Revista Brasileira de Ciência do Solo

Division - Soil Use and Management | Commission - Soil and Water Management and Conservation

Soybean Tillage Systems and Physical Changes in Surface Layers of Two Albaqualf Soils

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ABSTRACT: A compacted subsurface soil layer can be a limiting factor for soybean growing, reducing soybean yield. The aim of this study was to evaluate the effect of different tillage systems on the physical properties of two Albaqualf soils of the Central Plains region in the state of Rio Grande do Sul in southern Brazil. Two experiments were conducted: one in Santa Maria, RS, during the 2013/14 and 2014/15 crop seasons, and another in Formigueiro, RS, during the 2013/14 crop season. A randomized block experimental design with four replications was used. The treatments were: sowing using an offset double disc (T1); sowing using a fluted coulter disc (wavy disc with 12 waves) (T2); sowing with a knife runner opener (T3); sowing with a knife runner opener + press wheel mechanism for ground levelling (T4); sowing using a furrow opener upon a raised bed (T5); and chisel plough + sowing using an offset double-disc (T6). In the 2014/15 growing season, the T4 factor was changed using a knife runner opener 0.05 m from the planting row. A smaller reduction in the compacted subsurface soil layer was observed for both T1 and T2, which exhibited high soil bulk density values for the 2013/14 and 2014/15 crop seasons. Furthermore, T3, T5 and T6 led to a reduction in bulk density, and increasing total porosity and macroporosity in the soil, which consequently increased water infiltration, water storage capacity, and crop yield in areas with the presence of a compacted subsurface soil layer.

Keywords: compacted layer, deep tillage, raised bed, planter mechanism.

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Received: January 13, 2016

Approved: February 1st, 2016

How to cite: Sartori GMS, Marchesan E, De David R, Carlesso R, Petry MT, Aires NP, Giacomeli R, Aramburu BB, Silva AL. Soybean Tillage Systems and Physical Changes in Surface Layers of Two Albaqualf Soils. Rev Bras Cienc Solo. 2016;40:e0160019.

INTRODUCTION

An increase in cultivation of soybean in rotation with rice has been observed in recent crop seasons in lowland areas. This increase can be explained by the presence of weeds difficult to control in rice cropping areas, and by the need for rural income diversification. The use of crop rotation also indirectly improves physical and chemical soil conditions (Thomas et al., 2000). The predominant soil class in lowlands of Rio Grande do Sul is Albaqualf (Bamberg et al., 2009) formed inhydromorphic environment (Borges et al., 2004) with limited water drainage (Marchezan et al., 2002). When Albaqualf soils are cultivated with rainfed crops, as is the case of soybeans, plant growth and development may be hindered, mainly due to their naturally unfavorable physical conditions (Bamberg et al., 2009).

During the systematization process of land areas for irrigated rice, compacted soil layers can be found near the surface (Nunes et al., 2002; Reichert et al., 2008). Soil compaction is a major cause of physical degradation of agricultural soils (Mazurana et al., 2013), which indirectly it influences infiltration, hydraulic conductivity, temperature, and aeration of the soil (Borges et al., 2004). The effects of soil compaction on aeration can be evaluated by the amount of macropores (Valicheski et al., 2012). Soil compaction is manifested by increased bulk density and reduction in total porosity and macroporosity of the soil (Drescher et al., 2011), along with increased resistance to penetration (Spera et al., 2012). A study conducted by Mentges et al. (2013), evaluating hydro-physical and mechanical changes in the soil after eight years of rice crops grown in a conventional tillage system, showed an increase in bulk density and a decrease in total porosity and macroporosity.

A compacted soil layer reduces the water infiltration rate (Bonini et al., 2011) and decreases the least limiting water range in the soil profile (Kaiser et al., 2009). Furthermore, water availability to plants can be reduced as the soil structure is one of factors which directly influence water availability to crops by determining the arrangement of soil particles and therefore the distribution of pore diameters (Klein and Libardi, 2000). Soil compaction increases water retention but reduces water availability to plants.

Soybean producing areas may be adversely affected after years of stress from either lack or excess of water because both retention and availability of water can affect plant growth and yield (Costa et al., 2013) by affecting water uptake by plants (Carlesso, 1995). The study of management practices that improve hydro-physical properties of the soil becomes essential to optimize soybean cultivation in such areas. The hypothesis of this work is that sowing with a knife runner opener, sowing using a furrow opener upon a raised bed and chisel plough + sowing using an offset double disc improving soil physical quality.

Thus, the aim of this study was to evaluate the effect of different soybean tillage systems on the physical characteristics of the subsurface layer of two Albaqualf (*Planossolos*) soils of the Central Plains region in the state of Rio Grande do Sul in Brazil.

MATERIALS AND METHODS

Two experiments were performed: Experiment 1 during the 2013/14 and 2014/15 crop season and Experiment 2 during the 2013/14 crop season. Experiment 1 was carried out in the experimental lowland area of the Phytotechnology and Plant Science Department of the Federal University of Santa Maria (Universidade Federal de Santa Maria - UFSM), Santa Maria, Rio Grande do Sul (RS), Brazil, in soil classified as an Albaqualf (Soil Survey Staff, 2014), or *Planossolo Háplico Eutrófico* (Santos et al., 2013). The soil of the surface layer where the experiment was conducted belongs to the silty loam textural class (Table 1). We found 245, 208, and 547 g kg^{-1} of clay, sand, and silt, respectively, in the center of the two layers, and the following chemical properties, at 60 days before sowing, in the 0.0-0.2 m layer: pH(H_2O) (1:1) 5.4; P 18 mg dm^{-3}; K 60 mg dm^{-3}; Ca^{2+} 5.3 $cmol_c$ dm^{-3}; Mg^{2+} 2.4 $cmol_c$ dm^{-3}, and organic matter (OM) 2.0 % for the 2013/14 crop season; and pH(H_2O) (1:1) 5.4, P 15.3 mg dm^{-3}, K 44 mg dm^{-3}, Ca^{2+} 8.3 $cmol_c$ dm^{-3}, Mg^{2+} 3.1 $cmol_c$ dm^{-3}; and OM 2.0 % for the 2014/15 crop season.

