Grazing management under integrated crop-livestock system on physical soil attributes and grain yield soybean[1]

Thomas Newton Martin[2*], *Marcos da Silva Brum*[2], *Vinícius dos Santos Cunha*[2],
Paulo Eugênio Schaefer[2], *Joanei Cechin*[3], *Rodrigo Pizzani*[4]

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ABSTRACT

Integrated crop-livestock system (ICLS) can help improve the soil physical attributes, increasing the nutrients cycling and yield potential. We evaluated the effect of forage height management under ICLS on physical soil attributes and water infiltration. Field experiment was carried out for two consecutive years in a randomized complete block design, with three repetitions. Forage was managed under continuous grazing, grazing up to 30 cm (G30), 20 cm (G20) and 10 cm (G10) of height, and control without grazing. Soil bulk density (SBD), microporosity (MIP), macroporosity (MAP), and total porosity (TP) were measured before and after the grazing at 0-5; 5-10 and 10-20 cm layer depth. Water infiltration rate was evaluated using the concentric rings in eight periods (5, 10, 15, 20, 30, 60, 90 e 120 min after beginning of the process). SBD at 0-5 cm layer was not affected by the grazing management, whereas the MIP, MAP, and TP reduced after sheep grazing compared to ungrazed. Water infiltration rate was higher for the G10 management, with greater amount of accumulated infiltrated water. Path analysis showed positive effects of the soil physical attributes under ICLS to the grain yield soybean, allowing the farmers to enhance their profitability.

Keywords: *Glycine max* (L.) Merril; agricultural production systems; plant management; sheep farming; soil compaction.

INTRODUCTION

Soybean [*Glycine max* (L.) Merril] is the most important economic commodity from Brazil and widely used around the world. In the last years, new areas have been used for soybean production, especially in lowlands of the southern agricultural Brazilian fields historically managed under livestock (Maranhão *et al.*, 2019). However, most areas had limited factors for production like low soil fertility and reduced water retention, reducing the grain yield potential. In addition, several research has been reported the importance of conservationist soil practices to enhance the water infiltration and contribute to the yield potential in agricultural systems (Alary *et al.*, 2016; Silva *et al.*, 2019). In this sense, integrated crop-livestock system (ICLS) can contribute significantly to increase the yield potential and promote economic diversification through nutrient cycling and enhanced the soil physical characteristics, especially during the off-season in fields with low adoption of management practices (Garcia *et al.*, 2012).

ICLS in agricultural systems managed with grasses species during the winter growing season to meet the forage demand can enhance soil physicochemical attributes, increase the water infiltration capacity, reduce costs and

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[1] This work is part of the second author´s doctoral thesis.
[2] Universidade Federal de Santa Maria, Departamento de Fitotecnia, Santa Maria, Rio Grande do Sul, Brazil. martin.ufsm@gmail.com; marcossbrum@yahoo.com.br; vinicius.cunha@agcocorp.com; pauloeugenioschaefer@gmail.com
[3] Cientista Associado Syngenta Seeds, NSP Multicrop, Cascavel, Paraná, Brazil. joaneicechin@uepg.br
[4] Sociedade Educacional de Três de Maio, Departamento de Agricultura, Três de Maio, Rio Grande do Sul, Brazil. rodpizzani@yahoo.com.br
*Corresponding author: martin.ufsm@gmail.com

provide greater profitability compared to areas managed under monoculture (Souza *et al.*, 2010; Loss *et al.*, 2012). However, root growth and straw amount from the forage are factors that can directly affect the water dynamics and decomposition rate, reducing the grain yield in successive crops (Sato *et al.,* 2012). Furthermore, intensive grazing and excessive trampling can degradate the pasture and cause soil compaction, decreasing the water infiltration rate due to the changes of physical attributes like aggregates fragmentation, lower macropore volume, and increase of soil bulk density (Pulido *et al.*, 2016; Byrnes *et al.*, 2018). Thus, ICLS have greater importance under soil physical attributes triggered by animal trampling, especially for the soil surface where the reductions of infiltrated water into the soil can be significant and affect the yield (Andreolla *et al.,* 2015a).

