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Soil physical properties and root activity in a soybean second crop/maize rotation under direct sowing and conventional tillage

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Abstract

Soil degradation is the result of interactions involving the soil itself, human activity, climate, relief, and vegetation. These can lead to changes in —or even the loss of— certain characteristics of the soil, reducing its present and future productive capacity. The aim of this study was to determine the behaviour of a number of soil physical variables and total organic carbon content, as well as the root activity and yield of crops grown in rotation (soybean in 1998/1999 and maize in 1999/2000) under direct sowing (DS) and conventional tillage (CT) conditions. Root activity was assessed using an isotopic methodology involving the uptake of ^{32}P. The root activity of the soybean crop, which grew under normal rainfall conditions, was greater under CT conditions. That of the maize crop, which grew when rainfall was well below normal, was greater under DS conditions. Bulk density was higher and total porosity lower in the upper 0.10 m of the soil in the DS plots. Conventional tillage led to lower penetration resistance values in the upper layers of the soil profile. No differences in soil total organic carbon were found between the two tillage systems. The soil water content of the upper soil layers was higher under DS. The yield of the soybean crop under CT was 57% higher than under DS. The yield of maize was affected by water deficiency; higher yields were obtained with DS than with CT.

Additional key words: ^{32}P, soil properties, tillage system, yield.

Resumen

Efectos de algunos parámetros físicos y actividad de raíces en una rotación soja de segunda/maíz con siembra directa

La degradación del suelo es el resultado de las interacciones entre la actividad humana y el recurso suelo, clima, relieve y vegetación, produciendo pérdida de las características del suelo, conduciendo a una disminución de su capacidad productiva actual o futura. El objetivo del trabajo fue determinar el comportamiento de algunos parámetros físicos del suelo, carbono orgánico, rendimiento y la actividad de las raíces en una rotación bajo siembra directa (SD) y laboreo convencional (LC). La rotación empleada fue soja (1998/99), maíz (1999/00). Se evaluó la actividad radical mediante la utilización de ^{32}P. En periodos de precipitaciones normales, la actividad radical total fue mayor en LC; cuando existió déficit hídrico, como el ocurrido durante el desarrollo del maíz, la SD mostró una mayor actividad radical total. La densidad aparente fue más alta y la porosidad total más baja en los primeros 0,10 m en las parcelas tratadas con SD respecto de LC. Los tratamientos de LC presentaron una menor resistencia a la penetración en la parte superficial del perfil. El carbono orgánico no mostró diferencias entre los sistemas de laboreo. La humedad del suelo en los horizontes superficiales fue mayor bajo SD. Los rendimientos de soja con LC fueron un 57% superiores a los tratamientos de SD. El rendimiento de maíz fue afectado por falta de agua durante el desarrollo del cultivo, siendo el rendimiento de SD superior al de LC.

Palabras clave adicionales: ^{32}P, propiedades del suelo, rendimiento, sistemas de laboreo.

Introduction

Since the early 1970s, soybean production in Argentina has grown due to improved yields and the increase in the amount of land devoted to this crop (Casas, 1998). In 1970/1971 only 37,700 ha were devoted to soybean production; in 2002/2003 this had risen to 13,000,000 ha (SAGPyA, 2004). Currently, the Argentine crop is among the largest in the world.

The continued cultivation of soybean in rotation with wheat and maize, and eventually sunflower, has

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demanded the generation of a wide range of soil/environmental conservation techniques**.** Although there has been a continuous increase in productivity, the care of soil, water and biological resources has also improved.

Currently, agricultural scientists are searching for new ways to enhance crop production, reduce costs, and improve soil and water conservation while reducing the environmental impact of agriculture. Although this is a long-term endeavour, the goal provides motivation. The practice of crop rotation and conservation tillage, such as direct sowing (DS), is one of the avenues that require exploration (Casas, 2000).

