approved in 15/02/2023
[1]Part of the first author’s dissertation, presented to Programa de Pós-Graduação em Agronomia, Universidade Estadual do Centro-Oeste, Guarapuava, Paraná. This study was funded by the Paraná State Araucária Foundation (Fundação Araucária, Brazil), Coordination for the Improvement of Higher Education Personnel (CAPES, Brazil), and National Counsel of Technological and Scientific Development (CNPq)
[2]Programa de Pós-Graduação em Agronomia, Universidade Estadual do Centro-Oeste, Guarapuava-PR, Brazil, ernani_gn@hotmail.com (ORCID ID 0000-0002-9136-375X), vitorhugoouteiro@yahoo.com.br (ORCID ID 0000-0002-9465-3322)
[3]Departamento de Produção Vegetal, Escola Superior de Agricultura “Luiz de Queiroz” - Universidade de São Paulo, Piracicaba-SP, Brazil; rumbu@usp.br (ORCID ID 0000-0002-4112-3598)
[4]Departamento de Agronomia, Programa de Pós-Graduação em Agronomia, Universidade Estadual do Centro-Oeste, Guarapuava-PR, Brazil, mmuller@unicentro.br (ORCID ID 0000-0002-5466-2398), lrampim@unicentro.br (ORCID ID 0000-0001-8300-7424), cpott@unicentro.br (ORCID ID 0000-0002-4630-2659)
[5]Departamento de Agronomia, Universidade Estadual de Maringá, Maringá-PR, Brazil, cassiotormena@gmail.com (ORCID ID 0000-0003-2351-9289)

INTRODUCTION

No-tillage is widely used for agricultural production in tropical and subtropical Brazilian soils and makes the farming system more sustainable due to greater soil and water conservation (PÖHLITZ *et al*., 2018). In no-till, heavy machinery traffic is common, and growers are commonly concerned with soil compaction, especially in its cumulative effects over time. It is well known that soil compaction has negative effects on soil quality, such as reduced soil aeration and decreased water and nutrient availability and access in the soil (BASSEGIO *et al*., 2018). In addition, soil compaction increases soil bulk density, decreases soil water infiltration rate, and increases water runoff (BAI *et al*., 2009). However, in subtropical no-till soils, the effects of machine traffic on soil physical properties as well as the association of cover crops have been underexplored, especially in high-yielding environments.

We hypothesize that cover crops in the winter season promote soil decompaction. Soil compaction usually restricts the root system growth of plants due to limited access to water and nutrients, hampering the yield and sustainability of production systems (CALONEGO *et al*., 2017). External pressure also degrades soil physical quality attributes (SHAH *et al*., 2017).

One management practice to minimize soil compaction effects is periodic tillage with subsoilers and scarifiers, which reduces soil bulk density and soil resistance to penetration and increases soil water infiltration rate. However, adopting this practice impairs the no-till system, as it disrupts soil aggregates and usually has only short-term beneficial effects (CALONEGO *et al*., 2017). An alternative to mechanical subsoiling is biological tillage by cultivating different plant species with the potential to improve soil structure (INAGAKI *et al*., 2021; SUN *et al*., 2018). Cultivating cover crops in no-till has several advantages, such as protecting the topsoil against raindrop impact, increasing organic matter and building-up carbon in the soil, improving soil structure, recycling nutrients, increasing microbiota activity, suppressing the occurrence of weeds, increasing soil water infiltration rate, and reducing runoff (FERREIRA *et al*., 2018; OBOUR *et al*., 2021).

Water infiltration is the process of rain and surface water entering the soil (HUANG *et al*., 2017). Water infiltration is commonly affected by soil attributes and vegetation properties such as porosity, organic matter, soil bulk density, and root characteristics (LEUNG *et al*., 2015). Furthermore, vegetation also benefits water infiltration due to higher plant biomass, higher litter density, and higher root mass and density (HAO *et al*., 2020). Therefore, understanding the effect of cover crops on the water infiltration rate could help to improve agricultural production systems (CARVALHO *et al*., 2015).

In this context, it is necessary to evaluate the effects of machinery traffic and cover crops on soil water infiltration rate over time. Regarding soil management, some growers use natural fallow vegetation in the winter season, while others cultivate cover crops, and little is known about the impact of these practices on soil physical properties. Thus, the objective of this study was to evaluate the soil water infiltration rate and related soil properties in response to the long-term effects of tractor traffic levels and cover crops or spontaneous fallow vegetation in a Xanthic Hapludox soil over two growing seasons.

MATERIAL AND METHODS

Site description

The study was carried out in Guarapuava, Paraná state, Brazil (25°23’S, 51°27’W, altitude of 1041 m), over flat land topography and Cfb-Köppen climate. The soil was identified as a Xanthic Hapludox or *Latosolo Bruno* in the Brazilian soil classification system (SANTOS *et al*., 2018). Soil chemical analysis and particle size composition are presented in Table 1.

In July 2016, calcitic limestone ($CaCO_3$ 80%, < 0.25 mm) was applied at a dose of 2.5 Mg ha^{-1}, and the soil was scarified in the 0-0.30 m layer. Subsequently, black oat (*Avena strigosa* Schreb.) was sown with a row spacing of 0.17 m and a seeding rate of 360 seeds per m²; then, it was burndown 60 days after sowing. Traffic levels were carried out on October 27, 2016, after a rainfall period of approximately 70 mm, with an average soil moisture of 0.43 m³ m^{-3}. Four levels of machine traffic

Table 1 - Soil chemical attributes and particle size distribution in the 0-0.20 m depth layer at the experimental site

Depth	P (Mehlich-1)	Organic matter	pH	Al	H+Al	Ca	Mg	K	CEC	SBS	Clay	Silt	Sand
m	mg dm^{-3}	g dm^{-3}	$CaCl_2$	--------------- cmol$_c$ dm^{-3} ---------------						(%)	-------- g kg^{-1} --------		
0-0.2	5.2	16.1	4.8	0	5.2	2.2	1.8	0.3	12.6	45.7	748	215	37