Additionally, sustainable management of ICLS depend on the correct practices of grazing and animal stocking to reduce the soil compaction, making possible to increase their efficiency in production systems and promote the ecosystem multifunctionality in grasslands (Moraine *et al.,* 2014; Hu *et al.*, 2019). Furthermore, the relationship between variables can be studied through analysis and track. This analysis allows the study of the direct and indirect effects of several independent variables on a dependent (basic) variable, whose estimates are obtained through regression equations in which the variables are first standardized (Cruz *et al.,* 2014). Thus, approaches of the ICLS and management practices regarding the grazing intensity and amount of straw available for the soil cover are essential for the feedback in successive crops to reduce the impacts caused by animal trampling on soil physical attributes, especially in areas managed with sheep in which the information are still lacking to help the extensionists and farmers.

The goal of this research was to evaluate the effect of pasture height management in crop-livestock integration on physical characteristics and soil water infiltration.

MATERIAL AND METHODS

Field experiment was carried out in the municipality of Santa Maria (geographic coordinates: 29º 41’ 51” S; 54º 02’ 30” W, and 195 m above sea level) between May 2012 to 2014. Before the experiment installation, the field was managed under conventional system with the Italian ryegrass (*Lolium multiflorum*) during the winter growing season and pearl millet (*Pennisetum glaucum*) in the summer growing season. The soil was previously classified as Argissolo Vermelho (Santos *et al.,* 2013), similar to the Ultisoil (USDA Soil Taxonomy), with the soil chemical analysis performed at 0-10 cm layer depth showing these characteristics: pH = 4.1; SMP index = 5.7; organic matter = 21.44 g dm^{-3}; P = 1.79 mg dm^{-3}; K = 0.80 cmol$_c$ dm^{-3}; Cu = 1.19 mg dm^{-3}; Fe = 175.78 mg dm^{-3}; Zn = 1.36 mg dm^{-3}; Mn = 118.23 mg dm^{-3}; Al^{3+} = 0.96 cmol$_c$ dm^{-3}; Ca = 1.82 cmol$_c$ dm^{-3}; and Mg = 1.13 cmol$_c$ dm^{-3}. Furthermore, samples were previously collected at 0-5; 5-10 and 10-20 cm layer depths to evaluate the soil physical attributes, accordance with the values showed in the table 1.

The experiment was performed in a randomized complete block experimental design with three repetitions, using plots with 16 m^2 each. Five forage management were evaluated composed by continuous pasture (CP), exits of sheep animals when the pasture had a height of 30 cm (G30), 20 cm (G20), and 10 cm (G10), and ungrazed. The pasture composition during the winter season was formed by a consortium of black oats (*Avena sativa* L.) and Italian ryegrass (*Lolium multiflorum* Lam.), using a proportion of 3:1 (300 and 100 seedlings m^{-2}, respectively). The pasture sowing was performed in the second half of May, using seeds with good quality and incorporated slightly with a disc harrow.

Table 1: Soil bulk density (SBD), microporosity (MIP), macroporosity (MAP), and total porosity (TP) evaluated at 0-5, 5-10, and 10-20 cm layer depths before the experiment starts under integrated crop-livestock system

Depth layer	Soil physical attributes*			
	SBD (Mg m^{-3})	MIP (m^3 m^{-3})	MAP (m^3 m^{-3})	TP (m^3 m^{-3})
0-5 cm	1.45	0.35	0.15	0.50
5-10 cm	1.52	0.29	0.08	0.37
10-20 cm	1.41	0.27	0.08	0.35

*Values obtained before the experiment installation.

