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CROP PRODUCTION

Soil deep tillage performed before soybean cultivation on the rice cultivation in the following harvest

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ABSTRACT: *Soil decompaction is an alternative for soybean cultivation in rice areas, but it can affect the growth of irrigated rice in rotation. The objective of the study was to evaluate the effects of soil deep tillage performed before soybean cultivation on rice irrigation water, grain yield, and operational parameters of rice sowing carried out in the following crop season. Soil scarification was implemented in September 2017, prior to soybean crop season in the 2017/18 crop, and the rice experiment was conducted in the 2018/19 season. Treatments were: soil with scarification and soil without scarification. Deep tillage decreased soil density and increased macroporosity, microporosity, and total porosity. Rice cultivation decreased macroporosity and increased microporosity. Soil scarification management had no influence on operational parameters in rice sowing. Soil with scarification required 5.3% more water for rice irrigation than soil without deep tillage. In conclusion, soildeep tillage before the cultivation of soybean crop has effects on rice in thefollowing crop season, maintaining greater soil porosity in relation to the non-deep tillage area and increasing the amount of water needed for irrigation of rice cultivated in the sequence. Deep tillage did not affect sowing operational parameters and rice grain yield.*
Key words: *soil decompaction, porosity, traction force, Oryza sativa L.*

Efeito remanescente da escarificação do solo realizada antes do cultivo da soja, sobre o cultivo de arroz na safra seguinte

RESUMO: *A descompactação do solo é uma alternativa para o cultivo da soja em áreas de arroz, mas pode afetar o desenvolvimento do arroz irrigado em rotação. O objetivo do estudo foi avaliar o efeito remanescente da escarificação do solo realizada antes do cultivo da soja, sobre o uso da água de irrigação, o rendimento de grãos e parâmetros operacionais da semeadura do arroz, realizada na safra seguinte. A escarificação do solo foi feita no mês de setembro de 2017, anteriormente à soja na safra 2017/18 e o experimento de arroz foi conduzido na safra 2018/19. Os tratamentos foram:escarificação e não escarificação do solo. A escarificação aumentou a macroporosidade, a microporosidade e a porosidade total e diminuiu a densidade do solo. O cultivo do arroz reduziu a macroporosidade e aumentou a microporosidade. Não se observou influência do manejo de escarificação do solo sobre os parâmetros operacionais na semeadura do arroz. O solo escarificado necessitou 5,3 % a mais de água para irrigação do arroz, em relação ao solo não escarificado. Conclui-se que a escarificação do solo antes do cultivo da cultura da soja tem efeito remanescente em arroz na safra seguinte, mantendo maior porosidade do solo em relação à área não escarificada e elevando a quantidade de água necessária para irrigação do arroz cultivado na sequência. Não se verificou interferência da escarificação em parâmetros operacionais da semeadura e sobre o rendimento de grãos do arroz.*
Palavras-chave:*descompactação do solo, porosidade, força de tração, Oryza sativa L.*

To assist weed management in irrigated rice crops, and to diversify the income source of rural properties, producers have used the soybean crop (*Glycinemax* (L.) Merrill). This enables the use of herbicides with different action mechanisms compared to those used for rice, contributing to the reduction of the soil seed bank (AGOSTINETTO et al., 2018). However, some lowland area characteristics that favor irrigated rice cultivation become limiting when growing other species not adapted to this environment (e.g., soybean), thus requiring an adaptation of the area in order to grow these so-called dry-farming crops. In this sense, one adopted management practice for soybean cultivation is soil scarification, which breaks the compacted layer. This practice increased water infiltration and reduced soil density, rendering the soil more permeable and facilitating gas exchange with the atmosphere; consequently, improving root development and soybean productivity (SARTORI et al., 2016a; MARCHESAN et al., 2017).