CEC = cation exchange capacity; SBS = soil base saturation. Clay = particles with diameters smaller than 0.002 mm; Silt = particles with diameters between 0.002 mm and 0.053 mm; Sand = particles with diameters between 0.053 mm and 2.0 mm on soil were induced (0, 2, 5, and 20 machine traffic overlapping passes), passing through the entire plot area according to each treatment. To generate different soil compaction levels, a John Deere 7515 tractor was used with 140 HP and 75% of the tire volume with water, with a total weight of 6 Mg. The tractor was equipped with a diagonal tire number 18.4-38 on the rear axle and 16.9-26 on the front axle. Soil physical properties analyzed after soil compaction were previously published by Bareta Junior *et al*. (2022) and are shown in Table 2, indicating the values of soil bulk density, degree of compactness, macroporosity, microporosity, and total porosity in the four levels of machine passes. To determine these soil properties, undisturbed soil samples were taken in three soil layers (0.0-0.05, 0.07-0.12, and 0.17-0.22 m) using stainless steel cylinders approximately 5 cm high and 5 cm in diameter with a volume of 100 cm^3. A hydraulic sampler was used to insert the cylinders vertically into the ground (SPLIETHOFF *et al*., 2022). One cylinder was collected per soil layer in each experimental unit. The undisturbed soil samples were saturated with water for 48 hours. Then, they were subjected to a tension table using a matric potential of -6 kPa. Macroporosity was determined by the difference between the water content of the saturated soil and the water content at the matric potential of -6 kPa. Microporosity was determined as the soil water content at the matric potential of -6 kPa. Total porosity was the sum of macro- and microporosity. Afterward, the samples were dried in an oven at 105°C for 48 hours and weighed to determine soil bulk density (EMBRAPA, 2017). The degree of compactness was defined by the ratio of the soil bulk density and the bulk density reference, which was obtained with the Proctor test according to Bareta Junior *et al*. (2022).

Precipitation and temperature data were obtained from an automatic meteorological station (SIMEPAR/Brazil) located 300 m from the experiment (Figure 1). In the 2017 winter season, rainfall accumulated during the growth cycle of black oat and turnip (*Raphanus sativus* L. var. *oleiferus* Metzg.) reached approximately 650 mm and 200 mm, respectively (Figure 1). Water availability in black oats was above the evapotranspiration demand of the crop, which is ~250 to 450 mm (BACCHI; RANZI, 1996), while for turnip, it was lower than its demand of 300 to 400 mm (FIETZ *et al*., 2008).

In the summer, the rainfall accumulated in the growth cycle of maize (*Zea mays* L.) was above 800 mm, and for common bean, it was approximately 740 mm (Figure 1). The evapotranspiration demand of maize and common bean is ~ 500 to 800 mm (CARVALHO *et al*., 2015) and 500 mm, respectively (CARVALHO *et al*., 2015). Then, considering the accumulated values, the demand for evapotranspiration was sufficiently met for both crops.

Table 2 - Characterization of the soil physical properties[1] in the study area after traffic levels carried out in October 2016 in a Xanthic Hapludox at Guarapuava, PR

Soil physical properties	Depth (m)	Machine traffic (n° passes)			
		0	2	5	20
Soil bulk density (Mg m^{-3})	0.00-0.05	1.00	1.13	1.15	1.18
	0.07-0.12	0.96	1.05	1.07	1.10
	0.17-0.22	1.01	1.03	1.03	1.09
Degree of compactness (%)	0.00-0.05	84	95	96	99
	0.07-0.12	80	87	89	92
	0.17-0.22	84	85	85	90
Macroporosity (m^3 m^{-3})	0.00-0.05	0.15	0.08	0.09	0.07
	0.07-0.12	0.20	0.12	0.11	0.10
	0.17-0.22	0.14	0.11	0.11	0.07
Microporosity (m^3 m^{-3})	0.00-0.05	0.47	0.51	0.50	0.50
	0.07-0.12	0.43	0.48	0.47	0.49
	0.17-0.22	0.48	0.50	0.51	0.53
Total porosity (m^3 m^{-3})	0.00-0.05	0.62	0.59	0.58	0.58
	0.07-0.12	0.63	0.61	0.59	0.59
	0.17-0.22	0.62	0.62	0.62	0.60

[1]Adapted from Bareta Junior *et al*. (2022)