Tillage is a dynamic process that modifies some of the physical, chemical and biological properties of the soil closely related to the development and penetration of roots. Several researchers have reported that soil compaction leads to a reduction in root growth (Vehmeyer and Hendrickson, 1948; Tardieu and Manichon, 1987; Unger and Kaspar, 1994). It has also been observed that this negative effect increases as soil moisture diminishes (Unger and Kaspar, 1994). In contrast with conventional tillage (CT), DS increases the soil water content via the retention of the previous year's stubble (Erenstein, 1996) which offsets the negative effect of compaction. The effect of soil compaction on crops are therefore more noticeable in dry years. Other authors have pointed out that greater soil compaction can lead to reductions of 10-20% in maize yields (Soane *et al.*, 1981; Hillel, 1982).

The total organic carbon (TOC) content of the soil is also enhanced through the practice of DS, which generates a large amount of biological activity. In the long term, soils under reduced tillage can experience an increase in nitrogen availability via the provision of greater amounts of organic matter (Doran, 1980). In agreement with previous investigations performed in other regions (Ball *et al.*, 1996; Thomas *et al.*, 1996), the studies carried out in the humid Pampa have shown an increase in the organic matter content of the surface layers of soils under DS to be associated with greater structural stability and a reduced susceptibility to compaction (Quiroga, 1994).

Conservation tillage (such as DS and other techniques) promotes the accumulation of water in the soil (Chagas *et al.*, 1994; Mon and Irurtia, 1996; Barrios *et al.*, 1996, 1998). Soil water availability is one of the most important factors in maize production, since this crop is very sensitive to water stress between preflowering and the milky stage (Eck, 1986; Abrecht and Carberry, 1993; Andrade, 1993). Studies performed in the USA, reviewed by Allmaras *et al*. (1991), show that yields of maize and soybean under DS always surpass those obtained under CT in well drained soils and in those at some risk of drought. In soils with drainage problems they are normally better with CT. This implies that, under DS, the physical variables of soils with poor internal drainage due to the presence of a very well developed Bt horizon may be less than optimum at sowing and during crop growth.

The aim of the present study was to determine the behaviour of a number of physical variables of the soil, as well as the root activities and yields of crops, in a soybean second crop/maize rotation under DS and CT.

Material and Methods

This work was performed in 1997 at the «La Lomada» estate (Partido de Esteban Echeverría, Province of Buenos Aires, in the subregion of the «Pampa Ondulada») in an upland site with a Mollisol soil (Soil Survey Staff, 1999). The horizon depths were: AP: 0-0.10 m, A: 0.10-0.25 m, AC: 0.25-0.45 m, Bt: 0.45-0.72 m, and BC: from 0.72 m.

The experimental design was completely randomised with three replications for each treatment. The treatments were two tillage systems: DS and CT. Each experimental plot measured 300 m^2 (10×30 m); the entire experimental area covered 3,000 m^2.

From the onset of the study the rotation of crops was: sorghum (*Sorghum vulgare* L.) (1997/1998), wheat (*Triticum aestivum* L.) (1998), soybean [*Glycine max* (L.) Merr] second crop (1998/1999), and maize (*Zea mays* L.) (1999/2000). The data sets for the latter two crops were analysed under CT and DS conditions.

Conventional tillage was undertaken using a mouldboard plough followed by passes with a tandem disc harrow and cultivator. Direct sowing was performed immediately after the harvest of the previous crop (wheat); the plots were sprayed with 48% glyphosate herbicide (4 l ha^{-1}) on December 23, 1998.

Soybean [seed group 5 (4035) DEKALB] was sown on December 29, 1998, using a drill planter (Agrometal TX-7). The seeds had previously been inoculated with powdered *Bradyrhizobium japonicum*. The rate of sowing was 90 kg ha^{-1}; the seeding depth was 30 mm for DS and 50 mm for CT. Weeds were controlled with fluazifop-butyl in the DS plots. Mechanical weed control was performed under CT conditions. Fertilizers were not applied. The crop was harvested on May 2, 1999.