However, decompacting soil for soybean cultivation may be unfavorable for the rice crop in the

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following crop season, as this management technique causes an increase in the pore space of the soil – mainly the macroporosity – which in turn increases the water infiltration rate in the profile (DRESCHER et al., 2016). The effects of soil decompaction can last in part from one crop season to the next (MARCHESAN et al., 2017; FIN et al., 2018), and this may not only increase the water use for rice cultivation, but also have unknown consequences on the tractor's traction power requirement in mechanical interventions, such as seeding. Since this crop rotation practice is now consolidating, technical information on the effects of decompaction in mechanical seeding operations is still scarce. Thus, the study evaluated the effect of scarification of Planosol on irrigation water usage, grain yield, and operational parameters of irrigated rice crops, implemented one year after soybean crop season.

The experiment was conducted during the 2018/19 crop season in the lowlands area of Federal University of Santa Maria (UFSM) on systematized surface. The soil was classified as Haplic Eutrophic Arenic Planosol, belonging to the Vacacaí mapping unit (SANTOS et al., 2018). The soil had the following physical-chemical characteristics: Organic Matter= 1.9%, Clay=24.5%, S= 14.2 mg dm^{-3}, P-Mehlich= 9.5 mg dm^{-3}, K-Mehlich= 34 cmolc dm^{-3}, water pH=5.6, CEC pH7= 11.2 cmolc dm^{-3}, V=80%, and m= 62.7% in the 0-0.1 m layer.

In the 2017/18 season, the soil was scarified prior to conducting the experiment, which constitutes the treatment of the present study. The procedure was implemented in September 2017, using an apparatus equipped with five rods spaced 0.35 m apart and with working depth average of 0.35 m. Scarification was done in a continuous range, 15m wide × 70 m long. An equally sized strip with no slopes was left non-scarified. Soybean was seeded in both areas for the 2017/18 harvest. In November 2017, after the scarification procedure, the plot was harrowed to level the surface of the scarified soil, enabling soybean sowing on the revolved land. Soybeans were grown following the technical recommendations, yielding 5019 and 4158 kg ha^{-1} of grain in the scarified and non-scarified areas, respectively. After the soybean harvest, ryegrass was sowed at a density of 40 kg seeds ha^{-1}, which was desiccated 45 days before rice sowing.

The treatments consisted of two soil managements: scarified soil and non-scarified soil in the crop season preceding the experiment, these soil management were carried out thirteen months before sowing rice. As the scarification was implemented in only one strip in the previous season, the experimental units were placed next to each other within each management range, separated by sidewalls, with six repetitions of each unit measuring 10 m x10 m, totaling 12 experimental units. Rice seed sowing was carried out on October 17, 2018, using the Titan CL (RiceTec®, Alvin-TX, USA) hybrid cultivar at a density of 45 kg seeds ha^{-1}. The base fertilization was composed of 20 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1},and 80 kg K_2O ha^{-1}. The top fertilization consisted of 170 kg N ha^{-1}, divided into three applications (60% in V3, 20% in V6, and 20% in R0) plus 30 kg K_2O ha^{-1} in V3, according to the phenological scale proposed by COUNCE et al. (2000). Other crop treatments were conducted according to the technical recommendations for the culture.

A Massey Ferguson 4275 (AGCO®, Duluth-GA, USA) tractor equipped with Auxiliary front wheel drive (AFWD), 56 kW (75 hp) power, and 3750 kg ballasted mass was used for the sowing procedure. Coupled to the tractor, a SHM 11/13 (Semeato®, Passo Fundo-RS, Brazil) continuous flow seeder-fertilizer was used, composed of thirteen lines spaced 0.17 m apart, with a mass of 2165 kg(empty). The volumetric soil moisture before sowing was 0.32 and 0.31m^3 m^{-3} for the scarified and non-scarified treatments, respectively.

During the sowing process, the operational parameters were evaluated. The traction force was determined by means of a load cell with 100 kN capacity, coupled between the tractor drawbar and the seeder; fuel consumption via the use of a set of flowmeters; and the actual speed of displacement using a GPS connected directly to alight bar. The drive wheel slip was calculated based on tractor speed and drive wheel speed, according to methodology developed by GABRIEL FILHO et al. (2004). To obtain these parameters, the operational evaluations were conducted three times in the longitudinal direction of each soil treatment range.