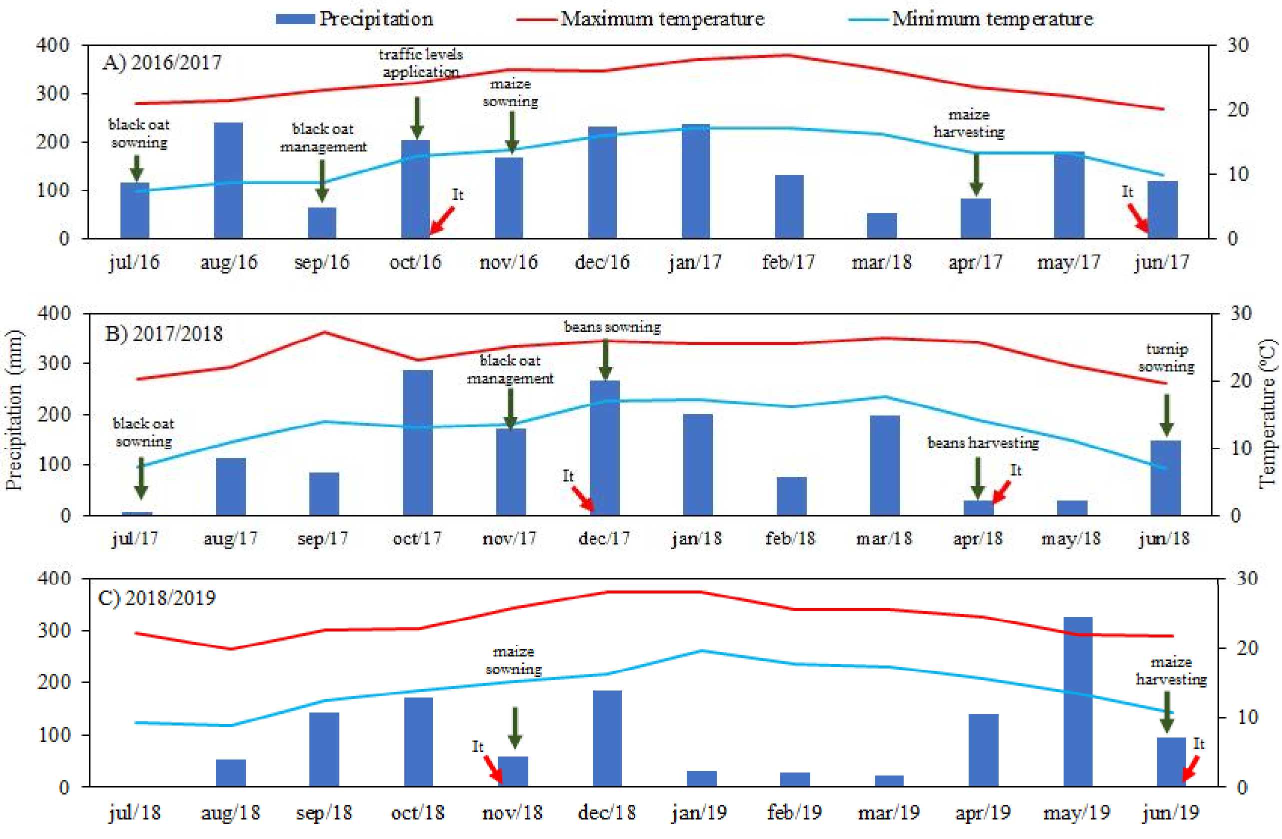
Experimental design and treatments

The experiment was carried out in a randomized block design and a 4 × 2 factorial scheme with four replications. The treatments corresponded to four tractor traffic levels (0, 2, 5, and 20 passes) and two winter crop management practices. The plot dimensions were 16 m × 5 m.

The winter crop management factor consisted of the presence of cover crops or natural fallow vegetation. In the treatment with cover crops, black oat was cultivated in the 2017 growing season, and turnip was cultivated in the 2018 growing season. Natural fallow vegetation was conducted by natural succession of spontaneous plants. The main spontaneous plants in the natural fallow treatment were *Bidens pilosa* L., *Conyza bonariensis* (L.) Cronq., *Lolium multiflorum* Lam., and *Digitaria horizontalis* Willd. Black oat cv IAPAR 61 was sown on July 22, 2017, in the winter, with a seeding rate of 360 seeds per m^2 (60 kg of seeds per ha) and a row spacing of 0.17 m. At the full flowering stage of the cover crops, all treatments were burndown with glyphosate at 2 L ha^{-1}. On June 29, 2018, forage turnip was sown with a Semeato SHM 11/13 seeder with a double disc furrow opener using approximately 180 seeds per m^2 (20 kg of seeds per ha). At the full flowering stage, the turnip plants were burndown with glyphosate at 2 L ha^{-1}.

In both treatments, the summer season had common beans (*Phaseolus vulgar*is L.) and maize (*Zea mays* L.) in the 2017/2018 and 2018/2019 growing seasons, respectively. On December 20, 2017, the bean cultivar Preto – IPR Tuiuiú was sown at a density of 240,000 plants per hectare with a spacing of 0.45 m. Basic fertilization was carried out with 20 kg ha^{-1} of N, 75 kg ha^{-1} of P_2O_5, and 50 kg ha^{-1} of K_2O. After 30 days of crop sowing, N topdressing at a dose of 50 kg ha^{-1} was carried out using urea. On November 12, 2018, the maize hybrid Agroceres 8780 VT PRO3 was sown, characterized by an early cycle and high yield potential. The seeding rate was 80,000 plants ha^{-1} under a row spacing of 0.45 m. Sowing was performed using Seeding SHM 11/13 with a double-disc furrow opener. Basic fertilization was carried out with 12 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5, and 60 kg ha^{-1} of K_2O. Thirty days after sowing, N topdressing at a dose of 100 kg ha^{-1} was carried out using urea.

Figure 1 - Accumulated monthly precipitation and monthly average maximum and minimum temperatures from July 2016 to June 2017 (A), July 2017 to June 2018 (B), and July 2018 to June 2019 (C) in Guarapuava, Paraná, Brazil. Green arrows indicate crop management. Red arrows indicate when the soil water infiltration test (It) and undisturbed soil sample collection were performed



Evaluations

Soil water infiltration was evaluated using a double-ring pressure infiltrometer with constant load (Figure 2), which supplies water to the soil with a hydraulic load (POTT *et al*., 2019). Concentric rings were used; the inner and outer rings had diameters of 0.20 m and 0.40 m, respectively. First, the straw layer was removed to expose the soil surface. Then, the rings were placed concentrically on the soil surface and were inserted vertically at a depth of 0.05 m. The water layer of the outer ring was kept constant to ensure that the infiltration process was in the vertical direction and to avoid lateral movement of water from the inner ring. The soil water infiltration rate was determined by the time required until infiltration stabilized for three consecutive measurements, which took two hours on average. The evaluation was carried out in each plot in the following periods: 0, 8, 14, 18, 25, and 35 months after machine traffic passes, measured after grain crop harvest and/or after cover crop burndown. In the same water infiltration rate evaluation periods, the soil physical properties of the undisturbed soil samples were evaluated.