Maize was sown with the same drill planter on October 19, 1999, using six seeds of the hybrid Pioneer (32K61 R21 31S000) per linear meter (0.75 m between rows). Atrazine was pre-emergence applied after sowing (2.5 l ha^{-1}). Fertilizers were not applied. Harvesting was performed on April 30, 2000.

The soil water content was measured with a neutron probe (Troxler 3300). An aluminium tube with a stopper at the bottom end (to isolate it from the water table) was installed at a depth of 1.5 m. To calibrate the neutron probe according to the manufacturer's recommendations, soil samples were taken every 0.1 m, and the soil water content determined by the gravimetric method. Soil water contents in the crop/maize rotation were recorded on 19/3/99, 29/3/99, 25/4/99, 25/5/99, 5/11/99, 20/12/99, 14/1/00, 4/4/00) every 10 cm until reaching a depth of 1 m.

An isotopic methodology was employed to evaluate root activity, using an assimilatable tracer placed at different depths and distances from the plants, using the technique of Jatimliansky *et al.* (1997). The use of ^{32}P, a β^- emitter with a half life of 14.29 d, is appropriate for this type of study since it is a nutrient easily assimilated by plants yet it is scarcely mobile in the soil. A solution of phosphoric acid labelled with ^{32}P [5 ml (22.2 MBq) at each deposition point] was therefore used. Each deposition point was defined by the coordinates of depth and distance from the row. The lateral distance between two consecutive probe holes was equal to or greater than 0.7 m. A polypropylene tube, 5 mm diameter and of variable length according to the depth required to position the ^{32}P, was inserted into each hole and the ^{32}P solution injected. After washing the inside of the tube with 5 ml of water, the top was covered with a plastic cap and the hole sealed with soil. The presence of roots was estimated at the coordinates for four depths (0.1, 0.25, 0.4, and 0.6 m) and three lateral distances (0.1, 0.2 and 0.3 m) from the row; all measurements were performed in triplicate. The aerial part of the plants were harvested for analysis 15 d after the application of the ^{32}P. The samples were dried in an oven until reaching a constant weight. The total phosphorus concentration of ground material was then determined by wet digestion using the method of Jackson (1964). Radioanalysis was performed on the same solution using a Beckman liquid scintillation counter to evaluate the specific activity of the ^{32}P. These determinations were performed during the stage of maximum development of the plants, just before flowering (Racz *et al.*, 1964; FAO/IAEA, 1975; Bohn, 1979; Jatimliansky *et al.*, 1997).

The bulk density of the soil was determined by the cylinder method (Blake and Hartge, 1986). The soil of each plot was sampled at a depth of 0-0.1 m and 0.1-0.2 m after the harvest in all the sowing lines. All samples were replicated six times for each type of tillage. The collected material was dried in an oven at 105ºC until reaching a constant weight (expressed in Mg m^{-3}).

The total porosity was determined from the bulk density data, taking the density of quartz (2.65 Mg m^{-3}) as the mean density of the solid phase of the soil.

The resistance of the soil to penetration at harvest was determined using a cone penetrometer (ASAE S313.1). Three measurements were taken in each plot at a depth of 0-0.1, 0.1-0.2 and 0.2-0.3 m.

The Walkley-Black micromethod (Jackson, 1964) was used to determine the TOC in samples taken after the harvest at a depth of 0-0.1 and 0.1-0.2 m.

At harvest, the plant biomass was determined in three 0.25 m^2 subplots in each plot. The collected material was dried at 70°C until a constant weight was reached. The grains were removed from the pods or corncobs for the determination of the grain weight. The height of the plants and the number of pods per soybean plant were also recorded.

Separate analyses of variance with respect to the effect of bulk density, total porosity, and resistance to penetration (at the different depths) were performed at the beginning and at the end of each crop cycle.

The net total root activity was determined for each crop before flowering. The soil water content was analysed as repeated measures over time (8) and space (10). The GLM procedure (SAS System software: SAS Institute Inc., 2001) was used for all calculations.

