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Mitigation of clayey soil compaction managed under no-tillage

Márcio Renato Nunes [a,*], José Eloir Denardin [b], Eloy Antonio Pauletto [c], Antonio Faganello [b], Luiz Fernando Spinelli Pinto [c]

[a] University of São Paulo, "Luiz de Queiroz" College of Agriculture, Avenida Pádua Dias, 11, CEP 13418-900 Piracicaba, São Paulo, Brazil
[b] Embrapa Trigo, Rodovia BR 285, km 294, P.O. Box 451, CEP 99001-970 Passo Fundo, Rio Grande do Sul, Brazil
[c] Federal University of Pelotas, Department of Soil Science, Campus Universitário s/n, P.O. Box 354, CEP 96010-900 Pelotas, Rio Grande do Sul, Brazil

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ABSTRACT

Soil compaction has always been a problem to the agricultural productivity, mainly in clayey soils under the no-tillage (NT). Alternatives to mitigate this problem are necessary. The aim of this study was to evaluate the effect of seeder equipped with fixed shanks openers, working at three depths, in a Ferralic Nitisol (Rhodic), under NT on the mitigation of soil compaction and corn (*Zea mays* L.) plant development. The test comprised three treatments regarding the depth at which the shank openers of a seeder used to sow corn worked: openers reaching up to 0.05 m; openers reaching up to 0.07 m; and openers reaching up to 0.17 m. The effect of these treatments was evaluated in relation to the determination of soil physical parameters, and corn plant parameters. The use of a seeder equipped with fixed shanks openers up to 0.17 m depth caused an increase in soil macroporosity and total porosity, and a decrease in soil bulk density, soil resistance to penetration and degree of compactness in the layer between 0.07 and 0.17 m. The improved physical conditions of the soil in this layer led to a further development of the root system of plants in greater depth, and consequently to a better development of corn plants with higher stalk diameter, root density and root length. The use of a seeder equipped with fixed shanks openers working up to 0.17 m depth, therefore, promoted physical improvement to the soil, favoring the development of corn plants, and presenting potential to mitigate the compaction of clayey soils under NT.

1. Introduction

The no-tillage (NT), adopted in more than 100 million hectares in the world, results in economic and environmental benefits (Derpsch et al., 2010). The compaction of soils managed under NT, however, has been frequently reported (Hubbard et al., 1994; Hamza and Anderson, 2005; Raper et al., 2005; Batey, 2009; Reichert et al., 2009; Nunes et al., 2014a). Soil compaction limits root development of plants (Bengough et al., 2011; Lipiec et al., 2012; Nosalewicz and Lipiec, 2014) which impairs the uptake of water and nutrients (Batey and McKenzie, 2006), consequently causing a decrease in crop yield (Hamza and Anderson, 2005; Chen and Weil, 2011). Alternatives to mitigate this problem are therefore necessary and of worldwide concern.

The profile of soils under NT, mainly clayey soils, typically has a layer, at around 0.07 and 0.20 m deep, characterized by high soil bulk density, high mechanical resistance to penetration of root and low soil permeability to air and water (Shipitalo and Protz, 1987; Reichert et al., 2009; Lahmar 2010; Farooq et al., 2011; Nunes et al., 2014a). These conditions concentrate the crop root system in the topsoil layer, at around 0.0–0.07 m (Reichert et al., 2009; Nunes et al., 2014b). The compacted soil layer (0.07–0.20 m) limits the water extraction from the subsoil to the topsoil layer (Lipiec et al., 2003), where the root system is concentrated leading to the water stress, even in short periods of drought. Buttery et al. (1998) argue that smaller root penetration of compacted soil aggravates the effects of drought and reduces the productivity of soybean (*Glycine max* (L.) Merrill). In Brazil subtropical humid climate region, crop losses are frequent, and, according to Denardin et al. (2008), these are associated to soil compaction under NT.

In general, seeders used in NT are equipped with disk and shanks, in order to open the furrow and lay fertilizer in the soil (Altikat and Celik, 2011; Casão Junior et al. 2012). These openers reach up to around 0.10 m deep, promoting local relief of the soil superficial compaction (Baker, 1976; C haudhuri, 2001 Ros et al., 2011; Silva et al., 2014a). Lower soil density (Kaspar et al., 1991;

* Corresponding author. Tel.: +55 19 999229218.
E-mail addresses: marcio_r_nunes@yahoo.com.br, marcio_r_nunes@usp.com (M.R. Nunes), denardin@cnpt.embrapa.br (J.E. Denardin), pauletto@ufpel.edu.br (E.A. Pauletto), afaganel@cnpt.embrapa.br (A. Faganello), lfspin@ufpel.edu.br (L.F.S. Pinto).