Figure 2 - Soil water infiltration test using a double-ring pressure infiltrometer with constant load. Guarapuava, Paraná, Brazil

An area of 4.5 m^2 per plot was harvested at the common bean full maturity stage to determine yield. Grain moisture was adjusted to 130 g kg^{-1}. The maize forage biomass was evaluated at the R5 stage when the milky grain aspect comprised between 50 and 75% of the grains. For that, maize plants from 0.83 m^2 of each subplot were cut at 0.1 m above the soil surface.

To obtain the relationship between the soil water infiltration rate and soil physical properties, soil bulk density and soil macroporosity were evaluated in the same period as the soil water infiltration rate.

Statistical analysis

Data were subjected to analysis of variance (ANOVA), and when significant, the means were compared by Tukey's test ($p < 0.05$). Soil water infiltration rates were compared across treatments of traffic levels and winter crop management using different lowercase letters. The average soil water infiltration rate in the different months was compared using line bars that indicate the minimum significant difference using Tukey's test ($p < 0.05$). Pearson correlation and regression studies were performed between the soil water infiltration rate and soil properties and crop yield to verify whether the other soil physical properties explain the soil infiltration rate and whether the soil water infiltration rate influences crop yield.

RESULTS AND DISCUSSION

The soil water infiltration rate was 45 mm h^{-1} lower at 20 passes of machine traffic compared to 0 passes in the evaluation immediately after the machine traffic passes (Figure 3A). There was an increase in the water infiltration rate 14 months after the machinery traffic at the levels of 2 and 5 traffic passes. At 18 months after the tractor passes, 2, 5, and 20 traffic passes improved the water infiltration rate compared with the evaluation immediately after the machine traffic. Thirty-two months after machine traffic, after the maize season, all traffic treatments increased the water infiltration rate.

The soil water infiltration rate was higher in the treatment with cover crops than in the fallow treatment in all periods (Figure 3B). The soil water infiltration rate was 226%, 20%, 46%, and 53% higher in the cover crops compared to fallow 14, 18, 25, and 32 months after the traffic levels, respectively.

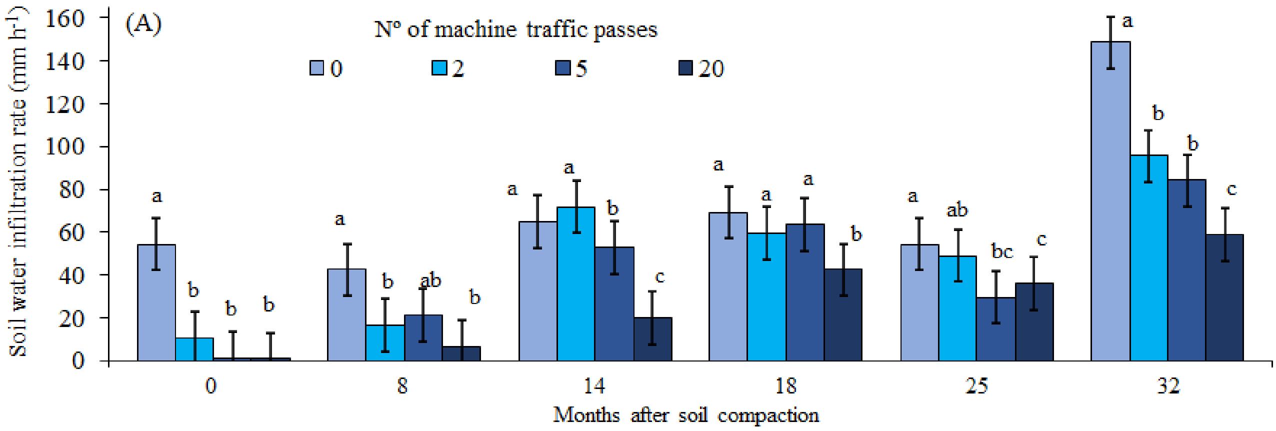
The water infiltration rate was negatively correlated with the soil bulk density in the three studied layers (Figure 4 A, B, C). On the other hand, the water infiltration rate was positively correlated with macroporosity in the 0.07-0.12 and 0.17-0.20 m layers (Figure 4 E and F). A trend of lower soil water infiltration rate and macroporosity and higher soil bulk density was observed in the treatment with 20 machine traffic passes, that is, lower soil infiltration rate and lower soil physical quality. When analyzing the soil water infiltration rate and soil bulk density together, a higher dependence was observed in the 0.07-0.12 m layer.

There was a trend toward a higher soil water infiltration rate and macroporosity and a lower soil bulk density at 32 months compared to 14 months in the 20 tractor passes treatment (Figure 5). This result suggests soil recovery from the soil compression process and indicates that the soil tends to return to its natural state after suffering heavy machinery traffic.

Common bean grain yield and water infiltration rate presented a positive correlation (Figure 6A). In the maize crop, a quadratic model was adjusted between forage yield and water infiltration rate (Figure 6B), indicating an increase in forage yield at higher water infiltration rates. The rotation system with cover crops presented a trend of higher yield in summer crops as well as a higher soil water infiltration rate compared to fallow. At lower traffic levels, the summer crops also presented higher yields and higher soil water infiltration rates, with a decreasing trend with more machine traffic passes.

The hypothesis that cultivating cover crops in the winter season promotes biological decompaction was confirmed. Soil water infiltration rate is directly affected by the soil porous system (KODESOVA *et al*., 2011).

