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SOIL SCIENCE

Energy demand for soil decompression and benefits in the establishment and productivity of soybean in the lowlands in the state of Rio Grande do Sul

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ABSTRACT: The present study assessed soil preparation in terms of the advantages it provides in lowering the physical obstacles and their influence on soybean cultivation, with reference to its establishment, development and yield, apart from quantification of the energy demand for tractor performance. The experiments were performed in the field adopting the randomized block design with a two-factor scheme (6x2). Factor A included a variety of soil preparations performed during the off-season of the soybean crop. Sowing was accomplished using the same fertilizer deposition mechanism only, and the areas having no soil preparation done were sown using various other fertilizer deposition mechanisms from the seeder, namely: (A1) sowing without soil preparation (SSPS)+double disc in the seeder (DD); (A2) SSPS+turbo disc (DT); (A3) SSPS+furrowing rod (HS); (A4) plow harrow+DD; (A5) scarified+DD and (A6) subsoiled+DD. Soil preparations before sowing were done on days 52 and 98 days, respectively, during the first and second harvests. Factor B included two soybean cultivars, namely: (B1) Nidera 6601 and (B2) Brasmax Valente. No interaction was observed between the factors investigated. While the scarification+DD showed the need for higher fuel consumption, the results were increased productivity. For the seeder-linked mechanisms, the HS gives more extensive root development of the plants and grain yield. On the contrary, while DD and DT show the combination of the highest operational capacity and lower fuel usage, this is related to lower grain yield.
Key words: compaction, plant death, plant development, root growth.

Demanda energética para descompactação do solo e benefícios no estabelecimento e na produtividade de grãos de soja em terras baixas no estado do Rio Grande do Sul

RESUMO: O estudo teve por objetivo determinar os benefícios de preparos mecânicos do solo na redução dos impedimentos físicos e seus reflexos no estabelecimento, no desenvolvimento e na produtividade de grãos de soja, além de quantificar a demanda energética ao trator para as operações. O experimento foi conduzido a campo no delineamento de blocos ao acaso em esquema bifatorial (6x2). O fator A foi composto por diferentes preparos do solo realizados no período de entressafra da soja, semeando apenas com o mesmo mecanismo de deposição do fertilizante, e por áreas sem preparo do solo semeadas com diferentes mecanismos de deposição do fertilizante da semeadora, sendo eles: (A1) semeadura sem preparo do solo (SSPS)+disco duplo na semeadora (DD); (A2) SSPS+disco turbo (DT); (A3) SSPS+haste sulcadora (HS); (A4) grade aradora+DD; (A5) escarificado+DD e (A6) subsolado+DD. Os preparos do solo anteriores a semeadura foram realizados 52 e 98 dias antes da semeadura, respectivamente, na primeira e segunda safra. O fator B foi composto por duas cultivares de soja, sendo elas: (B1) Nidera 6601 e (B2) Brasmax Valente. Não houve interação entre os fatores estudados. A escarificação+DD demanda maior consumo de combustível, porém reflete na maior produtividade. Para os mecanismos associados à semeadora, a HS propicia o maior desenvolvimento radicular das plantas e produtividade de grãos. Por outro lado, o DD e o DT possuem a maior capacidade operacional e menor consumo de combustível, porém, reflete em menor produtividade de grãos.
Palavras-chave: compactação, morte de plantas, desenvolvimento de plantas, crescimento radicular.

INTRODUCTION

For a century or more, the state of Rio Grande do Sul (RS) has had irrigated rice monoculture as the predominant grain-producing crop in the lowland areas. In fact, these sites in RS extend across approximately 5.4 million hectares, of which roughly 20 % are intended for the annual cultivation of rice (IRGA, 2020), with a large percentage of the plains left fallow or meant for large scale cattle breeding.

The lowlands in the RS, for the most part, are composed of the Planosols and to a lesser extent, the Gleisols, both having the typical flat relief and low hydraulic conductivity (LIMA et al., 2009). These features favor irrigated rice cultivation; however, this is limited to raising species that are intolerant

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to flooding. However, this agroecosystem can be made productive by crop rotation, which has given good results for its sustainability (HOKAZONO & HAYASHI, 2015).

Alternating crops has shown positive indications, which involve raising the soil quality and ensuring higher efficiency of weed control (MASSONI et al., 2013). However; although, the benefits crop diversification and the escalating demand for grains, apart from rice in the domestic and foreign markets are well recognized, crop rotation is not very widely practiced in the lowland regions because of the issues related to cultivation. At present, around 40 % of these stretches are already being cultivated in rotation, maintaining soybean as the principal crop, although with low yield of nearly 2,000 kg ha-1 (IRGA, 2022).