Results

Meteorological characterization of the 1998/1999/2000 seasons

During the growth of the soybean crop (January-May 1999), precipitation was normal for the region (Fig. 1). However, during the growth of the maize crop, a period of little rain occurred (October 1999-April 30, 2000).

The triple interaction *date x tillage x soil depth* had no significant effect ($P > 0.05$) on the soil water content. The interaction *date x depth* was significant ($P < 0.05$), therefore the soil water content at the ten depths on

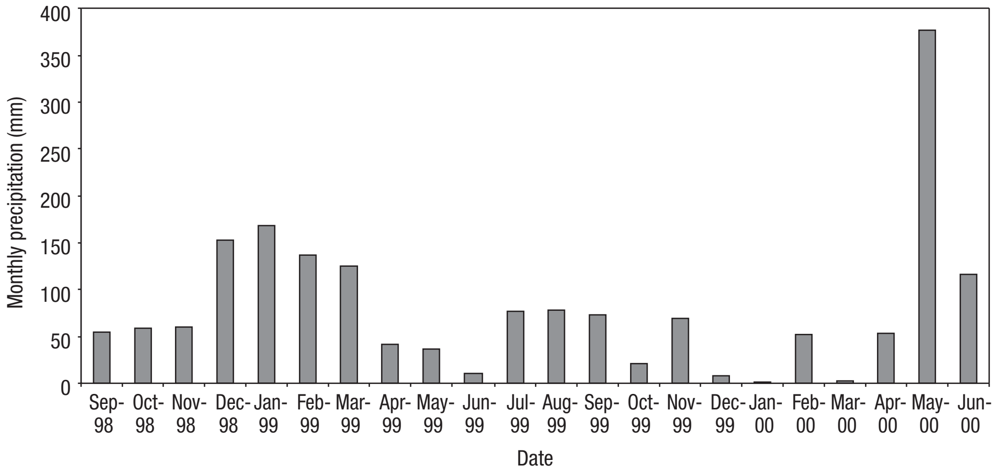

Figure 1. Monthly precipitations during the soybean/maize rotation (1998/1999/2000). *Source:* Chair of Climate. Facultad de Ciencias Agrarias. Universidad Nacional de Lomas de Zamora.

each date was analysed (Table 1). The soil water content in the upper centimetres of the soil profile (down to a depth of 0.4 m) was greater ($P < 0.05$) under DS than CT (Figs. 2 and 3). No significant differences ($P > 0.05$) were seen deeper in the soil profile.

The net total root activity in soybean was significantly higher ($P < 0.05$) under the CT than under the DS conditions. Under DS, the distribution of active roots was greatest at a depth of 0.1 m. It decreased markedly at 0.25 m, but increased gradually again from 0.4 m to 0.6 m. Under CT, the root activity recorded was different; the lowest values were recorded at depths of 0.1 m and 0.25 m, becoming markedly higher after this depth and reaching a maximum at 0.6 m (Table 2).

In maize, significant differences ($P < 0.05$) were seen in the net total root activity between the two tillage systems. Differences were also seen in terms of the distribution of root activity depending on depth. Under CT and DS, maximum root activity was seen at a depth of 0.1 m (Table 2).

The bulk density and total porosity of the soil differed significantly ($P < 0.05$) under the two tillage systems at a depth of 0-0.1 m; under CT conditions the soil showed a lower bulk density and higher total porosity than under DS conditions. At 0.1-0.2 m, no differences in bulk density and total porosity were seen between the tillage systems (Table 3). Significant differences ($P < 0.05$) between tillage treatments were also seen in terms of the soil's resistance to penetration; under DS conditions the soil showed higher resistance to penetration than under CT conditions at all depths and for both crops (Table 4). No significant differences were seen in terms of TOC during the rotation ($P > 0.05$); this was

Table 1. Differences in the soil water content between tillage treatments, depth and date (significance was set at $P < 0.05$)