Figure 3 - Soil water infiltration rate over time at (A) different levels of machine traffic passes and (B) winter crop management. Means followed by the same letter in each layer and each period did not differ by Tukey's test ($p < 0.05$). The lines in the bars represent the mean significant difference by Tukey's test ($p < 0.05$) according to time after soil compaction by machine traffic passes



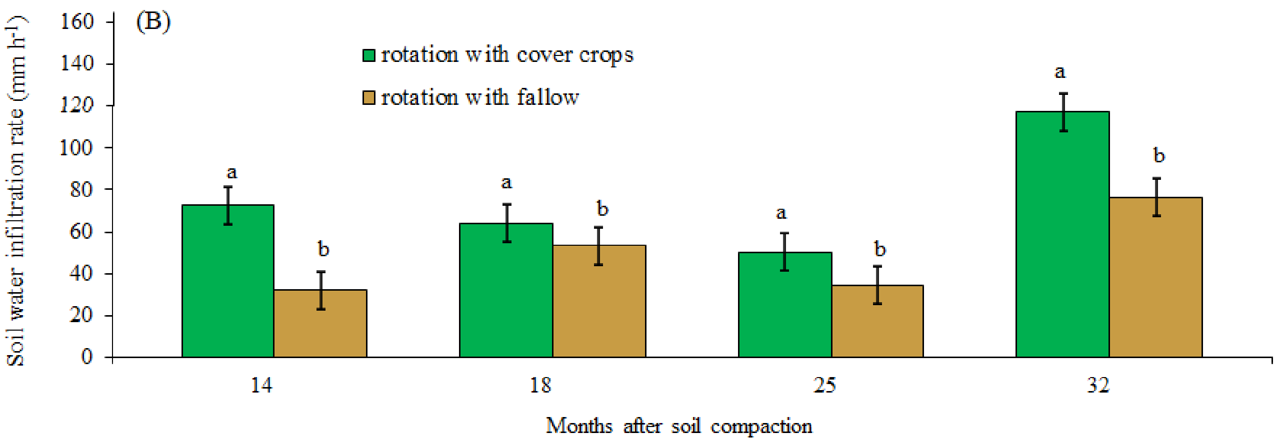
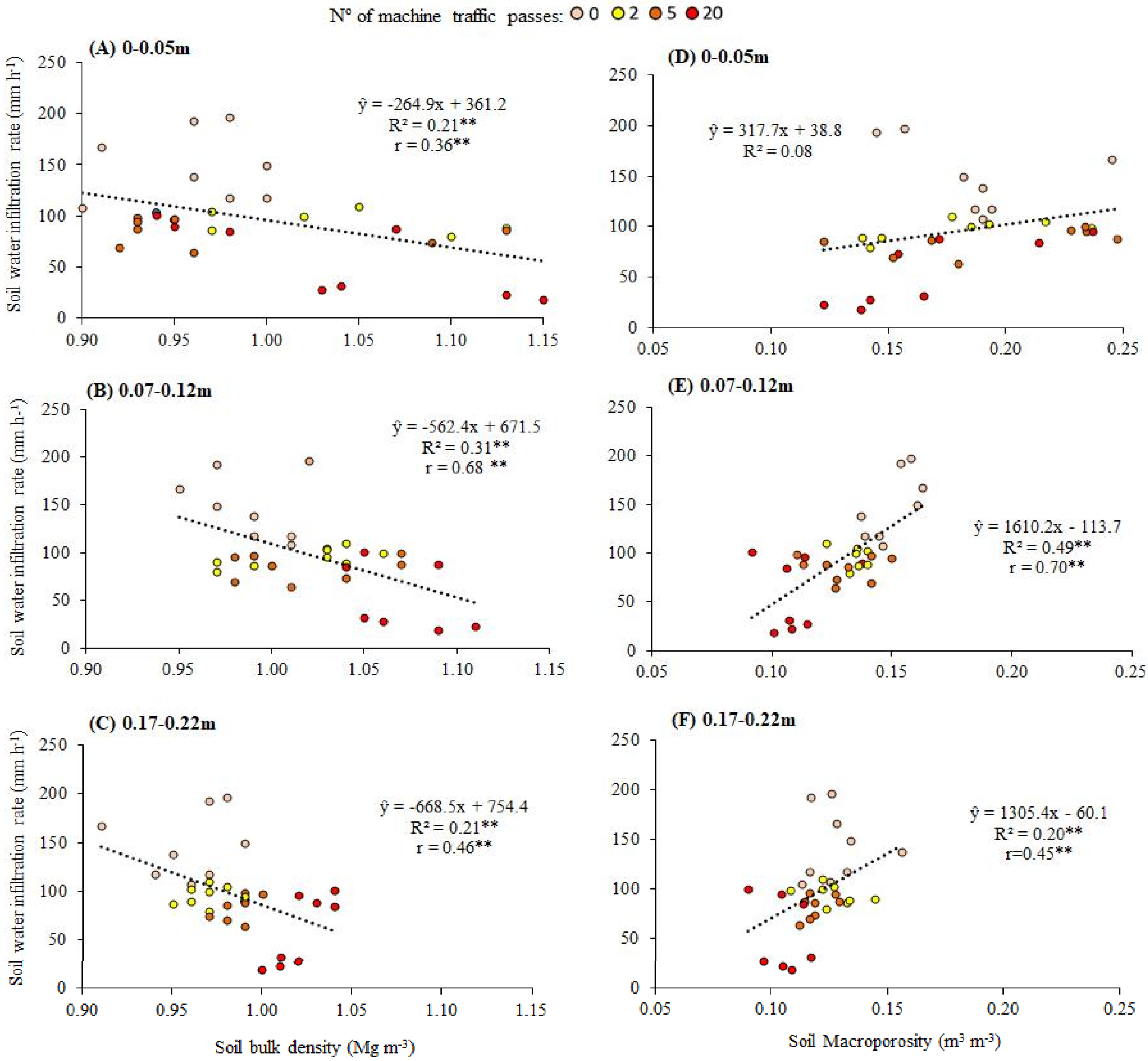