The 2013/14 crop season experiment was carried in an area which previously contained a soybean crop and the 2014/15 crop season experiment was carried out in an area which previously contained irrigated rice. After the preceding soybean and rice crops were harvested, the areas received 2.0 Mg ha^{-1} of lime and then disked and leveled. In the off-season, ryegrass was sown in the area, which was desiccated with glyphosate at rate of 960 g ha^{-1} a.i.. By the time the experiments were set up, practically no ryegrass remained.

A randomized block experimental design was used with four replications. The treatments were different soybean tillage systems (Figure 1): sowing using an offset double disc (T1); sowing using a fluted coulter disc (wavy disc with 12 waves) (T2); sowing with a knife runner opener (T3); sowing with a knife runner opener + press wheel mechanism for ground levelling (T4); sowing using a furrow opener upon a raised bed (T5); and chisel plough + sowing using an offset double disc (T6). In the 2014/15 growing season, the T4 factor was changed using a knife runner opener 0.05 m from the planting row.

Experiment 2 was carried out in a non-systemized area with gently rolling topography in the neighboring municipality of Formigueiro in soil classified as an Albaqualf (Soil Survey Staff, 2014), or *Planossolo Háplico Eutrófico típico* (Santos et al., 2013). In this experiment, the clay, sand, and silt found in the soil in the center of the 0.0-0.1 and 0.1-0.2 m layers were 360, 252, and 387 g kg^{-1}, respectively, and the textural class was silty clay loam in both layers (Table 1). At 50 days prior to sowing, the 0.0-0.2 m layer had the following physical-chemical properties: pH(H_2O) (1: 1) 5.2; P 2.2 mg dm^{-3}, K 112 mg dm^{-3}; Ca^{2+} 10.5 $cmol_c$ dm^{-3}; Mg^{2+} 8.0 $cmol_c$ dm^{-3}; and OM. 1.6 %.

Beef cattle were raised in the experimental area in the municipality of Formigueiro, and prior to the experiment the native pasture was desiccated with glyphosate at rate of 960 g ha^{-1} a.i.. A randomized block experimental design was used, with four replications. The treatments were the same as in Experiment 1 during the 2013/14 crop season, but without the raised bed system.

Chisel plough for Experiment 1 was performed at 45 and 19 days before sowing for the 2013/14 and 2014/15 crop season, respectively, in friable soil. For experiment 2, deep

Table 1. Particle size distribution and soil textural class in two soil layers. Santa Maria and Formigueiro, RS, Brazil, 2015

Particle size[1]	0.0-0.1 m	0.1-0.2 m
	g kg^{-1}	
	Experiment 1 - Santa Maria	
Clay	214	276
Sand	210	206
Silt	576	518
Textural class	silty loam	silty loam
	Experiment 2 - Formigueiro	
Clay	318	403
Sand	287	218
Silt	395	379
Textural class	silty clay loam	silty clay loam

[1] Determined by the pipette method (Donagema et al., 2011). Sand: 2 to 0.05 mm, silt: 0.002 to 0.05 mm, clay: <0.002 mm.

tillage was carried out at the time of sowing. Tillage depth in both experiments was about 0.25 m, and knives were spaced at a distance of 0.35 m. The knife runner opener, the furrow opener upon a raised bed, the offset double disc, and the fluted coulter disc (wavy disc with 12 waves) system had working depths of approximately 0.18, 0.12, 0.10, and 0.08 m, respectively. Sowing was carried out on November 7, 2013 and November 14, 2014, for Experiment 1. Due to a 245 mm rainfall two days after sowing during the 2013/14 crop season, reseeding took place on November 26, 2013. For experiment 2, sowing took place on November 5, 2013. The soybean cultivar used for both experiments was BMX Tornado at a seed density of 26 seeds m^{-2} in rows spaced at 0.50 m.

Sowing of T1, T2, T3, T4, and T6 was carried out with a MF 407 planter, weighing approximately 2,210 kg. Raised bed seeding (T5) was performed with a KF 8/5 - A seeder, weighing approximately 3870 kg. The average seeding speed for experiments 1 and 2 was 3.3 and 3.5 km h^{-1}, respectively. At sowing the average water volume content in the soil was 26 and 34 m^3 in the 0.0-0.2 m layer for Experiment 1 and 2, respectively. The experimental units were 40 × 3 m and 60 × 3 m for experiments 1 and 2, respectively, with an area of 15 m^2 each.

The properties analyzed from the soil samples were soil bulk density (BD), total porosity (TP), microporosity (Micro), macroporosity (Macro), micropore/macropore ratio, degree of compaction (DC), water content retained at field capacity, available water, and maximum soil water storage. Evaluations were performed at 10 days prior to sowing during the V6 and R3 soybean growth stages in both experiments in the 2013/14 crop season, and during growth stage R3 in the 2014/15 season.

For soil analysis, soil samples were collected from the 0.0-0.1 and 0.1-0.2 m depth layers in the planting row using volumetric rings of 4.0 cm height and 4.8 cm diameter. After collection, soil samples were sent to the laboratory and analyzed using the volumetric ring technique associated with a table tension with a 0.60-m water column, following the techniques described by Donagema et al. (2011). We considered the water retained at field capacity of -10 kPa and the permanent wilting point at -1500 kPa. To determine water availability, the permanent wilting point was subtracted from the field capacity.

The degree of compaction (DC) was calculated using the following equation: $DC = (BD/BD_{ref}) \times 100$, which relates bulk density in the field (BD) to a reference density value restrictive to plant growth. Soil DC was calculated by using two strategies to estimate density reference, namely: BD_c LLWR = 1.83803 - 0.00078 × clay as proposed by Reichert et al. (2009a) in which LLWR (Least Limiting Water Range) is zero, and BD_c LLWR = 1.77000 - 0.00063 × clay, according to Jones (1983) when considering restriction to root growth.

Water infiltration capacity was also evaluated in Experiment 1 in the V6 and R7 crop stages for the 2013/14 and 2014/15 crop seasons, respectively. The evaluations were performed in the planting row using the double ring infiltrometer method. Readings were taken over a 3-h period, as proposed by Sato et al. (2012).