Depth (cm)	Soybean				Maize			
	19-3-99	29-3-99	25-4-99	25-5-99	5-11-99	20-12-99	14-1-00	4-4-00
0-10	*	*	*	*	*	*	*	*
10-20	*	*	*	*	*	*	*	*
20-30	*	*	*	*	*	*	*	ns
30-40	ns	ns	ns	ns	ns	ns	ns	ns
40-50	ns	ns	ns	ns	ns	ns	ns	ns
50-60	ns	ns	ns	ns	ns	ns	ns	ns
60-70	ns	ns	ns	ns	ns	ns	ns	ns
70-80	ns	ns	ns	ns	ns	ns	ns	ns
80-90	ns	ns	ns	ns	ns	ns	ns	ns
90-100	ns	ns	ns	ns	ns	ns	ns	ns

* Significantly different. ns: not significantly different ($P < 0.05$).

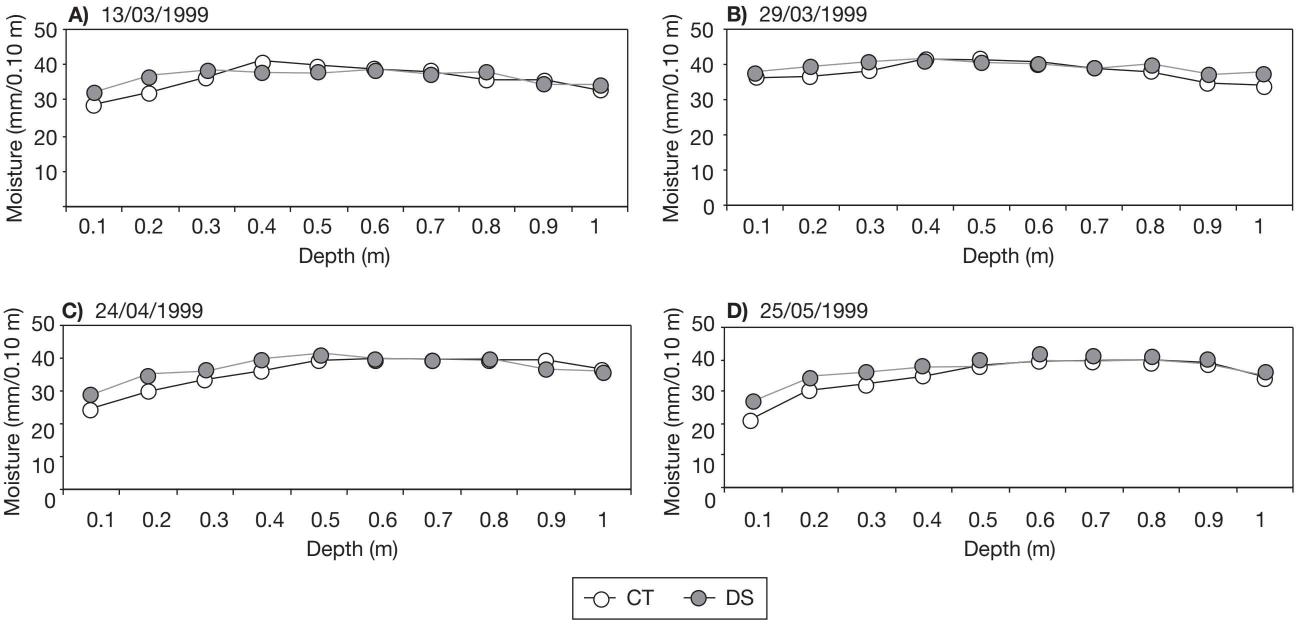

Figure 2. Soil water content during the growth of the soybean crop under direct sowing (DS) and conventional tillage (CT), as measured at different times in 1999: A) 13 March, B) 20 March, C) 24 April, D) 25 May.

not affected by the tillage method, although a slight increase was seen in the DS plots down to a depth of 0.2 m. The grain yield of the soybean second crop was significantly higher under the CT conditions, whereas the grain yield of maize was significantly higher under DS conditions (Table 6).