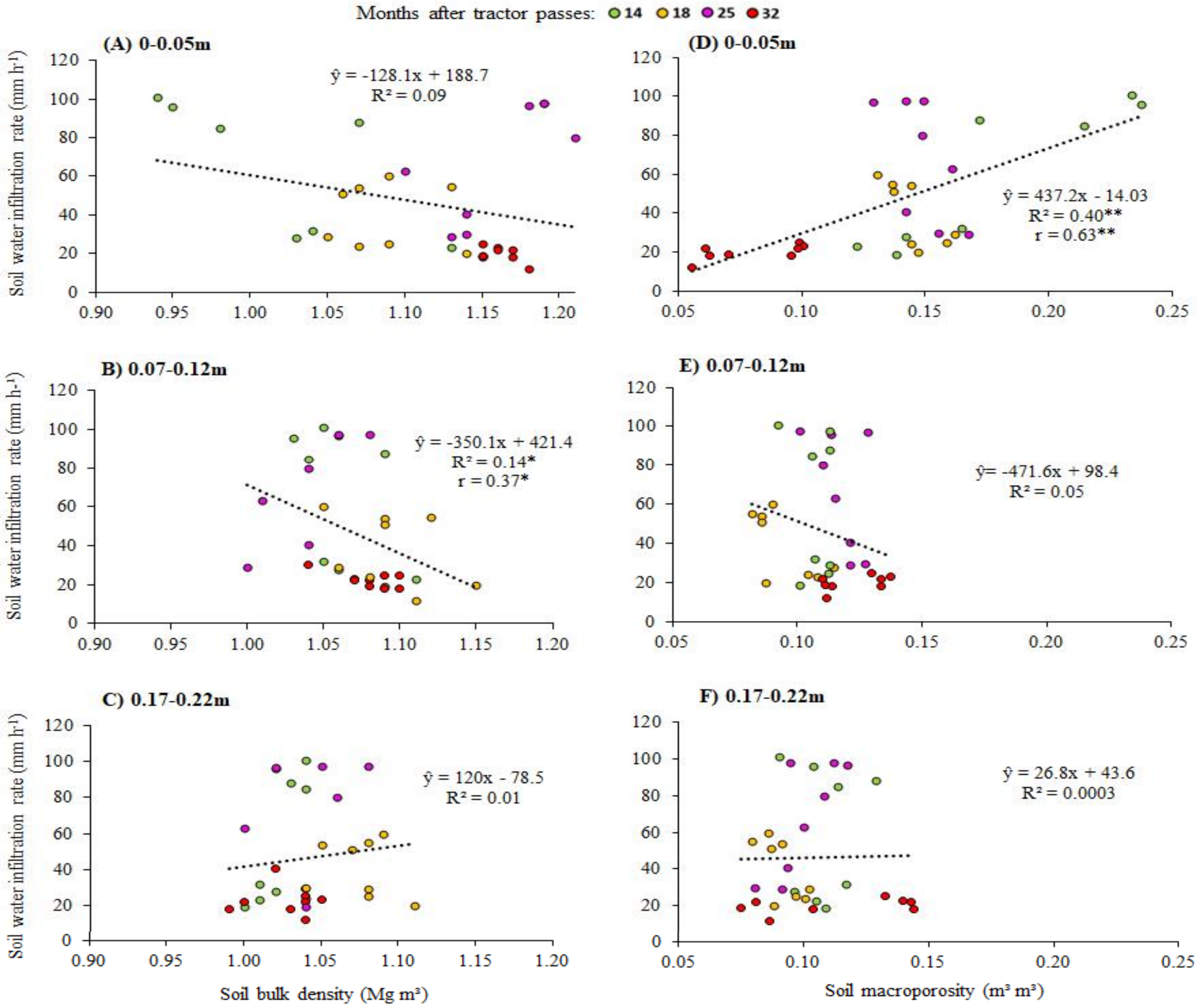
Figure 4 - Soil water infiltration rate 32 months after application of traffic levels according to soil bulk density (A, B, and C) and soil macroporosity (D, E, and F) in the 0.00 to 0.05 m, 0.07 to 0.12 m, and 0.17 to 0.22 m layers. **, * indicate significant regression at p < 0.01 and p < 0.05, respectively



Plant roots can affect soil porosity and increase soil water infiltration rate. This occurs especially due to the increased macroporosity, as the soil is the interface for water infiltration, establishing a positive correlation with the soil water infiltration rate (SUN *et al*., 2018). Roots, when decomposed, create channels (biopores) in the soil, which increase the pore space and form well-connected pores, thus increasing soil water infiltration rate (HAO *et al*., 2020). The channels formed by plant root decomposition increase the number of large pores in the soil profile (HAO *et al*., 2020) and can lead to water transport and solute movement as a preferential flow (PÖHLITZ *et al*., 2018).

Plant roots can also indirectly affect soil water infiltration properties by connecting and aggregating soil particles, which may increase soil cohesion and aggregate stability (GOULD *et al*., 2016). Roots also modify the soil physicochemical properties by releasing exudates and by root decomposition (WANG *et al*., 2019), forming stable canals (FISCHER *et al*., 2014). Poaceous species, such as oats and maize, tend to increase soil water infiltration rates more than other species, such as beans and turnips (LEUNG *et al*., 2015). At 25 months after machine traffic levels and after the cultivation of forage turnip, the soil water infiltration rate did not follow the growth trend in

Figure 5 - Soil water infiltration rate at 14, 18, 25, and 32 months after application of the 20 tractor passes according to soil bulk density (A, B, and C) and soil macroporosity (D, E, and F) in the 0.00 to 0.05 m, 0.07 to 0.12 m, and 0.17 to 0.22 m layers. **, * indicate significant regression at $p < 0.01$ and $p < 0.05$, respectively