Among the chief hindrances that restrict the rise in rainfed crops in this region are those caused by the features of hydromorphism, presence of a shallow surface soil layer, and compacted subsurface soil, which together produce soils having poor capability for water storage, as well as deficient in natural drainage (ROCHA et al., 2017). This compacted layer is formed by natural characteristics together with intense machine traffic under highly humid conditions (BAMBERG et al., 2009). This layer shows high soil density with low porosity, particularly due to the reduced macroporosity (MENTGES et al., 2013). Consequently, such soils possess poor pore continuity, which in turn affects the movement of water (SARTORI et al., 2016a), gases (MENTGES et al., 2016) and nutrients (KUHT et al., 2012) and thus, a lesser volume of soil for the roots to explore (SARTORI et al., 2016b). Hence, these factors limit the crop interms of establishment, growth and development (MENTGES et al., 2013; SARTORI et al., 2016a; COELHO et al., 2020), and the soil remains under anaerobic conditions for a longer time period.

Therefore, to intensify crop diversification and raise the productivity and profitability of rainfed species in this milieu, the risks must definitely be minimized, which mainly means improvement of the root environment. Suitable alternatives used during the off-season are scarification (GIACOMELI et al., 2016; SARTORI et al., 2016a), subsoiling and harrowing, which are known to lessen the issues that stem from physical impediments. Of these, scarification is most significant, as it encourages the breaking open of the subsurface layers resulting in a rise in the infiltration rate and thus, the water volume accumulated in the soil; this in turn, encourages the deeper growth of the root (NUNES et al., 2014). With increased infiltration, the water stress tends to decline, thus enhancing the soil aeration. When fertilizer deposition mechanisms related to the seeder are used, they further reduce the physical impediments. Among the many alternative mechanisms that can be used, the furrowing rod shows the most potential in reducing the influence exerted by compaction when compared to the others, the double disc in particular (SARTORI et al., 2016b; COELHO et al., 2020).The rod raises the mechanical penetration in the seeding line by lowering the soil porosity and its resistance to this mechanism.

However, it is noteworthy that proportional to the enhancements in the physical soil structure in the course of the off-season preparations and the use of the furrowing rod in the seeder, an increase is observed in the energy demands of the tractor, the fuel expenditure and needed traction force (FRANCETTO et al., 2016) and, thus, the operational costs.

Therefore, the present research ascertain the advantages of mechanical soil preparation in lowering the physical obstructions and their influence on the soybean cultivar, with respect to its establishment, development and productivity, besides evaluating the energy demands of the tractor during the operations.

MATERIALS AND METHODS

The experiments were performed during the agricultural harvests of 2019/20 and 2020/21, in the floodplain region of the Universidade Federal de Santa Maria (UFSM). According to the Köppen classification, the climate of this region is Cfa, with the characteristic subtropical and humid features, having no defined dry season, and annual rainfall of 1688 mm, on average (CLIMATE-DATA, 2020). The soil is categorized as Arenic Eutrophic Haplic Planosol (SANTOS et al., 2018).

The experiments were limited to the field, and adopted the randomized block design, in a 6x2 bifactorial scheme, having four replications; each experimental unit measured 50 m in length and 3 m in width, covering a total area of 150 m2. Factor A included a variety of soil preparations done during the off-season of the soybean crop, with sowing performed using only the same fertilizer deposition mechanism, and in the sites without soil preparation, sowing was done using different fertilizer deposition mechanisms from the seeder, namely: (A1) sowing without soil preparation (SSPS)+double disc in the seeder (DD); (A2) SSPS+turbo disc (DT); (A3)

SSPS+furrowing rod (HS); (A4) plow harrow+DD; (A5) scarified+DD and (A6) subsoiled+DD. Factor B included two soybean cultivars, namely: (B1) Nidera 6601 IPRO and (B2) BRASMAX Valente, which were selected, as they are the varieties raised the most in the lowland regions during the harvest of 2018/19. Furthermore, they possess different agronomic traits, where based on the companies that own each of these materials, BRASMAX Valente reveals higher rusticity and greater productive stability, while Nidera 6601 displays a better production ceiling.

The preparations which included scarification, subsoiling and harrowing were performed 52 and 98 days prior to sowing, for the first and second harvests, respectively. The scarification was done using a São José Industrial brand scarifier (model Ripper 11), having 11 rods with 0.3 m spacing between them and working at 0.30 m depth, on average. Subsoiling was performed using the Terrus DSR subsoiler, from GTS do Brasil, which had six rods with 0.6 m spacing between them and operating at 0.40 m depth. The harrowing was conducted with a 16-disc (24”) plow harrow (Baldan brand), working at 0.12 m depth. As a Massey Fergusson tractor, model MF 7719, with auxiliary front-wheel drive (TDA) and power of 145 kW, at 1,950 RPM was available, it was used to pull the implements used.

A Massey Fergusson tractor, model MF 6711 with TDA, with 85 kW a power, at 2000 RPM, was used to drive the seeder. The soybean was sown with a Massey Fergusson pantograph seeder-fertilizer, model MF 407, which had six rows spaced 0.5 m apart and a mass of around 2,200 kg. The seeder had a smooth 18” diameter disc for straw cutting. The mismatched double discs, 16 and 15” in diameter could work at 0.08 m depth, on average. The turbo discs, working at roughly 0.12 m depth on average, had 28 waves measuring 18”. Each of the furrowing rods were 0.43 m long and 9.8 mm wide, with tips having a 21.3 mm width and a 14º angle of attack, working at 0.2 m depth, and 0.25 m distance to the cutting disc. Sowing was then conducted on November 19th and 26th for the first and second harvests, respectively. For both cultivars the sowing density was 29.6 seeds m-2.