The results were subjected to the test of the assumptions of the mathematical model (normality and homogeneity of variances). Analysis of variance was performed using the F test and the means of the treatments, when significant, were compared by the Tukey test at 5 % probability.

RESULTS

Experiment 1

Soil physical properties at ten days before sowing (Table 2) indicated the presence of a more severely compacted soil layer at 0.1-0.2 m in both crop seasons (2013/14 and

2014/15). This can be inferred by the high values of bulk density (BD) and reduced values of total porosity (TP) and macropores compared to the 0.0-0.1 m layer. In this same layer, macro values indicate a restriction in aeration with values below 0.10 $m^3 m^{-3}$. Moreover, by comparing the density values observed with the reference values of density restrictive to plant and root growth (Table 2), these values are very close in the 0.1-0.2 m layer, which indicates a marked degree of compaction in this soil layer in both crop seasons. In the 0.1-0.2 m layer there were distinct responses arising from the different tillage systems in both crop seasons on the hydro-physical characteristics of the soil evaluated at different times after soybean seeding.

In the 2013/14 season (Table 3), soil water retention and availability, well as BD and microporosity (Micro) were not significantly affected by the tillage systems at the V6 stage in the 0.0-0.1 m and 0.1-0.2 m layers. However, T1 (offset double disc system) exhibited lower TP and Macro, and a greater micropore/macropore ratio in the 0.0-0.1 m layer compared to the other systems. No difference was found for the variables evaluated in the 0.1-0.2 m layer.

Similar to observations in the V6 stage, in the R3 stage there was lower macroporosity (Macro) and TP and a greater micropore/macropore ratio in T1. For soil water retention, in systems using an offset double-disc and a (double fluted-counter) wavy disc with 12 waves (T2), there was higher water retention compared to the shank and raised bed systems in the 0.0-0.1 m layer, without any differences in the 0.1-0.2 m layer. The fluted coulter disc (T2) and knife runner opener (T3) systems led to greater availability of water in the 0.0-0.1 and 0.1-0.2 m layer, respectively. For BD, there was no significant difference for the 0.1-0.2 m layer, where the highest densities were found in soil systems that used either offset double-disc or fluted coulter disc. Furthermore, low macropore values were found in depths up to 0.2 m in both systems; the highest macropore value was observed in the raised bed and knife runner opener system in the 0.0-0.1 and 0.1-0.2 m layers, respectively.

In the 2014/15 season (Table 4), the results were similar to those observed in the 2013/14 season. In the evaluation carried out during the R3 stage, there were no significant differences among the systems for water retention and availability, or for the quantity of micropores in the 0.0-0.1 and 0.1-0.2 m layers. Higher BD, lower TP, lower quantity of macropores, and higher micropore/macropore ratio were observed in both layers for the

Table 2. Soil water retention at field capacity (θ_{FC}), available water (AW), bulk density (BD), total porosity (TP), microporosity (Mi), macroporosity (Ma), Mi/Ma ratio, reference bulk density value restrictive to plant and root growth (BD_{ref}), and degree of compactness (DC) in two soil layers ten days prior to sowing. Santa Maria 2013/14 and 2014/15 crop season and Formigueiro 2013/14 crop season

Layer	θ_{FC} (-10 kPa)	AW	BD	TP	Mi	Ma	Mi/Ma	BD_{ref} (1)	BD_{ref} (2)	DC (1)
m	mm		$Mg m^{-3}$	$m^3 m^{-3}$				$Mg m^{-3}$		%
	Santa Maria – Experiment 1 (2013/14 crop season)									
0.0-0.1	38	27	1.33	0.53	0.40	0.13	3:1	1.67	1.64	80
0.1-0.2	35	21	1.67	0.42	0.36	0.06	6:1	1.62	1.60	103
	Formigueiro – Experiment 2 (2013/14 crop season)									
0.0-0.1	33	24	1.62	0.37	0.36	0.02	18:1	1.59	1.57	102
0.1-0.2	30	21	1.58	0.36	0.35	0.04	9:1	1.52	1.52	104
	Santa Maria – Experiment 1 (2014/15 crop season)									
0.0-0.1	36	24	1.45	0.43	0.33	0.10	4:1	1.67	1.64	87
0.1-0.2	34	22	1.60	0.37	0.30	0.08	4:1	1.62	1.60	99

The methods used were according to Donagema et al. (2011). θ_{FC} and AW: determined by Richards extractor device (Soils Moisture Equipment); BD: volumetric method; TP: calculation method with particle density; Mi: tension table method: 0.6 m tension; Ma: difference between TP and Mi. (1) BD_{ref} and DC: determined as proposed by Reichert et al. (2009); and (2) BD_{ref}: as proposed by Jones (1983).

Table 3. Soil water retention at field capacity (θ_{FC}), available water (AW), bulk density (BD), total porosity (TP), microporosity (Mi), macroporosity (Ma), and Mi/Ma ratio in the treatments at different soil depths. Santa Maria, Brazil. Experiment 1 in the 2013/14 crop season