Macroporosity, microporosity, total porosity, and soil density were determined by collecting undisturbed soil samples, using volumetric rings in the 0.0-0.1, 0.1-0.2, and 0.2-0.3 m depth layers. The soil collection was performed at two different times: 15 days before sowing and 15 days after rice harvesting. Samples were subsequently taken to a tension table with a water column of 0.6 m, according to the methodology described by OLIVEIRA (1968).

The applied water volume was measured using a hydrometer with a 4"diameter and nominal flow (Qn) of 60 m^3 h^{-1} from the beginning of irrigation in V3 and throughout the entire crop cycle. The water depth was maintained close to 0.1 m until harvest (R9 stage), totaling 110 days of water logging. Water usage was determined by the volume of applied water plus rainfall during the irrigation period.

Grain yield was determined by harvesting two samples of 5.1 m^2 in each experimental unit, when the average grain moisture content was 22%.Water productivity (WP) was obtained from the relationship between grain yield and water volume used by the crop. The evaluated parameters were subjected to the test of assumptions of the mathematical model (normality of errors and homogeneity of variances). The Shapiro-Wilk test was used for testing data normality. For analysis statistics, the paired bilateral *t*-test was performed for two samples together, at the level of significance of $P \leq 0.05$.

Prior to rice sowing, the treatments showed differences in the macroporosity, microporosity, and, consequently, the total porosity of the soil, with the 0.0-0.1 and 0.1-0.2 m layers showing higher values for these variables in the scarified soil than in the non-scarified soil (Table 1). In the deepest layer (0.2-0.3 m), the scarification performed in the previous harvest did not influence the pore space one year later. The increase in macroporosity after scarification was greater than that observed for microporosity: 54% and 28% versus 11% and 5% in the 0.0-0.1 and 0.1-0.2 m layers, respectively. Rice cultivation affected macroporosity in the three analyzed soil extracts, with reductions of 12%, 21%, and 8% for the 0.0-0.1, 0.1-0.2, and 0.2-0.3 m layers, respectively. This change in microporosity arises from the changes in the physical attributes of the soil caused by water, mainly in flooded conditions. Under flooding, the pore space of the soil is occupied by water, compressing the air present in the pores, causing the collapse of the larger aggregates and; consequently, soil disaggregation (KIRK, 2004). Moreover, fine particles dispersed in solution, such as clay, may percolate causing the obstruction of macropores and a decrease in their volume (KIRK, 2004; CUI et al., 2018), and; consequently, an increase in micropores.

Table 1 - Macroporosity (Ma), microporosity (Mi), total porosity (Pt), and soil density (Ds) before sowing and after harvest of irrigated rice crop in soil subjected to scarification in the previous soybean harvest. Santa Maria – RS, 2020.

Soil treatment	---Ma ($m^3\ m^{-3}$)---			---Mi ($m^3\ m^{-3}$)---		
	0.0 - 0.1m	0.1 - 0.2m	0.2 - 0.3m	0.0 - 0.1m	0.1 - 0.2m	0.2 - 0.3m
---Pre-sowing---						
Scarified	0.12 a[*]	0.09 a	0.08^{ns}	0.38 a	0.34 a	0.35^{ns}
Non-scarified	0.08 b	0.07 b	0.07	0.35 b	0.32 b	0.35
Average	0.10	0.08	0.08	0.36	0.33	0.35
p-value[1]	0.5554	0.9962	0.0098	0.0262	0.7650	0.6357
---Post-harvesting---						
Scarified	0.12 a	0.07 a	0.07 a	0.37^{ns}	0.36 a	0.40 a
Non-scarified	0.06 b	0.06 b	0.06 b	0.37	0.35 b	0.36 b
Average	0.09	0.06	0.07	0.37	0.36	0.38
p-value	0.0225	0.1966	0.879	0.4538	0.5839	0.2345
Soil treatment	---Pt ($m^3\ m^{-3}$)---			---Ds ($Mg\ m^{-3}$)---		
	0.0 - 0.1m	0.1 - 0.2m	0.2 - 0.3m	0.0 - 0.1m	0.1 - 0.2m	0.2 - 0.3m
---Pre-sowing---						
Scarified	0.51 a	0.43 a	0.42^{ns}	1.42 a	1.60 a	1.62^{ns}
Non-scarified	0.43 b	0.40 b	0.42	1.57 b	1.72 b	1.61
Average	0.47	0.42	0.42	1.49	1.66	1.62
p-value	0.4245	0.4733	0.0233	0.6678	0.9989	0.6647
---Post-harvesting---						
Scarified	0.48 a	0.43 a	0.47 a	1.46 a	1.50 a	1.48 a
Non-scarified	0.43 b	0.40 b	0.43 b	1.52 b	1.61 b	1.54 b
Average	0.46	0.42	0.45	1.49	1.56	1.51
p-value	0.3288	0.3943	0.2803	0.2547	0.2375	0.8740