Using 18 kg ha-1 of N, 72 kg ha-1 of P2O5 and 72 kg ha-1 of K2O as the base fertilizer in the sowing line, with an expected yield of five tons per hectare. At phenological stage V3 (FEHR & CAVINESS, 1977), 40 kg ha-1 of K2O was added to the soil surface. First, the seeds were treated with Fipronil (250 g L-1) and Carbendazin + Thiram (15 + 35%), at a 200 mL 100 kg-1 dosage. Further, peat inoculant, containing strains of Bradyrhizobium japonicum (100 g for 50 kg of seeds) was given as additional treatment. The rest of the cultural treatments were given, in line with the technical directions for the crop (CARAFFA et al., 2018).

With respect to the mechanization parameters, measurements of the force on the drawbar, fuel consumption, travel speed, and slippage were done. The operational capacity (hectare per hour), operational consumption (liters per hour) and drawbar power (conversion from kN to kW) were also assessed.

To accomplish the analysis of the variables, two different tractors were used based on machinery availability, namely the MF 7719 for soil preparation, and the MF 6711 for sowing. On both tractors, installation of the electronic instrumentation developed by RUSSINI (2009) and ROSA (2019) from the Agricultural Machinery Testing Center was done, (NEMA), from UFSM. At regular intervals of 1 second between measurements the data were drawn from the sensors, and stored in a Campbell Scientific data logger, model CR 1000.

The force on the traction bar that the equipment required was recorded via electrical pulses that a load cell with capacity 100 kN generated. A flowmeter from the Flow Mate brand (Oval M-III), model LSF, was employed to gauge fuel consumption; it provided several pulses which correlated to the fuel flow in a given time.

A 32-tooth gear was coupled to each tractor wheel to ascertain the speed of the movement of the driving wheels. Each of them was provided with an inductive type sensor to check the frequency as the gear teeth passed through the sensor. Then, the slippage was calculated according to the research done by GABRIEL FILHO et al. (2004) via the relationship between the real speed of the tractor, assessed by the distance-time relationship and the speed of the driving wheels.

The resistance to the mechanical penetration of the soil was established by taking 10 measurements per experimental unit, in the sowing line with a Falker digital penetrometer, model PLG 1020, up to 0.3 m depth. These evaluations were conducted 45- and 48-days post sowing the soybean, with the volumetric soil moisture registered as 0.29 and 0.30 m^3 m^{-3}, respectively, for the harvests of 2019/20 and 2020/21.

The Emergence Speed Index (ESI), unemerged seeds, plant death, and initial plant establishment and population were determined by demarcating, in each experimental unit, 10 linear meters. The ESI was established by daily counting the number of emerged plants, following the method suggested by MAGUIRE (1962). To assess plant death, the count was performed 45 days post sowing, excluding the number of emerged plants.

The grain productivity was assessed through manual harvesting of a 10 m2 area (2 rows x 5m) per experimental unit. After the grains were threshed, cleaned and weighed, data correction was done to 13% moisture and given in terms of percentage. In the case of the productivity gap for each crop, each treatment was subtracted from the most productive one. This difference in the productivity between treatments was understood to be the productivity gap, which was given as a percentage.

Data regarding the rainfall for the municipality of Santa Maria were drawn from the DISME/INMET meteorological station, situated 500 m from the location of the experiment.

The data thus drawn were submitted to the test of the assumptions of the mathematical model (homogeneity of variances and normality of errors). Employing the F test, the analysis of variance was performed with the means, when significance was observed, and comparison was done using the Scott-Knott test, at a probability of error of 5 %.

RESULTS AND DISCUSSION

The findings for the parameters corresponding to the agricultural mechanization for harrowing management are not listed, because the plowing harrow was less than the size required to match the power of the tractor (Table 1).

For soil preparation performed during the off-season (scarification and subsoiling) no differences were observed for travel speed, power requirement of the implement and tractor slippage. Regarding traction force, an 8 % rise was noted for scarification in comparison to subsoiling, which showed no significant difference from each other. However, when the traction force is divided by the number of rods for each piece of equipment, greater requirement is seen per rod for the subsoiler, where 11.9 kN is the requirement for each rod, a value 40 % more than the 7.1 kN identified for the scarifier. This difference may have a direct relation to the higher working depth and distance between the rods of the subsoiler. The force demand on each scarifier rod is in line with the findings of MACHADO et al. (2015) in a Red Nitisol, where 8.4 kN was the requirement, at 0.35 m depth.