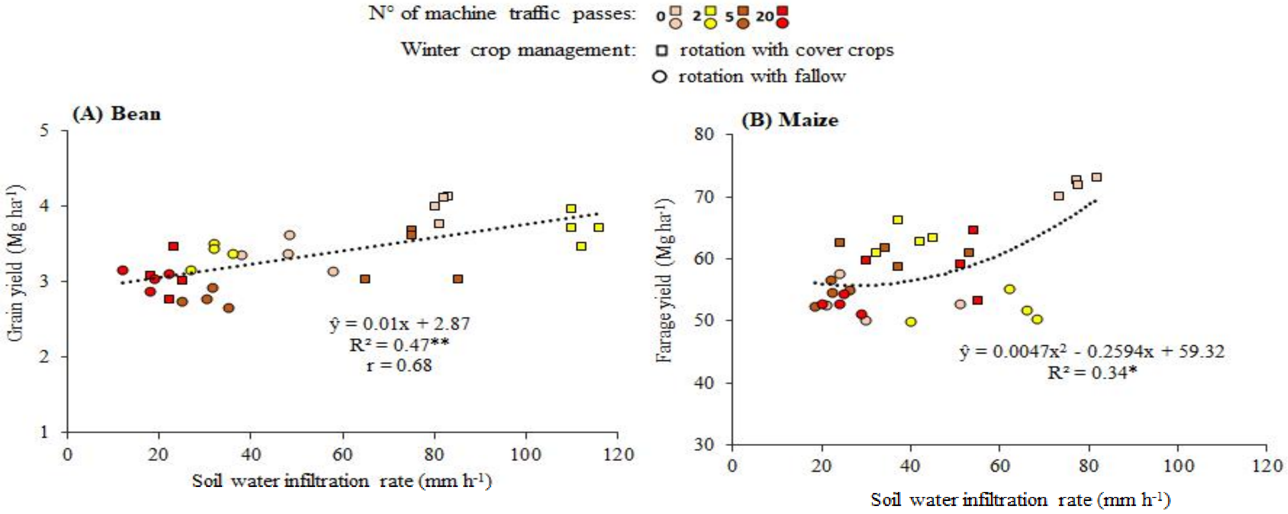


relation to the previous period evaluated at 18 months, possibly due to root occupation in the soil pore space, which blocks the water flow paths (LEUNG *et al*., 2015), since roots were not yet fully decaying.

Machine traffic decreased soil physical quality, impacting the soil water infiltration rate, especially with increased soil bulk density and reduced soil macroporosity (Figure 4), consequently impairing crop yield (Figure 6). The increase in soil bulk density is commonly related to a reduction in macroporosity (BONETTI *et al*., 2019), which reduces soil water infiltration rate (Figure 4). In the soil compaction process, soil bulk density increases and porosity decreases, in which the macropores are disrupted, impairing soil water infiltration rate (SERVADIO *et al*., 2001).

Over time, soil physical resilience was observed, that is, a gradual recovery of the soil macroporosity after machine traffic. This behavior can be justified by the ability of the soil to return to its natural state after suffering natural or anthropogenic stresses, with wetting and drying cycles, which contribute to the structural regeneration of a compacted soil (CHINN; PILLAI, 2008). Biological activities, root growth, and faunal activity can also enhance soil restructuring (CORSTANJE *et al*., 2015; GUBIANI *et al*., 2015). Additionally, texture, organic matter, soil biological properties, and soil use and management affect soil resilience (CORSTANJE *et al*., 2015). A compacted Oxisol (*Latossolo Vermelho*) was investigated, and it was reported that after several cycles of contraction

Figure 6 - Common bean grain yield (A) and maize fresh forage yield (B) and their soil water infiltration rate in response to different machine traffic passes and winter crop management. **, * indicate significant regression at $p < 0.01$ and $p < 0.05$, respectively



and expansion, it could return to its natural state (GUBIANI *et al*., 2015).

The use of cover crops improves soil physical quality, with a higher soil water infiltration rate and consequently higher crop yield (CALONEGO *et al*., 2017). In this study, we verified a decrease in soil bulk density, an increase in macroporosity, and an increase in water infiltration rate (Figures 4 and 5). Consequently, crop yield was higher (Figure 6), which may be associated with better soil aeration conditions (BARETA JUNIOR *et al*., 2022) and a greater ability to infiltrate rainwater due to lower surface runoff, thus generating greater water storage in the soil (BLANCO-CANQUI; WORTMANN, 2020).

Using cover crops in rotation contributes to soil physical recovery due to improved soil biological conditions that influence soil structure formation and stability, favoring soil water infiltration rate (SEIDEL *et al*., 2017). Additionally, cover crops were reported to improve macroporosity and reduce soil bulk density in the 0-0.10 m layer (LEUNG *et al*., 2015). This can also be associated with greater plant root biomass and more drying and wetting cycles (ALMEIDA *et al*., 2018).

Our study showed the negative effect of machine traffic on soil properties and crop yield. In the long term, after soil compaction, the soil recovered physical quality properties, such as a reduction in soil bulk density and an increase in macroporosity and soil water infiltration rate. Furthermore, the soil showed resilience after suffering soil compaction caused by machine traffic, which was enhanced by cover crops.

CONCLUSIONS

1. The soil was resilient after suffering anthropic action by machine traffic, minimizing the soil compaction problem 18 months after machinery traffic. Using rotation with cover crops, the soil compaction was reverted in 14 months;
2. In response to winter crop management in the long term, 14 months after moderated soil compaction treatments (2 passes of machine traffic), the soil recovered physical quality properties, showing reduced soil bulk density and increased macroporosity and soil water infiltration rate;
3. Compared to winter fallow, the use of cover crops in rotation with grain crops improved the soil water infiltration rate and soil physical properties, which therefore increased common bean grain yield and maize forage yield;
4. It is necessary to maintain and diversify the crop rotation system to preserve and enhance the soil physical properties and to protect the water quality in the long term. We recommend that future studies increase the number of samples collected within the year during all seasons to observe the dynamics of changes in soil physical properties in relation to cover crops.

REFERENCES

ALMEIDA, W. S. *et al*. Effect of soil tillage and vegetal cover on soil water infiltration. **Soil and Tillage Research**, v. 175, p. 130-138, 2018.

BACCHI, B.; RANZI, R. On the derivation of the areal reduction factor of storms. **Atmospheric Research**, v. 42, n. 1/4, p. 123-135, 1996.