Tillage system	θ_{FC} (-10 kPa)	AW	BD	TP	Mi	Ma	Mi/Ma
	—— mm ——		Mg m^{-3}	—— m^3 m^{-3} ——			
				V6[(1)]			
				0.0-0.1 m			
Offset double disc (DD)	36^{ns}	23^{ns}	1.34 ^{ns}	0.48 c	0.36^{ns}	0.12 b	2.9:1 a
Fluted coulter disc	34	23	1.30	0.49 bc	0.36	0.14 ab	2.7:1 ab
Knife	33	23	1.28	0.51 abc	0.35	0.16 ab	2.2:1 ab
Knife + M	32	23	1.24	0.52 ab	0.34	0.19 a	1.8:1 b
Raised Bed	33	23	1.25	0.54 a	0.34	0.21 a	1.6:1 b
Chisel plough + DD	32	24	1.30	0.50 bc	0.33	0.17 ab	1.9:1 ab
Mean	33	23	1.29	0.51	0.35	0.17	2.2:1
CV (%)	5.8	8.2	5.56	3.26	5.3	18	20.45
				0.1-0.2 m			
Offset double disc (DD)	33^{ns}	19^{ns}	1.60^{ns}	0.42^{ns}	0.33^{ns}	0.10^{ns}	3.3:1^{ns}
Fluted coulter disc	30	16	1.62	0.42	0.31	0.10	3.8:1
Knife	32	19	1.44	0.49	0.33	0.16	2.1:1
Knife + M	31	19	1.48	0.45	0.33	0.14	2.5:1
Raised Bed	31	18	1.46	0.45	0.32	0.13	2.6:1
Chisel plough + DD	31	18	1.53	0.48	0.32	0.16	2.2:1
Mean	31	18	1.52	0.45	0.32	0.13	2.7:1
CV (%)	5.4	8.8	6.21	7.5	4.0	25.3	28.7
				R3[(1)]			
				0.0-0.1 m			
Offset double disc (DD)	37 ab	25 ab	1.41^{ns}	0.49 b	0.38 ab	0.11 c	3.5:1 a
Fluted coulter disc	39 a	28 a	1.37	0.51 ab	0.41 a	0.10 c	3.9:1 a
Knife	33 c	24 ab	1.27	0.54 a	0.40 a	0.14 bc	2.9:1 ab
Knife + M	34 bc	23 b	1.28	0.53 ab	0.35 b	0.18 ab	1.9:1 b
Raised Bed	33 c	21 b	1.26	0.55 a	0.35 b	0.20 a	1.7:1 b
Chisel plough + DD	37 ab	26 ab	1.35	0.53 ab	0.39 a	0.14 bc	2.8:1 ab
Mean	35	24	1.32	0.52	0.38	0.15	2.8:1
CV (%)	4.0	8.9	5.13	4.0	4.0	14.1	20.6
				0.1-0.2 m			
Offset double disc (DD)	35^{ns}	22 ab	1.63 ab	0.48 a	0.36^{ns}	0.13 b	2.9:1 b
Fluted coulter disc	35	22 ab	1.64 a	0.42 b	0.36	0.06 c	5.7:1 a
Knife	35	23 a	1.37 c	0.52 a	0.37	0.20 a	1.9:1b
Knife + M	34	21 b	1.35 c	0.51 a	0.35	0.16 ab	2.1:1 b
Raised Bed	35	22 ab	1.40 bc	0.52 a	0.35	0.16 ab	2.1:1 b
Chisel plough + DD	35	21 b	1.30 c	0.52 a	0.36	0.16 ab	2.2:1 b
Mean	35	22	1.45	0.49	0.36	0.15	2.8:1
CV (%)	3.5	3.5	6.9	4.6	3.4	12.1	19.75

^{ns}: no significant at $p \leq 0.05$. Means not followed by the same letter in the column differ by the Tukey test at 5 % probability. [(1)] Plant development stage. The methods used were according to Donagema et al. (2011); θ_{FC} and AW: determined by Richards extractor device (Soils Moisture Equipment); BD: volumetric method; TP: calculation method with particle density; Mi: table method: 0.6 m tension; Ma: difference between TP and Mi; M: press wheel mechanism for ground leveling.

double disc system. Use of the knife runner opener near the planting row led to lower BD and greater TP in the 0.1-0.2 m layer, which is also the layer with the greatest amount of macropores in the deep tillage system.

Furthermore, the systems tested in this study influenced maximum water storage in the soil in the 0.0-0.2 m layer, and water infiltration capacity in both crop seasons. The offset double disc and the fluted coulter disc systems led to lower water storage capacity in the V6 and R3 stage (Figure 2a). In the knife runner opener, raised bed, and chisel plough systems, there was water storage capacity of 8, 9, and 6 mm, respectively, which is higher than the average of the double disc at V6, which was 11, 12, and 11 mm, respectively, which, in turn, was higher than the capacity of the offset double disc at R3. Similar results were found in the 2014/15 season (Figure 2c) in the evaluation at R3 in the knife runner opener, raised bed, and chisel plough systems, where the soil exhibited a water infiltration capacity of 12, 6, and 7 mm, which is higher than in the offset double disc system. Water infiltration capacity (Figure 2d) was highest for the chisel plough system, followed by the knife runner opener and raised bed systems (2013/14 season). These systems increased infiltration capacity by 97, 31, and 15 %, respectively, compared to the average of systems using offset double disc and fluted coulter disc. In the 2014/15 season, the increase was 173, 57, and 18 % for these same systems.

Overall, comparing the average values of all tillage systems in both seasons and evaluation periods with offset double disc values in the 0.0-0.1 m layer, there was an overall 10 %

Table 4. Soil water retention at field capacity (θ_{FC}), available water (AW), bulk density (BD), total porosity (TP), microporosity (Mi), macroporosity (Ma), and Mi/Ma ratio in the treatments at different soil depths. Santa Maria, Brazil. Experiment 1 in the 2014/15 crop season

Tillage system	θ_{FC} (-10 kPa)	AW	BD	TP	Mi	Ma	Mi/Ma
	mm		Mg m^{-3}	m^3 m^{-3}			
				R3[1]			
				0.0-0.1 m			
Offset double disc (DD)	36^{ns}	24^{ns}	1.58 a	0.38 b	0.33^{ns}	0.05 c	5.9:1 a
Fluted coulter disc	35	23	1.31 b	0.48 a	0.32	0.14 b	2.3:1 b
Knife	34	22	1.19 b	0.53 a	0.30	0.21 a	1.3:1 b
Knife[1]	36	23	1.34 b	0.47 a	0.32	0.15 ab	2.1:1 b
Raised Bed	35	23	1.34 b	0.47 a	0.32	0.15 ab	2.1:1 b
Chisel plough + DD	36	24	1.31 b	0.49 a	0.31	0.18 ab	1.7:1 b
Mean	35	23	1.34	0.47	0.32	0.15	2.6:1
CV (%)	4.6	8.3	7.38	8.26	7.6	19.5	30.47
				0.1-0.2 m			
Offset double disc (DD)	34^{ns}	23^{ns}	1.66 a	0.35 c	0.31^{ns}	0.07 c	4.5:1 a
Fluted coulter disc	34	22	1.54 ab	0.39 bc	0.29	0.09 bc	3.0:1 ab
Knife	36	23	1.37 c	0.46 a	0.32	0.13ab	2.3:1 b
Knife[1]	39	26	1.45 bc	0.43 ab	0.31	0.11 abc	2.7:1 b
Raised Bed	35	22	1.50 abc	0.41 abc	0.30	0.11 abc	2.8:1 b
Chisel plough + DD	34	22	1.40 bc	0.45 ab	0.30	0.15 a	2.2:1 b
Mean	35	23	1.49	0.41	0.31	0.11	2.9:1
CV (%)	11.0	16.7	4.76	6.77	6.15	18.72	21.8