For sowing, the furrowing mechanism or cutting disc of the fertilizer deposition with the seeder-fertilizer revealed differences in the parameters assessed. The SSPS+DD and SSPS+DT treatments used the lowest strength and power in the traction bar, but maintained greater work speed. The results reported by SOUZA et al. (2020) were similar, when the DD was employed in the seeder-fertilizer in Latos soloVermelho, with reduced slippage, power demand and traction force in comparison with the furrowing rod. In this context, when HS was used, the speed of the movement of the mechanized set reduced by 22 % when compared with other furrowing mechanisms,

Table 1 - Travel speed of the mechanized set (TSMS), traction force and drawbar power as a function of soil preparation during the off-season, as well as fertilizer deposition mechanisms related to the soybean seeder-fertilizer in the lowland regions, during the 2019/20harvest. Santa Maria, RS. 2022.

Management	----------TSMS (km h^{-1})--------		--------Traction force(kN)------		------Drawbar power (kW)-----	
	SMDO	Sow.	SMDO	Sow.	SMDO	Sow.
SSPS + DD	-	4.89 a[(1)]	-	10.5 c	-	14.3 c
SSPS + TD	-	4.73 a	-	11.5 c	-	15.3 c
SSPS + FR	-	3.76 c	-	35.5 a	-	37.1 a
Grading+ DD	-	-	-	-	-	-
Scarification + DD	3.08^{ns}	4.31 b	78.0 a	13.5 b	66.4^{ns}	17.5 b
Subsoiling + DD	3.32	4.34 b	71.6 b	16.9 b	65.7	20.4 b
CV (%)	6.59	8.14	5.29	9.03	6.31	12.55
Average	3.47	4.40	54.8	17.3	49.6	20.6

[(1)]Means not followed by the same letter differ from one another with the Scott-Knot test (P ≤ 0.05). ns: not significant. SMDO: soil management during the off-season. Sow: sowing. SWSP: sowing without soil preparation. DD: double disc. TD: turbo disc. FR: furrowing rod.

for those regions where no management was done during the off-season. This drop also caused a rise in the slippage, to achieve roughly 33%, a value that exceeded the one accepted by the ASABE (2006) as sufficient to provide maximum traction efficiency, from 8 to 10 %.

The SSPS+HS management without soil preparation during the off-season, however, worked at greater depth. The use of the HS required a 322 % increase in the FT and 251 % in traction power when compared with the disc averages, with the traction force at 5.9 kNpersowing line, which exceeded the ASAE recommended limit (2003), 3.5 kN for soils left undisturbed.

It is noteworthy that when HS is used, greater force and power from the tractor will be required when the mechanism tip is working directly in the range of the highest soil compaction (PALMA et al., 2010), as recorded in the present experiment (Figure 1). Therefore, when the furrowing rod tip is working either above this layer or below it with more mechanical resistance, penetration into the soil may necessitate lower traction force (TRICAI et al., 2016).

It is also significant that irrespective of the operating depth, the fixed seeder mechanisms, like the HS, necessitate higher traction force than do the mobile furrowers (LEVIEN et al., 2011). This observation is vindicated by the function of HS, which mobilizes the soil at deeper levels and promotes the breakdown of the more compacted layers, unlike DD, whose sole objective is to open up the furrow. Conversely, in order to subdue the rise in friction between the equipment and soil particles, higher energy expenditure is needed (FRANCETTO et al., 2015).

In the case of the DD and DT treatments, 1.84 kN was the average force required on the drawbar per sowing line. This value is almost similar to the findings of FRANCETTO et al. (2015) (1.75 kN), in Red Argosol, and by LEVIEN et al. (2011) (1.93 kN), in a Red Nitisol which was highly clayey in texture. These results exerted a direct impact on the rise in the operational capacity and a drop in the hourly and operational fuel consumption, in comparison with the other treatments (Table 2).

For preparations employing the scarifier and subsoiler, no notable differences were observed between the two, with respect to the hourly fuel consumption; however, the capacity and operational consumption between both pieces of equipment showed differences. For the soil scarification process,