The base fertilization was calculated in accordance with the recommendations to cold season grasses, using 350 kg ha^{-1} of the formulation NPK 05-15-30 (SBCS, 2004), and the nitrogen fertilization was distributed in three moments: 20% in the sowing, 40% after first and 40% after second animal pasture. Five Corriedale sheep, with an average age of twelve months, was used in each plot to perform the grazing and manage the forage height. The average of pasture height was measured in 25 random points of the plot, using the *sward stick* method adapted from Barthram (1986), with monitoring before the sheep entrance and after exists grazing. In 2012, residuals forage weight for the soybean were 3.3, 2.3; 2.1, 1.7, and 1.2 tons ha^{-1} in ungrazed, G30, G20, G10, and CG, respectively, whereas in 2013 the residual straw amount was of 4.2, 2.4, 2.3; 1.3, and 1.2 tons ha^{-1}, respectively.

Soybean was sown in the first half of November under no-tillage system, using rows spaced at 0.45 m and a population density of 250 thousand plants ha^{-1}. Soil physical attributes evaluated were soil bulk density (SBD), microporosity (MIP), macroporosity (MAP), and total porosity (TP) measured at 0-5 cm, 5-10 cm, and 10-20 cm depth layers after the soybean harvest. Samples were collected with cylindrical rings of undisturbed structure between the rows. The water infiltration rate (WIR) was measured by the double concentric cylindrical ring method in eight periods (5.0, 10, 15, 20, 30, 60, 90 and 120 min after the beginning of the process). Data obtained from the infiltrated water in relation to their respective periods were transformed by the empirical model developed of Kostiakov (1932), used to calculate the WIR into the soil (mm h^{-1}).

The results were submitted to homogeneity and normality analysis by Bartlet and Shapiro-Wilk testing. Variance analysis ($p < 0.05$) was performed, and when significant, the average of treatments compared by the Tukey´s test ($p < 0.05$). For the WIR, regression analysis was performed with adjustment for the non-linear exponential model of two parameters, $I = kt^{\alpha}$, in which I = refer to the cumulative WIR in the time (mm h^{-1}), K represents the water infiltration capacity (mm), t is the time variable (min), and α is the infiltration index (mm min^{-1}).

The path analysis considered the soybean grain yield as a dependent variable and the other evaluated variables as independent. The diagnosis of multicollinearity was performed in which a weak collinearity was found. The Genes software (Cruz, 2013) was used.

RESULTS AND DISCUSSION

Significant differences were found for the SBD, MIP, MAP and TP in grazing systems managed under ICLS and evaluated at different depth layers (Table 2). SBD at 0-5 cm depth increase strongly in CP, G10, and G20 compared to the G30 and ungrazed management system, demonstrating that intensive pasture changes this soil physical attribute (Table 2). In contrast, other results did not report significant changes of the SBD at the surface layer in ICLS managed with sheep, in which the lower compaction effects can occur due to the aggressive root volume of hibernal grasses and correctly adjustment of animal stocking (Severiano *et al.*, 2010; Andreolla *et al.*, 2015b). Additionally, higher compaction was found at 5-10 cm depth layer in CP and G10 grazing management, with values approximately 7% greater than G30 and ungrazed (Table 2). The increase of soil compaction at the 5-10 cm depth layer due to the animal trampling can occur mainly under no-tillage system and potentialized by the machine flows and implements used during the management operations. Similar effects on the plow foot formation with higher values of SBD up to 5 cm depth layer were reported in areas managed under ICLS, which intensive machinery traffic and greater animal trampling increase the soil compaction (Conte *et al.*, 2008). Grazing management did not affect the soil compaction at the 10-20 cm depth layer under ICLS (Table 2). Furthermore, the values of SBD between 5-10 and 10-20 cm depth layers were similar for the G30 and ungrazed management, suggesting that the height forage should be considered in ICLS.