[*]Means not followed by the same letter in the same column differ from each other by the bilateral *t*-test at 5% of significance; [1] P-value of the Shapiro-Wilk normality test; ^{ns}= not significant by the bilateral *t*-test.

The reduction in macropore volume resulting from irrigated rice cultivation has also been reported by MENTGES et al. (2013) and YI et al. (2020), who attribute the decrease in this physical character to the continuous oil flooding period, which decreases contact between particles and aggregates. This period also decreases the transport of fine particles due to the soil profile in addition to reducing biological activity in flooded soils. Thus, rice cultivation under flooding conditions promotes structural changes in the soil and a gradual increase in its compaction (BEUTLER et al., 2012).

Unlike macroporosity, there was an increase in microporosity after the cultivation of irrigated rice, with the exception of the superficial layer in the scarified area. This increase occurred regardless of treatment (Table 1). However, in the deeper layer, the scarified area showed greater microporosity, possibly also due to the reduction in pore size by fine particle percolation. Before rice cultivation, the relationship between microporosity and macroporosity in the 0.0-0.1, 0.1-0.2 and 0.2-0.3 m layers on average was 3.7:1 and 4.5:1 on scarified and non-scarified soil, respectively; whereas after the harvest, the ratio increased to 4.3:1 and 5.7:1, representing an increase of 16% and 26%, respectively. The increase in the soil micro/macropore ratio after cultivation may be associated with flooding, which changes pore distribution as a function of fine particle percolation, decreasing the diameter of the larger pores (KIRK, 2004; CUI et al., 2018).Except for the deepest layer (0.2-0.3 m), the soil density in the scarified area was lower than in the non-scarified area.

The scarified area used 553 m^3 ha^{-1} more water than the non-scarified area (Table 2). Of this, 63% (345 m^3 ha^{-1}) was required to establish the water depth in V3. This increase in water use could be related to the increase in porosity that soil scarification provided, since this treatment increased the pore volume in the 0.0-0.3 m layer by approximately 120 m^3 ha^{-1}, increasing the air space to be filled with water at the time of irrigation. Another factor that may have caused this increase in water use is the disruption of the compacted layer (approximately 0.15 m deep) by scarification (data not mentioned), which may have allowed greater water flow at depth,as reported by SARTORI et al. (2016b), where scarification provided an increase of 10 mm ha^{-1} in water infiltration capacity in the same soil type as that of the present study. Likewise, in a Gleysol commonly cultivated with irrigated rice, GOULART et al. (2021) also reported an increase in water infiltration post-scarification for dryland crops, ranging between 3.0 and 10.5 fold increases compared to direct seeding or cultivation on ridges, 140 days after sowing. According to PRANDO et al. (2010), scarification on a Red Nitosol also provided a higher water infiltration rate in the 0.0-0.2 m layer in the first harvest after the treatment. DRESCHER et al. (2016) found that scarification of an Oxisol increased the infiltration rate for up to 24 months, after which the infiltration rate decreased.