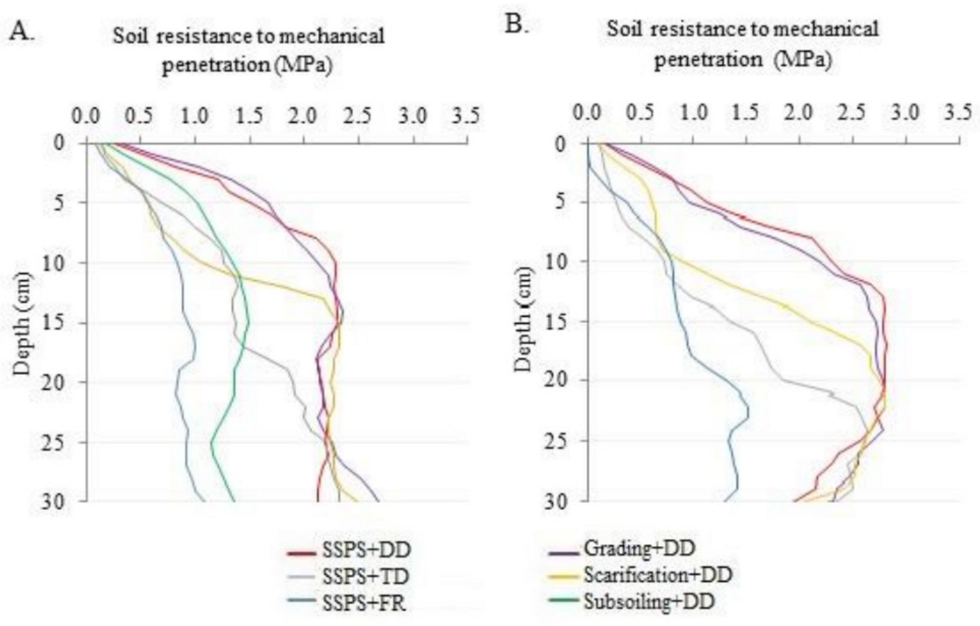

Figure 1 - Soil resistance to mechanical penetration in the sowing line caused by the soil preparation during the off-season and fertilizer deposition mechanism related to the seeder-fertilizer in the lowland regions during the 2019/20 (A) and 2020/21 harvests (B). Santa Maria, RS. 2022. The volumetric soil moisture in the 0-0.3 m depth layer on average was 0.30 $m^3 m^{-3}$ and 0.27 $m^3 m^{-3}$, respectively for the 2019/20 and 2020/21 harvests.

Table 2 - Wheel slippage of the driving wheels (WSDW), theoretical operational capacity, hourly consumption and operational consumption based on the off-season soil preparation and fertilizer deposition mechanism related to the seeder-fertilizer in the lowland areas for the 2019/20 harvest. Santa Maria, RS. 2022.

Management	-------WSDW (%)------		Theoretical operational ----capacity(ha h^{-1})----		Hourly consumption ----------(L h^{-1})---------		Operational consumption ----------(L ha^{-1})---------	
	SMDO	Sow.	SMDO	Sow.	SMDO	Sow.	SMDO	Sow.
SSPS + DD	-	6.2 c[(1)]	-	1.47 a	-	8.9 d	-	6.1 c
SSPS + TD	-	9.5 b	-	1.42 a	-	9.2 d	-	6.5 c
SSPS + FR	-	32.6 a	-	1.13 b	-	16.9 a	-	15.1 a
Grading+ DD	-	-	-	-	-	-	-	-
Scarification + DD	23.9^{ns}	11.2 b	1.01 b	1.40 a	26.7^{ns}	12.9 b	26.4 a	9.2 b
Subsoiling + DD	21.8	6.6 c	1.19 a	1.38 a	25.2	11.6 c	21.3 b	8.4 b
CV (%)	31.6	7	7.63	6.54	4.4	5.5	8.3	9.9
Average	16.09	11.86	0.95	1.35	20.56	11.52	20.92	8.81

[(1)]Means not followed by the same letter differ from one another with the Scott-Knot test ($P \leq 0.05$). ns: not significant. SMDO: soil management during the off-season. Sow: sowing. SWSP: sowing without soil preparation. DD: double disc. TD: turbo disc. FR: furrowing rod.

the requirement of 26.7 L ha-1 indicated a 19 % increase in the fuel consumption in comparison to subsoiling. This could be likely, chiefly linked to the decrease in operational capacity, with a drop of 0.18 ha h-1, besides the parabolic shape of the rods and wider distance at the tips.

For the use of HS, the increased force on the drawbar, as well as the decreased travel speed have a direct effect, causing it to have the lowest operational capacity when the mechanisms of the fertilizer seeder were assessed. Besides the lower operational capacity, the employment of HS produced a 123 % spike in the diesel usage.

It is also noteworthy that the use of the DD for the scarification and subsoiling preparations when compared with the SSPS management, produced a 36 and 25 % rise in the force and traction power demands, respectively, further escalating the fuel usage by 32 %. This finding may be related to the deeper levels reached by the tractor and seeder tires into the scarified regions due to the higher rolling resistance, which necessitates greater energy costs to ensure movement of the mechanized assembly (RODRIGUES, 2015).

The mobilization induced by soil preparation during the off-season and the fertilizer deposition mechanisms related to the seeder, produced alterations in the resistance to the mechanical penetration into the soil (RP). At the time of assessing the RP, the water content in soil showed an average of 0.30 m^3 m^{-3}in the 0-0.3 m layer.

From figure 1, it is clear that among the treatments in this study, the scarified+DD showed the highest reduction in RP, but below the value of 1 MPa up to the depth of 0.3 m. In this same soil profile, the subsoil+DD when assessed, lowered the values to 1.5 MPa. The variation between these two soil preparations is caused by the greater distance between the subsoiler rods, which results in minimal soil disturbance in comparison with the scarifier. It is noteworthy that this equipment, particularly the subsoiler, will show the highest efficiency (reduction in PR) when operations are performed with the soil in a friable state. However, because of the features of this environment, like low water infiltration capacity, the lowland regions are left undisturbed for long durations under highly humid conditions (BUENO et al., 2020), a state that is below the ideal for performing these operations, which results in decreased windows of time for preparation.