^{ns}: no significant at $p \leq 0.05$. Means not followed by the same letter in the column differ by the Tukey test at 5 % probability. [1] Plant development stage. The methods used were according to Donagema et al. (2011); θ_{FC} and AW: determined by Richards extractor device (Soils Moisture Equipment); BD: volumetric method; TP: calculation method with particle density; Mi: table method: 0.6 m tension; Ma: difference between TP and Mi; [1]knife runner opener 0.05 m from the planting row.

reduction in soil BD compared to the offset double disc system, as well as a 13 % increase in porosity and 76 % increase in soil macroporosity compared to the offset double disc.

In the 0.1-0.2 m layer, BD decreased by 11 % comparing the average of all systems with the offset double disc. In addition, there was an increase of 11 % in TP and 35 % in Macro in the average of all systems compared to the offset double disc.

As a result, the offset double disc had the lowest grain yield, with an average yield of 4082 and 3759 kg ha^{-1} in the 2013/14 and 2014/15 crop season, respectively, compared to the knife runner opener raised bed, and chisel plough systems, where the grain yield values were 4405, 4345 and 4484 kg ha^{-1} for the 2013/14 season, respectively, and 4327, 4013, and 4749 kg ha^{-1} for the 2014/15 season, respectively (Sartori et al., 2015).

Experiment 2

Soil physical properties (Table 2) also indicated the presence of compacted soil up to the depth of 0.2 m, which was more evident in the 0.0-0.1 m layer. Noteworthy is the high value of BD, over 1.6 Mg m^{-3}, and the low macroporosity, less than 0.05 m^3 m^{-3}, in both layers. Moreover, in both layers evaluated (0.0-0.1 and 0.1-0.2 m), the density values observed were higher than the restrictive reference density values for plant and root growth (Table 2), which can also be observed by the degree of compaction (DC) higher than 100 %.

This experiment did not show any differences in soil water retention and availability and microporosity in the soil during the V6 stage (Table 5). During the same period of evaluation, there was a lower BD and micropore/macropore ratio for knife runner opener and chisel plough systems. Moreover, these systems led to an increase in Macro and TP compared to the offset double disc and fluted coulter disc systems in the 0.0-0.1 m layer. In the 0.1-0.2 m layer, the knife runner opener system caused the greatest reduction in BD and the micropore/macropore ratio, as well as

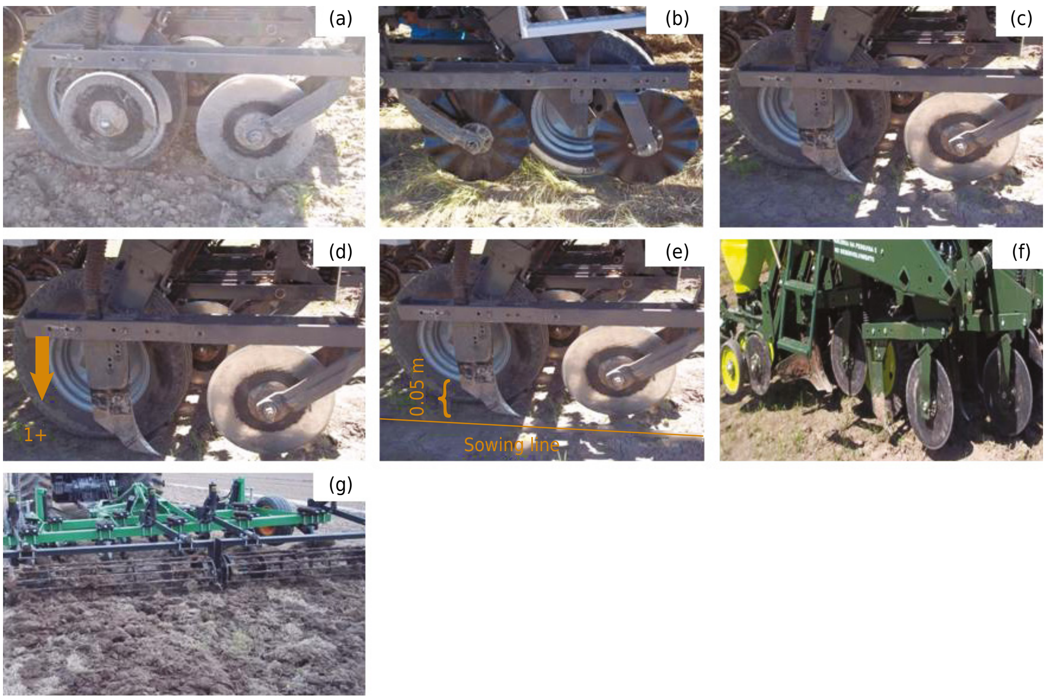

Figure 1. Tillage systems used for soybean: sowing with offset double disc (a); sowing with a fluted coulter disc (b); sowing with a knife runner opener (c); sowing with a knife runner opener + press wheel mechanism for ground levelling (1) (d); sowing with knife 0.05 m from the planting row (e); raised bed system (f); and chisel plough + sowing using an offset double disc (g). Arrow indicates position in which the soil press wheel mechanism for ground levelling was placed.