Discussion

The soil water content in the upper centimetres of the soil profile (down to 0.4 m) was greater under DS conditions; this agrees with results reported by Chagas *et al*. (1994), Barrios *et al.* (1996, 1998), Mon and Irurtia

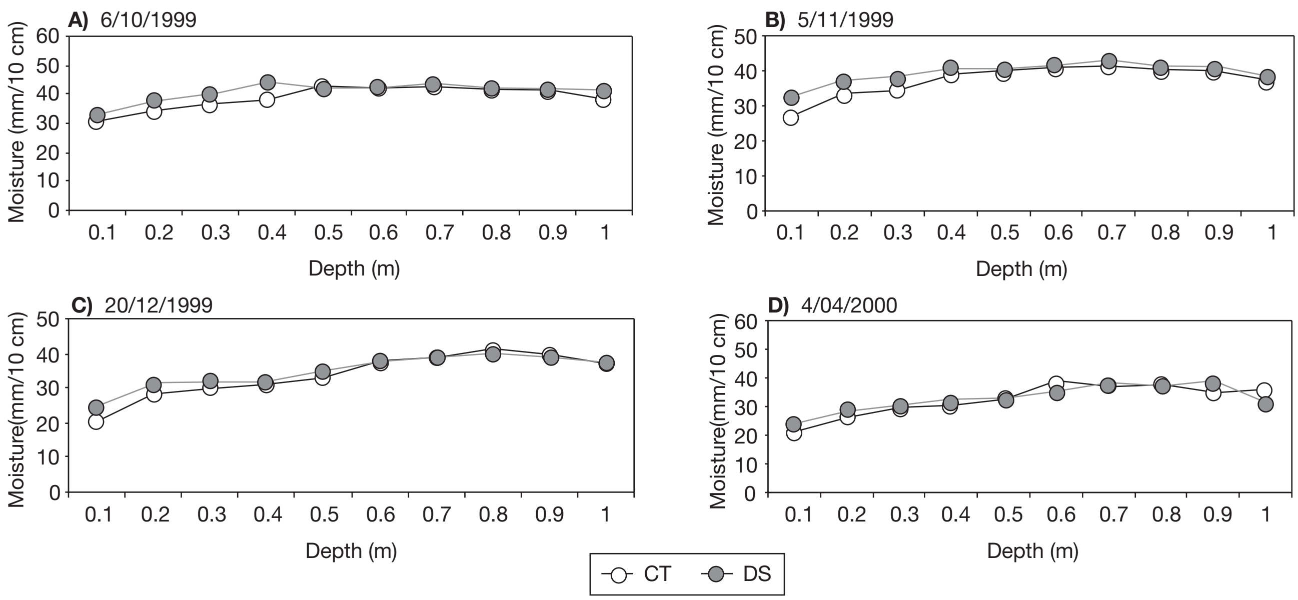

Figure 3. Soil water content during the growth of the maize crop under direct sowing (DS) and conventional tillage (CT), as measured at different times: A) 6 October 1999, B) 5 November 1999, C) 20 December 1999, D) 4 April 2000.

Table 2. Distribution of root activity (%) by depth, and total root activity [counts per minute (cpm)] in soybean (S) and maize (M)

Tillage	Depth (m)								Total root activity (cpm)[1]	
	0.10		0.25		0.40		0.60			
	S (%)	M (%)	S (%)	M (%)	S (%)	M (%)	S (%)	M (%)	S	M
CT	18.33	91.40	15.36	0.30	24.8	8.2	41.49	—	68,033 A	160 A
DS	36.65	68.00	14.12	0.20	19.0	3.90	30.18	28.1	49,630 B	194B

CT: conventional tillage. DS: direct sowing. S: soybean second crop. M: maize. [1] In columns, means with the same letter are not significantly different (P < 0.05).