The treatments with SSPS+DD and SSPS+DT; however, displayed the highest penetration resistance, showing values that exceeded 2 MPa, at about 0.1 m depth. When compared with the mechanisms related to the seeder, the SSPS+HS revealed the most decrease in the RP, and maintained the values under 1.5 MPa up to 0.18 m depth; this corroborates the findings by COELHO et al. (2020), who reported a drop of up to 0.2 m in the RP.

On studying the parameters which refer to the initial establishment of the plants (Table 3), the preparations with SSPS+DD and SSPS+DT were observed to statistically present the lowest speed for the rate of emergence, highest percentage for non-emerged seeds and seed mortality plants, the smallest establishment and; consequently, the smallest initial population of plants in both harvests studied. From the data it is evident that on average for the treatments cited earlier, around 65 % of the seeds in the 2019/20 harvest failed to emerge, together with about 16 % of plant death; this means that besides the low emergence, there was a rise in the mortality. All of these issues produced only 30% of plant establishment.

This sequence of negative results may likely be linked to the 34 mm rainfall that occurred three days immediately post sowing (Figure 2). This phenomenon, in association with the poor water infiltration into the soil, caused by the presence of a compacted layer in these treatments, promoted soil saturation for a longer time span. Under such conditions, limited oxygen may have been available for the seeds to accomplish the germination process. The oxygen lack could have caused a drop in cellular respiration, exerting a negative influence on the seed reserves being transformed into ATP (Adenosine Triphosphate), which controls the formation of new tissues, during the most critical phases in plants for oxygen deficiency (TAIZ et al., 2017). Besides these issues, the lower ESI, meaning the longer the duration for the seeds to emerge, the greater the attack of soil pathogens like Pythium and Phytophthora, which are frequently more severe under conditions of high soil humidity or conditions of flooding (YOU & BARBETTI, 2017). Further, surface sealing may also have been another contributor to the poor establishment of the plants. The SSPS+HS, plow harrow+DD and scarified+DD treatments, on the other

Table 3 - Emergence speed index (ESI), percentages of non-emerged seeds (PNS), dead plants (DP) and establishment (E) and initial plant population (IPP) as related to soil preparation during the off-season and the mechanisms of fertilizer deposition connected to the seeder-fertilizer in two soybean cultivars, and for two agricultural years in a lowland region. Santa Maria, RS. 2022.

--------Harvest 2019/20--------					
Management	ESI	PNS (%)	DP (%)	E (%)	IPP (pl m^{-2})
SSPS + DD	10.8 c[(1)]	67.3 a	12.8 a	28.6 b	8.0 b
SSPS + TD	13.0 c	62.5 a	19.1 a	30.6 b	8.6 b
SSPS + FR	21.2 a	37.5 b	1.4 b	61.7 a	17.3 a
Grading+ DD	23.2 a	32.2 c	4.1 b	65.1 a	18.2 a
Scarification + DD	22.9 a	27.0 c	3.8 b	70.3 a	19.7 a
Subsoiling + DD	18.8 b	38.0 b	5.1 b	59.0 a	16.5 a
--------Cultivars--------					
NS 6601	19.1^{ns}	43.5^{ns}	8.1^{ns}	53.0^{ns}	14.8^{ns}
BMX Valente	17.3	44.7	7.3	52.1	14.6
Average	18.2	44.1	7.7	52.5	14.7
CV (%)	24.5	19.2	54.0	16.4	16.4
--------Harvest 2020/21--------					
SSPS + DD	16.6 b	31.8 a	14.5 a	58.6 b	16.4 b
SSPS + TD	18.4 b	28.2 a	17.1 a	60.5 b	17.0 b
SSPS + FR	23.9 a	15.7 b	4.8 b	80.2 a	22.5 a
Grading+ DD	24.2 a	11.6 b	4.0 b	84.8 a	23.8 a
Scarification + DD	22.8 a	9.1 b	1.9 b	89.3 a	25.0 a
--------Cultivars--------					
NS 6601	20.8^{ns}	21.0^{ns}	8.2^{ns}	71.4^{ns}	20.0^{ns}
BMX Valente	20.6	17.4	8.8	78.0	21.8
Average	21.2	19.2	8.5	74.7	20.9
CV (%)	18.2	41.1	65.8	17.9	17.9

[(1)]Means not followed by the same letter differ from one another with the Scott-Knot test ($P \leq 0.05$). ns: not significant. SMDO: soil management during the off-season. Sow: sowing. SWSP: sowing without soil preparation. DD: double disc. TD: turbo disc. FR: furrowing rod.