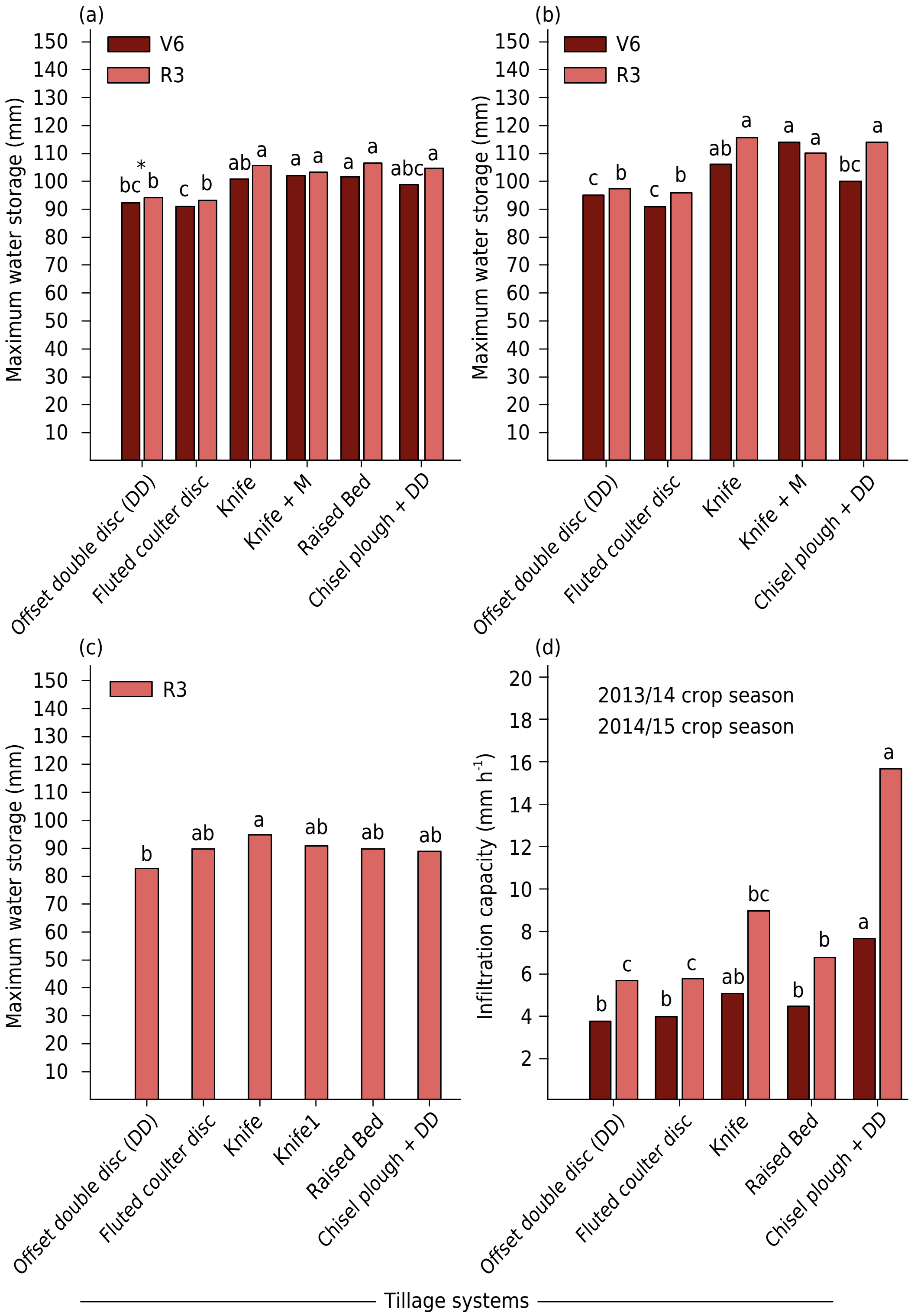

Figure 2. Maximum water storage in the soil at 0.0-0.2 m as a function of tillage systems in V6 and R3 plant growth stages in Santa Maria, 2013/14 (a) and 2014/15 (c) crop seasons; and Formigueiro 2013/14 crop season (b). Water infiltration capacity in soil in Santa Maria, Brazil (d). Experiment 1, 2013/14 and 2014/15 crop seasons. Bars followed by the same letters do not differ significantly by the Tukey test at 5 % probability.

increased TP and Macro of the soil. In stage R3, in both the 0.0-0.1 and 0.1-0.2 m layers, the offset double disc and fluted coulter disc systems showed the highest BD values and micropore/macropore ratio. In addition, these systems exhibited increased micropores in the 0.0-0.1 m layer. For the knife runner opener and chisel plough systems, there was a reduction in BD, an increase in TP and Macro, and a reduction in the micropore/macropore ratio.

Table 5. Soil water retention at field capacity (θ_{FC}), available water (AW), bulk density (BD), total porosity (TP), microporosity (Mi), macroporosity (Ma), and Mi/Ma ratio in the treatments at different soil depths. Formigueiro, Brazil. Experiment 2 in the 2014/15 crop season