Greater SBD values found at the 5-10 and 10-20 cm depth layers after two years under ICLS should not be characterized as limiting to the root growth and soybean plant development. Reinert *et al.* (2008) described that SBD values greater than 1.75 Mg m^{-3} in agricultural systems with sandy soils can constraint the root development and reduce the grain yield potential due to the lower water infiltration and reduced nutrients uptake by the plants. Moreover, G30 and ungrazed management have greater residue amount on the surface layer after grazing compared to the intensive pasture (CP, G10, and G20), protecting the soil and reducing the compaction (Table 2). Studies have been demonstrated that adequate amount of straw on the soil surface can enhance the nutrient cycling, reduce the raindrop's impacts, and better the physical soil quality (Fidalski, 2015). Additionally, other results reported increasing the soil organic matter content under ICLS systems managed with grazing greater than 25 cm height, highlighting the correct management of the ICLS can improve the soil physical quality and increase the grain yield (Fidalski *et al.*, 2010; Fidalski, 2015).

MIP reduced in G10 and G20 management compared to the ungrazed at the 0-5 cm depth layer, with values up to 9% lower than G30 and ungrazed (Table 2). CP management reduced approximately 14% of the MIP at 5-10 cm depth layer than other pasture systems, whereas the G10 and G20 caused reductions of 5% on the MIP compared to ungrazed at 10-20 cm depth layer (Table 2). In agricultural systems, micropores are usually located inside the aggregates and have an important role in the water-retaining into the profile. ICLS managed with black oat and ryegrass during the winter growing season without an adjustment of forage height and animal stocking can increase the soil compaction on the surface layer and reduce the micropores amount (Lanzanova *et al.*, 2007).

Table 2: Soil bulk density, microporosity, macroporosity, and total porosity evaluated at 0-5, 5-10, and 10-20 cm depth layers after the grazing management under integrated crop-livestock system

Depths	Grazing management*				
	G10	**G20**	**G30**	**Ungrazed**	**CP**
			Soil bulk density (Mg m^{-3})		
0-5 cm	1.46 a B	1.44 a B	1.38 b B	1.40 b B	1.47 a C
5-10 cm	1.59 a A	1.53 b A	1.47 c A	1.49 c A	1.57 a A
10-20 cm	1.51 a B	1.49 a A	1.48 a A	1.49 a A	1.52 a B
			Microporosity (m^3 m^{-3})		
0-5 cm	0.27 b A	0.27 b A	0.29 a A	0.29 a A	0.26 b A
5-10 cm	0.27 a A	0.27 a A	0.28 a A	0.27 a B	0.25 b B
10-20 cm	0.27 b A	0.27 b A	0.28 b A	0.29 a A	0.28 b A
			Macroporosity (m^3 m^{-3})		
0-5 cm	0.11 b A	0.11 b A	0.11 b A	0.18 a A	0.11 b A
5-10 cm	0.08 b B	0.06 b B	0.12 a A	0.12 a B	0.07 b B
10-20 cm	0.10 a A	0.05 c B	0.08 b B	0.06 c C	0.06 c B
			Total porosity (m^3 m^{-3})		
0-5 cm	0.38 b A	0.38 b A	0.40 b A	0.47 a A	0.37 b A
5-10 cm	0.35 b B	0.33 c B	0.40 a A	0.39 a B	0.32 c C
10-20 cm	0.37 a A	0.32 c B	0.36 a B	0.35 b C	0.34 b B

*G10 = 10 cm of post-grazing residue; G20 = 20 cm of post-grazing residue; G30 = 30 cm of post-grazing residue; and CG = continuous grazing. Same uppercase letters in the column, and, lowercase letters in the line did not differ by Tukey test ($p < 0.05$).