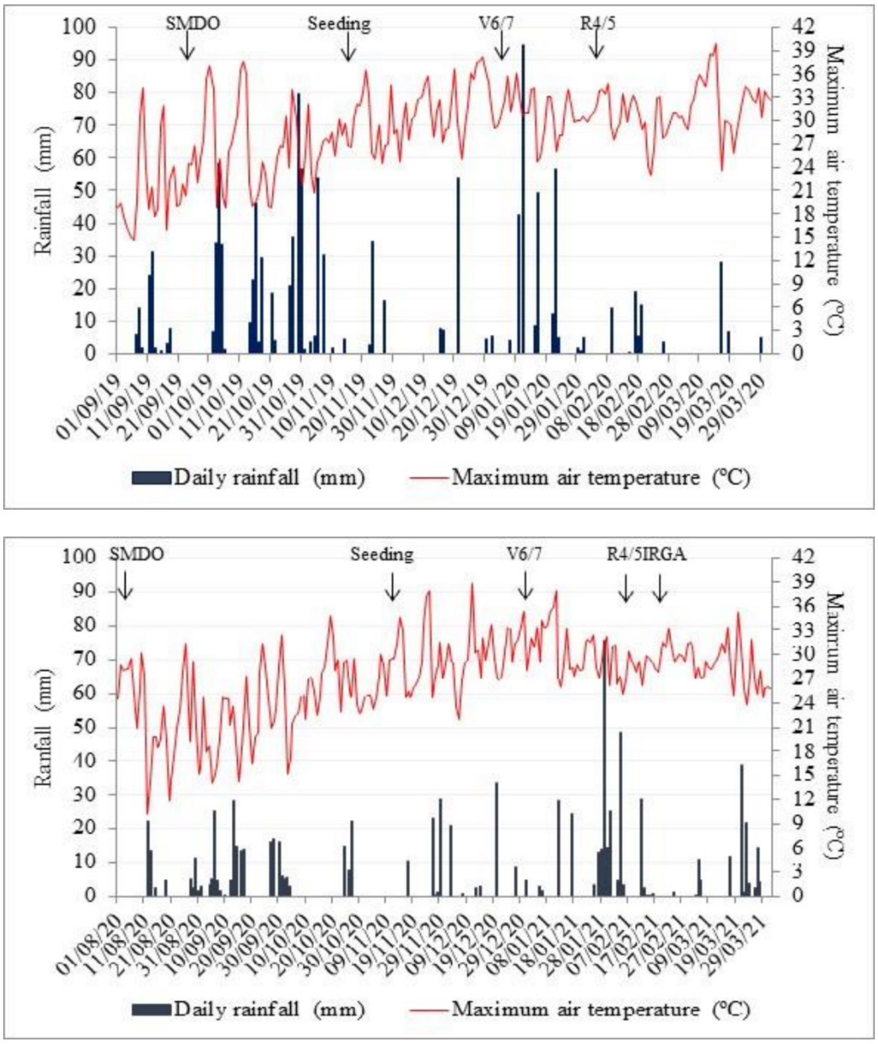

Figure 2 - Daily rainfall (mm) and maximum air temperature (ºC) during the 2019/20 (A) and 2020/21 harvests (B) agricultural harvests in the Santa Maria municipality. Santa Maria, RS. 2022. SMDO: Soil management during the off-season.

hand, during both harvests, and the subsoiled+DD treatment, during the 2019/20 harvest, are clearly discerned as having the highest initial plant population, and represent the best established, and having the lowest percentage of mortality.

Root growth was directly influenced by soil compaction. The lowest growth of the taproot, for both the phenological stages, as well as for the two harvests investigated, were noted for the SSPS+DD, SSPS+DT and harrow+DD treatments (Table 4). The greatest difference observed for the treatments cited earlier was seen in the R4/5 stage where the taproot in the 2019/20 harvest revealed 15.3 cm as the average root length, which was 39 % below the root seen in the scarified+DD and subsoiled+DD treatments, during the 2020/21 harvest, where the average length was 13.7 cm, which in turn was 31 % less than the average recorded for the SSPS+HS and scarified+DD treatments, which showed the longest root growth. Soil compaction thus exerts a direct effect on the rates of root elongation, inflicting damage to the growth anatomy of the entire root system, which includes the primary (pivoting) and secondary (adventitious) structures (MORAES et al., 2020).

It is also important to highlight that when the fertilizer deposition mechanisms of the seeder were directly compared, the furrowing rod used over the double disc and turbo disc increased the TL

Table 4 - Taproot length (TL), relative grain productivity (RGP) and productivity gap (PG) in relation to soil preparation during the off-season and fertilizer deposition mechanisms linked to the seeder-fertilizer in two soybean cultivars and for two agricultural years in the lowland regions. Santa Maria, RS. 2022.