Tillage system	θ_{FC} (-10 kPa)	AW	BD	TP	Mi	Ma	Mi/Ma
	mm		Mg m^{-3}	m^3 m^{-3}			
			V6[1]				
			0.0-0.1 m				
Offset double disc (DD)	33^{ns}	24^{ns}	1.46 ab	0.43 ab	0.35^{ns}	0.08 ab	5.1:1 ab
Fluted coulter disc	35	26	1.55 a	0.39 b	0.36	0.04 b	8.6:1 a
Knife	31	23	1.29 b	0.49 a	0.34	0.16 a	2.4:1 b
Knife + M	31	23	1.30 ab	0.49 ab	0.33	0.16 a	2.1:1 b
Chisel plough + DD	32	26	1.27 b	0.50 a	0.35	0.19 a	2.3:1 b
Mean	33	25	1.4	0.46	0.34	0.12 a	4.1:1
CV (%)	6.5	6.3	8.2	9.5	7.4	39.9	40.8
			0.1-0.2 m				
Offset double disc (DD)	35^{ns}	24^{ns}	1.46 a	0.43 b	0.35^{ns}	0.07 b	5.3:1 a
Fluted coulter disc	34	28	1.47 a	0.42 b	0.37	0.07 b	5.6:1 a
Knife	33	27	1.28 b	0.50 a	0.34	0.16 a	2.1:1 b
Knife + M	32	23	1.31 ab	0.49 ab	0.34	0.15 a	2.3:1 b
Chisel plough + DD	33	25	1.38 ab	0.46 ab	0.35	0.12 ab	2.9:1 ab
Mean	33	25	1.38	0.46	0.35	0.11	3.6:1
CV (%)	8.8	9.2	5.4	6.3	8.9	21.1	32.2
			R3[1]				
			0.0-0.1 m				
Offset double disc (DD)	37 a	26 ab	1.43 ab	0.44 bc	0.36 a	0.07 a	5.2:1 a
Fluted coulter disc	38 a	27 a	1.57 a	0.38 c	0.37 a	0.05 a	6.9:1 a
Knife	31 b	23 bc	1.30 bc	0.49 ab	0.32 ab	0.17 b	2.0:1 a
Knife + M	30 b	22 c	1.28 c	0.50 a	0.30 b	0.19 b	1.7:1 b
Chisel plough + DD	32 b	24 abc	1.21 c	0.52 a	0.32 ab	0.20 b	1.7:1 b
Mean	33	24	1.36	0.47	0.34	0.14	3.5
CV (%)	6.0	6.0	4.8	5.62	6.4	23.4	37.9
			0.1-0.2 m				
Offset double disc (DD)	37^{ns}	27^{ns}	1.52 a	0.40 b	0.37^{ns}	0.04 b	9.5:1 a
Fluted coulter disc	38	27	1.54 a	0.40 b	0.37	0.04 b	10.6:1 a
Knife	35	27	1.22 b	0.52 a	0.36	0.16 a	2.3:1 b
Knife + M	35	25	1.22 b	0.52 a	0.36	0.16 a	2.2:1 b
Chisel plough + DD	33	28	1.22 b	0.52 a	0.36	0.16 a	2.5:1 b
Mean	36	27	1.35	0.47	0.36	0.11	5.4:1
CV (%)	8.9	15.0	6.9	7.6	12.1	28.2	35.7

^{ns}: no significant at $p \leq 0.05$. Means not followed by the same letter in the column differ by the Tukey test at 5 % probability. [1] Plant development stage. The methods used were according to Donagema et al. (2011); θ_{FC} and AW: determined by Richards extractor device (Soils Moisture Equipment); BD: volumetric method; TP: calculation method with particle density; Mi: table method: 0.6 m tension; Ma: difference between TP and Mi; M: press wheel mechanism for ground leveling.

Furthermore, the shank and deep tillage systems showed greater water storage in the soil compared to the offset double disc system. These systems showed an increase of 11 and 5 mm in V6, and 18 and 17 mm in R3 in water storage, respectively, compared to the offset double disc system.

In the 0.0-0.1 m layer, considering the average values for fluted coulter disc, knife runner opener , knife runner opener + press wheel mechanism for ground levelling, and chisel plough systems in both evaluation periods, there was a 7 % reduction in BD in relation to the offset double disc system. Moreover, in the double disc system, the TP and macropores in the soil were 8 and 93 %, respectively, which is lower than the averages of the other systems. These systems in the 0.1-0.2 m layer reduced BD by 11 % when compared to the offset double disc system, and showed an increase from 15 to 132 % in TP and Macro.

Therefore, grain yield in the offset double disc system had the lowest average, with an average yield of 2642 kg ha^{-1}, compared to the knife runner opener system, which was 2970 kg ha^{-1}, and the chisel plough system, which was 2698 kg ha^{-1} (Sartori et al., 2015).

DISCUSSION

The soils on which the experiments were preformed have a layer of high BD near the soil surface. The 0.1-0.2 m layer in Experiment 1 and the 0.0-0.1 m layer in experiment 2 stand out mainly because of their higher BD values (Nunes et al., 2014), which resulted in poor aeration porosity (Gubiani et al., 2014; Nunes et al., 2014). This may be related to the fact that, in Experiment 1, the area was used for growing irrigated rice, where decompaction of the soil occurred as deep as 0.07 m, mainly due to the tillage practice of discing (Munareto et al., 2010). This partially explains the lower density of the surface layer (0.0-0.1 m) in the area of Experiment 1. The increased BD values in the 0.1-0.2 m layer may be associated with the fact that the areas in which Experiment 1 took place were systematized in both crop seasons. In a study carried out by Nunes et al. (2002) in Albaqualf soils in the municipality of São João do Polêsine about 40 km northeast from the town of Santa Maria, researchers found that systematization increased soil subsurface density, due to the traffic of heavy machinery. Similarly, Parfitt et al. (2014) found that the average BD of 1.60 Mg m^{-3} (prior to systematization) changed to 1.67 Mg m^{-3} as result of the systematization process and machine traffic. Thus, a denser soil layer in the areas of Experiment 1 may also be associated with the systematization process of the area. In addition, the study carried out by Pedrotti et al. (2001), evaluating the compaction of an Albaqualf soil under different management systems, found that all of the tillage systems evaluated had soil mechanical resistance to penetration values higher than 2.0 MPa, especially in the 0.1-0.2 m layer, and maximum resistance values were observed in the management system with continuous irrigated rice crops. According to the same author, conventional tillage contributes to physical degradation of the soil due to increased soil mechanical resistance to penetration.

In Experiment 2 of this study, beef cattle were raised in the area prior to the experiment; due to cattle trampling, the higher density layer was concentrated closer to the soil surface. A study conducted by Capurro et al. (2014) found a higher density in the 0.09 to 0.12 m layer and associated this result with accumulation of pressures imposed by animal trampling. Another study by Vzzotto et al. (2000), also evaluating the changes in physical properties of an Albaqualf soil subjected to cattle trampling, found reduced porosity and increased BD in the top 0.05 m layer.