Evaluating the TP, ungrazed system showed greater values at 0-5 and 5-10 cm depth layers, with 0.47 and 0.39 m^{-3} m^{-3}, respectively, whereas all grazing management reduced the TP evaluated at 0-5 cm depth layer (Table 2). Furthermore, CP management have TP values approximately 27 and 22% lower than ungrazed system measured at 0-5 and 5-10 cm depths (Table 2). For G30, the TP values were 10% higher on the soil surface, and approximately 25 and 7% higher at 5-10 and 10-20 cm depth layers compared to the CP. Forage managed with 30 cm of height caused small changes on the TP into the soil profile in comparison of the intensive grazing (Table 2). The ICLS with bean (*Phaseolus vulgaris*) during the summer growing season and absence of grazing reported greater TP and lower SBD measured up to 10 cm depth layer (Andreolla *et al.*, 2015a). These authors demonstrated that the absence of animal trampling provides higher root concentration on the soil surface as well as increase the organic matter from the plant residue decomposition during the off-season period, helping to better the soil physical attributes.

WIR values were higher for the G10 and CP systems under ICLS during the evaluated period compared to the systems upon lower grazing intensity (Figure 1). For example, WIR in G10 measured up to 30 min after the process beginning was of 9.4 mm h^{-1}, values approximately 62% higher compared to the ungrazed. In G30 management had lower WIR values into the soil profile compared to the other grazing systems, with values 30% lower than G10 system

(Figure 1). Soil physical changes after intensive grazing, especially the increase of SBD and reduction of porosity, cause greater penetration resistance and superficial development of the plant root, although these attributes can favor the WIR under ICLS managed adequately (Moraes *et al.*, 2014). In addition, the reduction of MAP caused by the animal trampling depends on the several factors, such as soil texture, forage management, stocking animal, and amount of straw residue make to the next crop, can increase the WIR into the soil profile due to presence of root plants and higher organic matter in the ICLS (Andreolla *et al.*, 2015b). Residue produced during the winter growing season are important to reduce the soil bulk density, increase the organic carbon and water storage compared to the system without straw residues (Chalise *et al.*, 2019), demonstrating the importance of good management under ICLS.

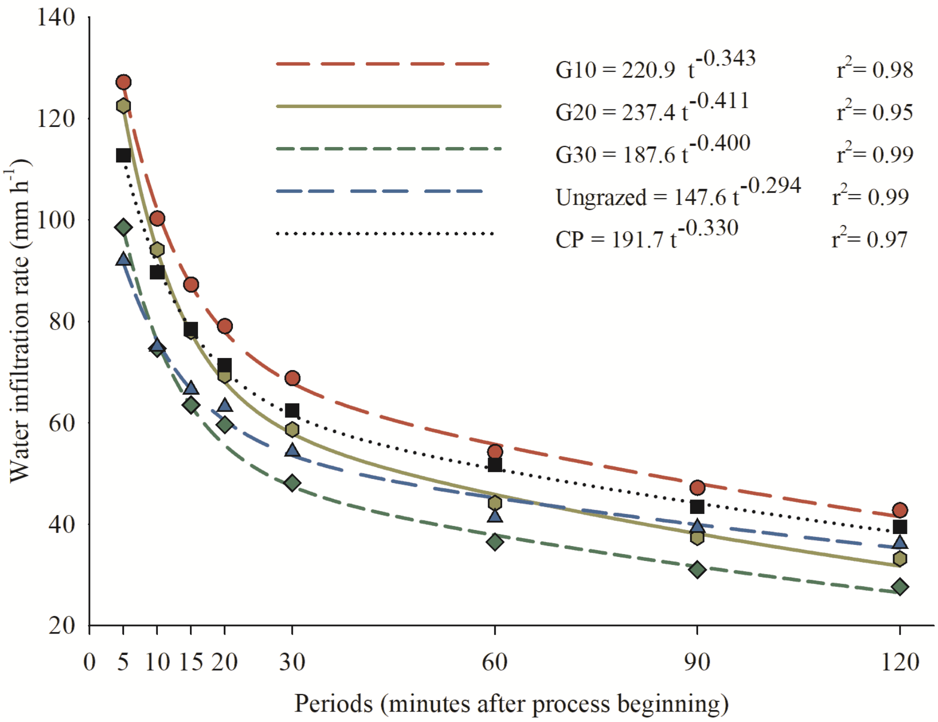

Figure 1: Water infiltration rate under ICLS after different post-grazing residues in succession of the soybean evaluated over two years after experiment installation. G10; G20 and G30 are residues of 10, 20 and 30 cm post-grazing, respectively; and CP = continuous pasture.