BAI, Y. *et al*. Soil structure and crop performance after 10 years of controlled traffic and traditional tillage cropping in the dryland loess plateau in China. **Soil Science**, v. 174, n. 2, p. 113-119, 2009.

BARETA JUNIOR, E. *et al*. Critical limits of soil physical attributes for corn and black oat in a Xanthic Hapludox. **Revista Ciência Agronômica**, v. 53, p. e20207533, 2022.

BASSEGIO, D. *et al*. Guar root and shoot growth as affected by soil compaction. **Pesquisa Agropecuaria Tropical**, v. 48, n. 2, p. 163-169, 2018.

BLANCO-CANQUI, H.; WORTMANN, C. S. Does occasional tillage undo the ecosystem services gained with no-till? a review. **Soil and Tillage Research**, v. 198, p. 104534, 2020.

BONETTI, J. A. *et al*. Impact of a long-term crop-livestock system on the physical and hydraulic properties of an Oxisol. **Soil and Tillage Research**, v. 186, p. 280-291, 2019.

CALONEGO, J. C. *et al*. Soil compaction management and soybean yields with cover crops under no-till and occasional chiseling. **European Journal of Agronomy**, v. 85, p. 31-37, 2017.

CARVALHO, D. F. de *et al*. Water erosion and soil water infiltration in different stages of corn development and tillage systems. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 19, n. 1, p. 1072-1078, 2015.

CHINN, C.; PILLAI, U. P. P. Self-repair of compacted Vertisols from Central Queensland, Australia. **Geoderma**, v. 144, n. 3/4, p. 491-501, 2008.

CORSTANJE, R. *et al*. Probing the basis of soil resilience. **Soil Use and Management**, v. 31, p. 72-81, 2015.

EMBRAPA. **Manual de métodos de análise de solo**. 3. ed. Brasília, DF: Embrapa, 2017.

FERREIRA, A. O. *et al*. Driving factors of soil carbon accumulation in Oxisols in long-term no-till systems of South Brazil. **Science of the Total Environment**, v. 622-623, p. 735-742, 2018.

FIETZ, C. R. *et al*. **Estimativa da precipitação provável para o Estado de Mato Grosso**. Dourados: Embrapa Agropecuária Oeste, 2008.

FISCHER, C. *et al*. How do earthworms, soil texture and plant composition affect infiltration along an experimental plant diversity gradient in grassland? **Plos One**, v. 9, n. 6, p. e98987, 2014.

GOULD, I. J. *et al*. Plant diversity and root traits benefit physical properties key to soil function in grasslands. **Ecology Letters**, v. 19, n. 9, p. 1140-1149, 2016.

GUBIANI, P. I. *et al*. Relação entre densidade do solo e conteúdo de água em repetidos ciclos de contração e expansão em um Latossolo. **Revista Brasileira de Ciencia do Solo**, v. 39, n. 1, p. 100-108, 2015.

HAO, H. *et al*. Vegetation restoration and fine roots promote soil infiltrability in heavy-textured soils. **Soil and Tillage Research**, v. 198, p. 104542, 2020.

HUANG, Z. *et al*. Legume grasslands promote precipitation infiltration better than gramineous grasslands in arid regions. **Land Degradation and Development**, v. 28, n. 1, p. 309-316, 2017.

INAGAKI, T. M. *et al*. Mechanical and biological chiseling impacts on soil organic C stocks, root growth, and crop yield in a long-term no-till system. **Soil and Tillage Research**, v. 211, p. 104993, 2021.

KODESOVA, R. *et al*. Soil structure and soil hydraulic properties of Haplic Luvisol used as arable land and grassland. **Soil and Tillage Research**, v. 111, n. 2, p. 154-161, 2011.

LEUNG, A. K. *et al*. Effects of the roots of *Cynodon dactylon* and *Schefflera heptaphylla* on water infiltration rate and soil hydraulic conductivity. **Hydrological Processes**, v. 29, n. 15, p. 3342-3354, 2015.

OBOUR, A. K. *et al*. Cover crops to improve soil health in the North American great plains. **Agronomy Journal**, v. 13, p. 4590-4604, 2021.

PÖHLITZ, J. *et al*. Computed tomography and soil physical measurements of compaction behaviour under strip tillage, mulch tillage and no tillage. **Soil and Tillage Research**, v. 175, p. 205-216, 2018.

POTT, C. A *et al*. Métodos para determinação de infiltração de água no solo. *In*: BERTOL, O. J. *et al*. **Manual de manejo e conservação do solo e da água para o Estado do Paraná**. Curitiba: NEPAR-SBCS, 2019. p. 201-208.

SANTOS, H. G. *et al*. **Sistema brasileiro de classificação de solos**. 5. ed. rev. e ampl. Brasília, DF: Embrapa, 2018.

SEIDEL, E. P. *et al*. Evaluation of aggregate distribution and selected soil physical properties under maize: jack bean intercropping and gypsum rates. **African Journal of Agricultural Research**, v. 12, n. 14, p. 1209-1216, 2017.

SERVADIO, P. *et al*. Effects on some clay soil qualities following the passage of rubber-tracked and wheeled tractors in central Italy. **Soil and Tillage Research**, v. 61, n. 3/4, p. 143-155, 2001.

SHAH, A. N. *et al*. Soil compaction effects on soil health and cropproductivity: an overview. **Environmental Science and Pollution Research**, v. 24, n. 11, p. 10056-10067, 2017.

SPLIETHOFF, J. *et al*. Development and validation of a hydraulic sampler for collection of undisturbed soil samples. **Archives of Agronomy and Soil Science**, v. 68, n. 4, p. 431-446, 2022.

SUN, D. *et al*. The effects of land use change on soil infiltration capacity in China: a meta-analysis. **Science of the Total Environment**, v. 626, p. 1394-1401, 2018.

WANG, L. *et al*. Soil loss: effect of plant litter incorporation rate under simulated rainfall conditions. **Land Degradation & Development**, v. 30, n. 10, p. 1193-1203, 2019.