The effects of tillage systems in reducing soil compaction in planting rows were more expressive in the deeper layer (0.1-0.2 m). This may be associated with the presence of higher organic matter content in soil surface, greater microorganism activity and wetting and drying cycles that contribute to differentiation between the soil layers (Drescher et al., 2011), and higher root volume, which do not allow significant changes in BD (Capurro et al., 2014). In addition, from the uppermost soil layer to approximately 0.07 m in depth, the effect of tillage equipment on the soil is greater (Munareto et al., 2010), which contributes to a reduction in soil compaction. The double and notched disc tillage systems had the least impact on reduction in BD in the soybean crop in the planting row, and this can be explained by less action in depth and lateral soil movement in the planting row of these systems compared to the knife runner opener raised bed, and chisel plough systems.

However, the fluted coulter disc, by having a larger contact area, could also be an important tool for soil decompression in the planting row. A study conducted by Santos et al. (2010) found that notched discs affected the soil less than flat blades. According to these authors, these results may be due to the fact that there is no additional load on the equipment to increase its penetration in the soil. In this regard, Mion and Benez (2008), evaluating the efforts of five furrow opening mechanisms (even discs, corrugated discs, undulated discs, double discs, and shanks) with variation in vertical load, found that the shank promotes greater soil mobilization with less horizontal effort, reaching higher work depths because only the tip of the shank promotes resistance.

As for the discs, according to the Mion and Benez (2008), more power is needed for them to penetrate, cut through soil and straw, and overcome rolling resistance and friction on the sides of the discs. These authors found that the wave disc showed the greatest lateral force values in relation to other mechanisms for vertical loads of 1500, 2250, and 3000 N. Considering the average of all vertical loads in absolute numbers, the soil area mobilized by the corrugated disc was second only to the shank. Thus, in our study the reduced impact of the fluted coulter disc system can be partially explained by the lack of load on the seeder to provide greater penetration and decompression effect on the compacted soil layer.

Offset double disc and fluted coulter disc were less effective in reducing BD and increasing Macro, as observed in both experiments. In contrast, shank, raised bed, and chisel plough systems had positive effects in terms of reducing BD and increasing the percentage of macropores and TP. This response may be associated with the different working depths of the systems. The soil depth for the shank was approximately 0.18 m at the time of sowing, 0.12 m for the raised beds, and 0.25 m for the chisel plough system. The depth of the offset double disc and fluted coulter disc in soil was approximately 0.1 and 0.08 m, respectively.

The lower effect of the offset double disc may be associated with its performance at shallower soil depths (Drescher et al., 2011). The our results are in agreement with those obtained by Koakoski et al. (2007), wherein the breaker type knife system promoted, on average, a 24.3 % increase in soil porosity compared to the offset double disc system. Increasing the depth of action of the shanks (0.17 m) increases the volume of soil favorable to root growth, due to the reduction of the compacted layer in the planting row (Nunes et al., 2014). These authors found that use of the shank leads to increased Macro and TP and BD and resistance to penetration of the compacted layer in the planting row, corroborating the results found in this study. This reduction in BD and consequent increase in TP are related to increased Macro.

Except for Experiment 1 during the 2013/14 crop season, in the offset double disc system, macro was under 10 %, which may be critical since gas flow and water movement in the soil are closely related to Macro to ensure root oxygenation (Silva et al., 2005). This may be related to the maintenance of high levels of BD; soils with lower density have higher porosity (Gubiani et al., 2014).

Soybean tillage systems howed less effect on water retention and availability compared to other variables, possibly because these properties are more influenced by soil properties. Soils with finer particles (clay or silt) and higher organic matter content have higher water retention, because organic matter is important for water availability and retention (Reichert et al., 2009b). Furthermore, Klein and Libardi (2000) report that the soil structure and texture, type and amount of clay, and organic matter content are the factors that affect water availability to crops.

Soil microporosity (Micro) was also little affected in either experiment by the tillage systems evaluated, corroborating results found by Drescher et al. (2011), in which Micro did not respond to soil management practices, because it is a soil characteristic .

An important effect of the tillage systems on the soil was increased water infiltration capacity, especially for the chisel plough and knife runner opener systems. This can be explained by greater reduction in BD in the deepest soil layer studied (0.1-0.2 m) for these systems, and consequent increase in hydraulic conductivity (Camara and Klein, 2005). The changes caused by agricultural use on pore distribution, mechanical properties, and water and gas transport processes within the soil are related to BD (Gubiani et al., 2014). In addition, an increase in BD decreases soil water content (Gubiani et al., 2015).

Increased soil macroporosity with the use of chisel plough, knife runner opener, and raised bed systems may have contributed to increased capacity for water infiltration because water infiltration can decrease when there are compacted layers, due to reduced Macro (Bonini et al., 2011). These results are consistent with studies from Camara and Klein (2005), in which soil tillage to an average depth of 0.25 m increased the water infiltration rate.

Increased infiltration capacity for chisel plough, knife runner opener, and raised bed systems may explain why these systems had greater soil water storage potential. The greater quantity of macropores facilitates drainage and contributes to water storage in the soil layers underlying excess water which infiltrates the tillage layer (Kunz et al., 2013).

Finally, based on the results obtained in the two experiments, chisel plough, knife runner opener and raised bed systems reduce BD in the planting row. These systems improve the hydro-physical characteristics of the soil, such as BD, TP, Macro, infiltration capacity, and water storage in the soil, resulting in higher grain yield in Albaqualf soils with the presence of a compacted layer near the soil surface. The offset double disc and fluted coulter disc systems showed less effect on BD reduction in the planting row under the conditions simulated by these experiments.

CONCLUSIONS

Soybean tillage systems with the use of offset double disc and fluted coulter disc showed less effect of tillage and maintained higher bulk density layer in the planting row.

Chisel plough, raised bed, and knife runner opener systems reduce soil bulk density in the planting row, thus increasing total porosity, macroporosity, and grain yield.

Chisel plough and the use of knife runner opener increase water infiltration rate and storage in the soil.

ACKNOWLEDGMENTS

We would like to thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for providing the first author with a fellowship. We also wish to acknowledge the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for providing a research fellowship to the second author and a doctoral studies grant to the first author, as well as the Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) for providing a scholarship to the third author.

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