Path analysis using the correlations of soil physical attributes at 0-5, 5-10 and 10-20 cm depth layer, and WIR under ILCS showed positive effects on the soybean yield (Figure 2). Considering the total effect (TE), MAP at 0-5 cm depth, MIP and MAP at 5-10 cm depth, and WIR provide the greatest effects, with positive values of 0.471, 0.254, and 0.447, respectively (Figure 2). Higher direct effects (DE) were found for MAP at 0-5 cm depth layer, with a positive value of 0.334, whereas the greatest indirect effects (IE) occurred for the MIP at 5-10 cm depth layer (Figure 2). On the other hand, all soil physical attributes at 10-20 cm depth layer evaluated by the path analysis showed negative effects on the soybean yield, with values ranged from 0.025 to 0.701 (Figure 2). Additionally, the SBD showed negative effects on the soybean yield considering the direct and indirect effects between the associated variables, regardless of the depth layer evaluated (Figure 2).

Soil cover are essential to reduce the SBD on the surface layer and increase the MAP, with positive effects in the WIR and soybean yield (Chalise *et al.*, 2019). Similar results were reported in agricultural systems managed under ICLS, in which the greater soil aggregation and organic matter can reduce the soil density and increase the porosity, allowing to increase the water storage into the soil profile (Loss *et al.*, 2011; Costa *et al.*, 2015). Additionally, our results showed a positive interrelationship between the amount of water infiltrated into the soil and SBD during the period (Figure 2).