--------------Harvest 2019/20--------------				
Management	---------TL (cm)---------		RGP (%)	PG (%)
	V6/7	R4/5		
SSPS + DD	11.6 d[(1)]	14.5 c	4119 d	72
SSPS + TD	13.0 d	14.8 c	4221 d	74
SSPS + FR	17.9 b	22.1 b	4970 b	87
Grading+ DD	14.7 c	16.7 c	4695 c	82
Scarification + DD	20.0 a	25.2 a	5742 a	100
Subsoiling + DD	18.9 a	24.5 a	5414 a	94
--------------Cultivars--------------				
NS 6601	16.3^{ns}	19.4^{ns}	4846^{ns}	-
BMX Valente	15.8	19.9	4874	-
Average	16.0	19.6	4860	-
CV (%)	10.7	12.4	7,1	-
--------------Harvest 2020/21--------------				
SSPS + DD	10.3 b	12.5 b	3764 c	77
SSPS + TD	11.7 b	13.5 b	3861 c	79
SSPS + FR	16.7 a	19.4 a	4233 b	86
Grading+ DD	12.9 b	15.1 b	4222 b	86
Scarification + DD	18.2 a	20.3 a	4908 a	100
--------------Cultivars--------------				
NS 6601	13.9^{ns}	16.2^{ns}	4077^{ns}	-
BMX Valente	14.0	16.2	4318	-
Average	14.0	16.2	4198	-
CV (%)	15.2	12.4	10,2	-

[(1)]Means not followed by the same letter differ from one another with the Scott-Knot test ($P \leq 0.05$). ns: not significant. SMDO: soil management during the off-season. Sow: sowing. SWSP: sowing without soil preparation. DD: double disc. TD: turbo disc. FR: furrowing rod.

observed by 31 and 29 % at the R4/5 stage, for the first and second harvests respectively.

When relative grain productivity was considered, the scarified+DD treatment had the most productivity of 5,742 and 4,908 kg ha-1, which corresponded to 100 % for the first and second harvests, respectively; it showed no statistical difference from the subsoil+DD management in the 2019/20harvest (Table 4). In another manner of analysis, the SSPS+HS, plow harrow+DD, SSPS+DT and SSPS+DD preparations stopped yielding 13, 18, 26 and 28 % in the 2019/20 harvest, and 14, 14, 21 and 23 %, in the 2020/21 harvest, respectively, in comparison to the scarified+DD treatment.

These findings concur with those of GOULART et al. (2020), in which scarification caused a productivity boost by 19 %. The same authors proposed that this response was caused by the improvement in the physical attributes and the decreased PR, together with the higher ability for water to infiltrate and be stored in the soil, thus enhancing the conditions during times of water stress. It is also noteworthy that, among the sites where no soil preparation was done during the off-season, sowing with HS produced a 13 and 15 % increase in the 2019/20 harvest, and a 7 and 9 % rise, in the 2020/21 harvest, compared to the DT and DD treatments, respectively.

As a final examination of the findings, it can be concluded that the soybean productivity rise in the lowlands depends upon a decrease in the physical soil impediments. As noted from this research, the productivity differences observed between the treatments is directly linked to the efficiency of each management in lowering the resistance to soil penetration. In light of this understanding, scarification, due to the smaller distances between the equipment rods linked to the working depth, offered the best physical conditions of the soil, and thus the higher productivity of grain.

Another likelihood is subsoiling the soil, which in the experiments performed induced high productivity. However, as greater distances are present between the rods of the subsoiler, the efficiency for decompacting is seen to depend more on the low soil humidity (friable); this implies, that the duration of soil preparation using this equipment is short. Therefore, it becomes crucial to further extend this research into managing this factor. In the present study, this was not done because all the operations were conducted out in an area having good surface drainage and after a 14-day period without rain, a rather unusual phenomenon for this period of the year.

Keeping in mind the disadvantage of depending upon low humidity for preparing the soil during the off-season, employing any one of these models will scarcely be done for the whole area, because in order to accomplish this, numerous machines will be needed, increasing the expenditure of this venture. In light of this, the HS in the seeder is the furrowing mechanism that has the highest potential to minimize the influence of compaction and boost the productivity. In just a single operation, physical improvements can be made to both the soil and sowing. The rise in cost of this mechanism is less than its benefits; however, adopting it may affect lower operational capability, necessitating the use of a greater number of machines or working hours. The use of the DD and DT as furrowers, however, facilitates higher seeding speed; although, it cannot contribute towards improving the soil profile, leaving the plants more susceptible to climate variations, and thus lowering the productivity.

CONCLUSION

Management using the scarification and sowing techniques with a double disc raises the demand for higher fuel consumption; however, it offers the highest decrease in resistance to penetration and productivity when compared with management with no soil preparation at all during the off-season, by sowing using a double disc or turbo disc.

Among the mechanisms linked to the seeder, the furrowing rod contributes towards better root growth and productivity of the soybean in the lowlands.

Seeding without prior soil preparation and with the use of the double disc and turbo disc shows the greatest operational capacity with the lowest fuel usage; however, the soil compaction issues are not alleviated; which therefore, lowers the productivity.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest between them.

AUTHORS' CONTRIBUTIONS

All the authors have made equal contributions to the formulation and writing of the manuscript. All authors have critically reviewed the manuscript and given approval of the final version.

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