Rice grain yield did not differ significantly between the soil management techniques (Table 2). Under these saturated soil conditions, particle cohesion decreases, which also reduces soil resistance to penetration, facilitating the growth of rice roots (BEUTLER et al., 2012). No significant difference was observed in WP; although, grain yield subtly followed the increase in water use despite there being no difference between the management treatments. This was thus reflected in the proportional WP values between the two soil managements, which presented values of 1.18 and 1.20 kg m^{-3} for scarified and non-scarified soil, respectively. No significant differences

Table 2 - Traction force (TF), fuel consumption (FC), displacement speed (DS), and drive wheel slip (DWS) during seeding and water usage (WU), grain yield (GY), and water yield (WY) of irrigated rice in soil subjected to scarification in the previous soybean harvest. Santa Maria – RS, 2020.

Soil treatment	TF (kN)	FC (L h^{-1})	DS (km h^{-1})	DWS (%)	WU (m^3 ha^{-1})	GY (kg ha^{-1})	WY (kg m^{-3})
Scarified	6.39^{ns}	12.10^{ns}	7.22^{ns}	8.50^{ns}	10950 a*	12961^{ns}	1.18^{ns}
Non-scarified	5.45	11.80	7.30	9.23	10397 b	12447	1.20
Average	5.92	11.95	7.25	8.87	10674	12704	1.19
P-value[1]	0.5635	0.2868	0.0387	0.8777	0.1047	0.2276	0.8088

[*]Means not followed by the same letter in the same column differ from each other by the bilateral *t*-test at 5% of significance; [1] P-value of the Shapiro-Wilk normality test; [ns]= not significant by the bilateral *t*-test.

between the two treatments were observed in the operating parameters during rice sowing (Table 2). The average displacement speed of the two treatments was 7.25 km h^{-1}. The average traction force of the two treatments was 5.92 kN, which takes into account the fact that the seeder had 13 sowing lines, and the pulling force required by each line was 0.46 kN. This required force value was similar to that reported by SILVEIRA et al. (2005), who reported that the traction force demanded on the drawbar reached 6.55 kN on average when using a 14-row continuous flow seeder.

Drive wheel slip, fuel consumption, displacement speed, and effective work capacity did not differ statistically between the treatments (Table 2). These results corroborated those by MAHL et al. (2004) who studied a corn crop grown on Red Nitosol 18 months after scarification.

The use of a plowing mechanism for fertilizer deposition requires higher traction forces as the working depth increases (PALMA et al., 2010). However, for rice cultivation, this type of mechanism is not necessary, as the crop grows in saturated soil. This is a determining factor for the lack of significant differences between treatments, since the seeder-fertilizer had a double-disc seed deposition and fertilizer mechanism, common in continuous flow seeders. This causes the traction force demand, the wheel slip and, consequently, fuel consumption to below than a fertilizer deposition system with the presence of a furrower rod.

Furthermore, the condition of the soil at the time of sowing was not favorable to make distinctions in the operational parameters between the two soil management treatments, since the soil moisture at thetime of operation was 0.32 and 0.31 m^3 m^{-3} with and without scarification, respectively. This humidity was equivalent to 84 and 88% of the field capacity (microporosity) of the soil, indicating that the water content was not sufficiently high enough to hinder machine traffic, since drier soils exhibit greater mechanical resistance (CORREA et al., 2019).

Associated to this fact, scarification process was carried out one year before sowing. Hence; although, scarified soil exhibits features that indicated the permanence of the management effects such as greater macroporosity and lower soil density (Table 1), it did not exert great influence on the reduction of operational efficiency. As noted by AMORIM et al. (2019), the seeding of rice on a scarified soil decreased displacement speed and operational capacity and increased drive wheel slip and fuel consumption of the tractor and seeder compared to soil subjected to plowing and harrowing. However, these authors attributed these differences to lesser consolidation and greater soil irregularity, as the soil was probably less structured after scarification, something that did not occur in the soil of the present study,as it was sown one year after management.

In conclusion, when a soybean crop is used before rice cultivation, and if soil scarification is performed to render physical conditions more favorable to its growth, some effects last at least one harvest after its completion. These effects include maintaining a greater soil porosity and providing increased water use for rice irrigation in the next crop season, but without affecting grain yield. Under the conditions of the present study, there was no influence of soil scarification on the operational parameters during rice harvest.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS' CONTRIBUTION

The authors contributed equally to the manuscript.

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