Table 3. Mean values for bulk density and total porosity according to tillage system and depth

Tillage	Bulk density (Mg m^{-3})		Total porosity (%)	
	0-0.10 m	0.10-0.20 m	0-0.10 m	0.10-0.20 m
Soybean				
CT	1.17 A	1.22 A	56 A	54 A
DS	1.28 B	1.22 A	52 B	54 A
Maize				
CT	1.14 A	1.23 A	57 A	54 A
DS	1.29 B	1.22 A	52 B	54 A

In columns, means with the same letter are not significantly different (P < 0.05).

(1996), and Mora Gutiérrez *et al*. (2001). This greater accumulation of water is possible because of the soil cover provided by the stubble in the DS plots (Wierenga *et al*., 1982). An increased soil water content is regarded as one of the most important advantages of conservation tillage under water stress conditions (Erenstein, 1996).

During periods of normal precipitation, total root activity was greater under the CT conditions. However, during periods of water deficit, such as that experienced during the maize growth period, DS allowed greater root activity; this agrees with that reported by Allmaras *et al.* (1991).

The soil in the plots under DS showed a higher bulk density and lower total porosity than under CT conditions. These results agree with those reported by Bravo and Andreu (1995), Sharrat (1996), and Secco *et al*. (1997).

Direct sowing led to a greater resistance to penetration than CT at all depths, as reported by Hill and Cruse (1985), Vidal (1994), Bravo and Andreu (1995), Elissondo *et al*. (2000), Ferreras *et al.* (2000), Vidal and Costa (2000), Barrios *et al.* (2004) and Rollan *et al.* (2004). The yields of soybean and maize were not affected by the increase in the bulk density and resistance to penetration seen in the upper centimetres of the soil profile since they never reached critical levels.

Table 4. Resistance to penetration (MPa) at different depths

Tillage	0-0.10 m	0.10-0.20 m	0.20-0.30 m
Soybean			
CT	0.4 A	0.64 A	1.12 A
DS	1.2 B	1.3 B	1.38 B
Maize			
CT	0.5 A	1.6 A	1.9 A
DS	1.3 B	2.2 B	3.1 B

In columns, means with the same letter are not significantly different (P < 0.05).

Table 5. Total organic carbon content (g kg^{-1}) in the soybean (1998-1999)/maize (1999-2000) rotation for the two tillage systems at two sampling depths (m)

Tillage system	Soybean		Maize	
	0-0.10	0.10-0.20	0-0.10	0.10-0.20
CT	23.6 A	23.3 A	22.6 A	22 A
DS	25 A	24 A	23.1 A	22.7 A

In columns, means with the same letter are not significantly different (P < 0.05).

Table 6. Mean yields (kg ha^{-1}) achieved with the two tillage systems

Tillage system	Yield	
	Soybean	Maize
CT	2,500 A	2,800 A
DS	1,500 B	4,200 B

In columns, means with the same letter are not significantly different (P < 0.05).

The TOC content was no different in the tillage treatments ($P > 0.05$), although a slight increase in favour of DS was observed, as reported by Barreto (1989) and Poulton *et al.* (1996).

In conclusion, in the upper layers of the soil (down to approximately 0.45 m, where the Bt horizon begins) the water content was higher under DS than under CT conditions. No differences were observed deeper in the soil profile.

The soybean crop under DS showed greater root activity in the upper 0.1 m of the soil profile. However, the total activity of roots was higher under CT conditions. The maize crop showed greater root activity under DS. For the maize crop under CT, nearly all the root activity was in the upper 0.1 m.

Higher bulk density values were observed in the upper 0.1 m of the soil in the plots under DS. At depths over 0.2 m, the bulk density values were similar for both treatments.

Following the crop of wheat, soybean yields under CT were 57% higher than under DS. However maize yields under DS exceeded those achieved under CT, showing that under low precipitation conditions this tillage system favours the development of this crop.

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