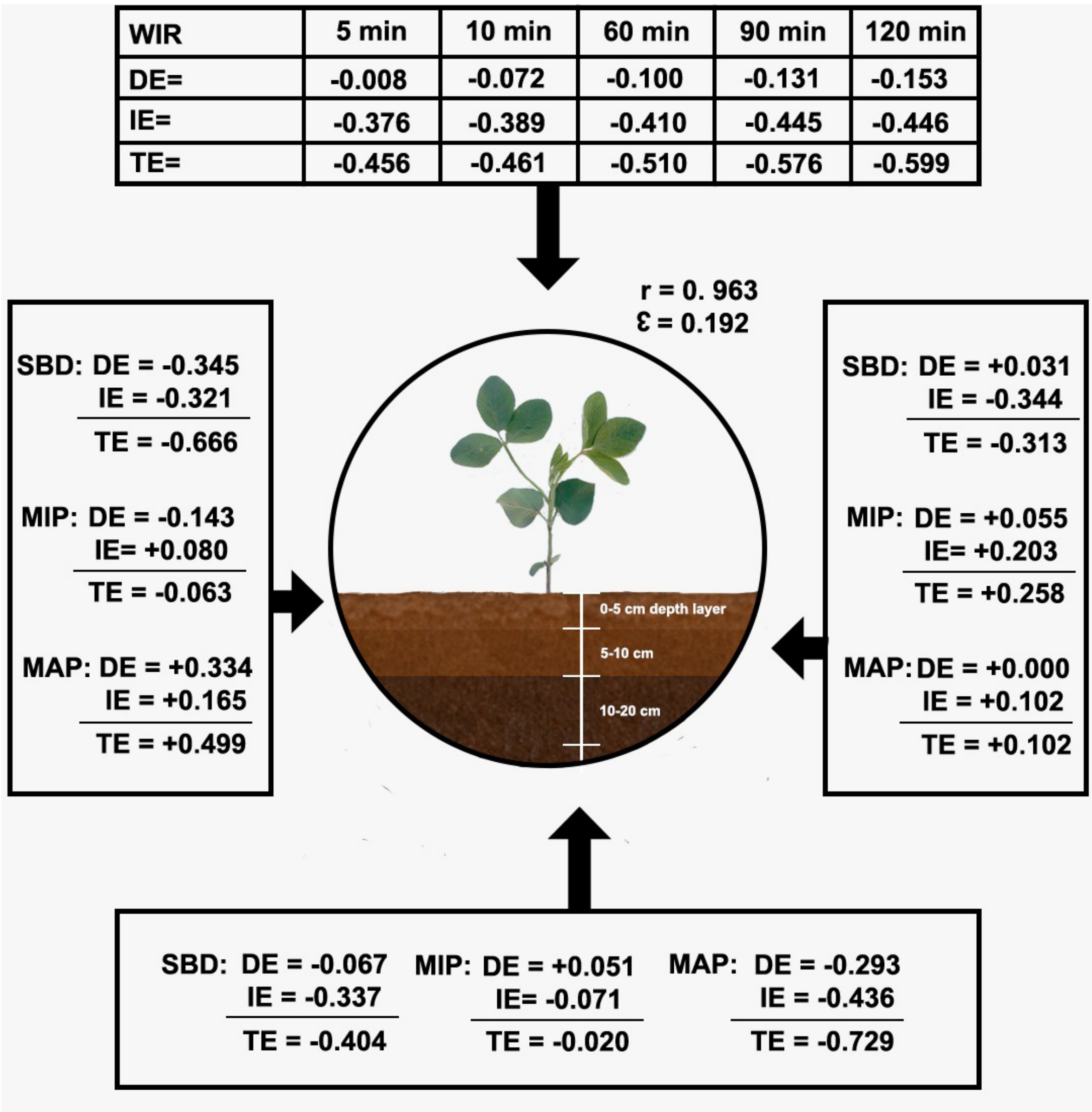

Figure 2: Partial data from the trail analysis (presentation of significant results), containing direct effects (DE), indirect effects (IE) and total effects (TE) of the variables soil bulk density (SBD), microporosity (MIP), macroporosity (MAP), and water infiltration rate (WIR) on the soybean yield using the path analysis with multicollinearity. The 15, 20, and 30 minutes data for the infiltration were not presented because they did not present significant results. r: determination coefficient and Ɛ experimental error.

Path analysis results from the multicollinearity showed a high coefficient of determination between variables and effect, with a value greater than 96% on the soybean yield and residue of 0.192 (Figure 2). Hoogerheide *et al.* (2007) described the importance to make a good assessment of the variables to select a specific attribute, especially for positive correlations in a group and negative for another, avoiding unwanted changes in the path analysis and bad conclusions. However, the analysis of quantitative variables like grain yield, its conclusive scope is restricted for the variables studied due to environmental changes and lower heritability (Ferrari *et al.*, 2018). Thus, the response of a dependent variable evaluated by the path analysis depends on its relationship with the independent variables and higher values of the coefficient of determination in relation to its residual variable (Machado *et al.*, 2017).

In general, ICLS can provide positive effects on the soil physical attributes and increase the soybean grain yield, especially in fields with adequate control of pasture height and animal stocking. Furthermore, although sheep are small animals compared to cattle, its use in ICLS needs caution for the management adopted practices to provide the better condition for the successive crops, especially on soil physical attributes.

CONCLUSIONS

G30 management does not affect significantly the SBD and MIP compared to ungrazed system, but reduce the MAP and TP.

SBD at 0-5cm depth layer increase significatively under intensive pasture with sheep, whereas the MAP and TP reduces under ICLS.

WIR is influenced by soil compaction and macropore volume, with a greater infiltration rate in the G10 and continuous grazing systems.

Soil physical attributes show positive correlation with the soybean yield evaluated by path analysis, demonstrating that the ICLS can be consider a tool to increase the grain yield.

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