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Damora and Pandey, 1995), lower soil resistance to penetration (Veiga et al., 2007) and better soil structure (Tormena et al., 2008; Silva et al., 2014a) have been reported in the row compared with the interrow on soil under NT. This working depth (0.10 m), however, is not enough to break the compacted layer existing in the soil under NT. Greater depth of action of the planter seeder could therefore be an alternative to break the layer of compacted soil and promote better physical conditions for root development of agricultural crops in soils managed under NT.

In a recent study, Nunes et al. (2014a) observed that the use of seeder equipped with fixed shanks openers working at 0.17 m depth might relieve soil compaction, in the subsurface, in areas under NT. Hypothetically, this would enable the deepening of the crop species root system, thus, decreasing risks of crop losses due to water stress. Nunes et al. (2014a), however, only assessed the effects of the employment of this planter seeder on soil attributes. Therefore, more detailed studies to assess the development of crops sowed with this type of disruptive element soil seeder need to be performed.

The hypotheses presented in this paper are: (i) the use of seeders equipped with fixed shanks openers, working at the compacted layer depth, improve soil physical root growth conditions on clayey soil compaction under NT; and (ii) a seeder equipped with fixed shanks openers, working at the compacted layer depth, improve the development, in depth, of the corn root system. The objective of this study was to evaluate the effect of a seeder equipped with fixed shanks openers, working at three depths, in a Ferralic Nitisol (Rhodic) under NT, on the mitigation of soil compaction and the development of corn plants.

2. Material and methods

2.1. Experimental design and area

The study was carried out at the Embrapa Trigo Experimental Field, in Passo Fundo, Rio Grande do Sul, Brazil (28°11′20″S, 52°19′62″W), in a Ferralic Nitisol (Rhodic) (USDA, 2012) situated at 691 m altitude. The experimental area soil physical characterization, the water dispersed clay (Gee and Or, 2002), and the soil organic carbon (determined through the Walkley–Black method), is found in Table 1. The local relief is gently undulating with 3% slopes in the experimental area. The climate, according to the Köppen classification, is Cfa (subtropical humid), with rainfall well distributed throughout the year ranging from 1300 to 1800 mm year, with higher values in May and June (Nimer, 1989).

Table 1
Physical characterization and organic carbon (OC) of the Ferralic Nitisol (Rhodic) used in the study on mitigation of clayey soil compaction under no-till.

Layer (m)	Clay ($g\,kg^{-1}$)	Silt	Sand	WDC	Pd ($kg\,m^{-3}$)	OC (%)
0.00–0.07	595	193	212	310	2,680	1.91
0.07–0.17	590	201	209	360	2,730	1.31
0.17–0.20	603	190	207	350	2,750	1.24
0.20–0.30	663	166	171	420	2,730	1.17

WDC: water dispersed clay; Pd: particle density.

The experimental area had been under NT for over ten years, in a crop production model comprised by the succession of soybean (*Glycine max* (L.) Merrill) in the summer and wheat (*Triticum aestivum* L.) in the winter. The soil in this area clearly presented physical degradation of the layer between 0.07 and 0.20 m depth, revealed in an expeditious evaluation performed in the field by the method of the cultural profile (Tavares Filho et al., 1999), in 0.3 m deep and 0.3 m wide soil pits.

The field experiment was designed in randomized blocks, with four replications and three treatments, resulting in 12 plots with dimensions of 8 × 6 m each (48 m^2). The species grown throughout the test (September 2009 to February 2012) were: corn (*Zea mays* L.), from September 2009 to February 2010; wheat, from June to November 2010; soybean from November 2010 to March 2011; rye (*Secale cereale* L.), from April to September 2011; and corn, from September 2011 to February 2012. In this period, the summer crops were sown with seeder (Fig. 1a) equipped with a fixed shank opener (Fig. 1b), in order to produce the furrow and also lay the fertilizer into the soil. The treatments comprised the opener depth as follows: T5 = openers reaching up to 0.05 m; T7 = openers reaching up to 0.07 m; and T17 = openers reaching up to 0.17 m. The treatments T5 and T7 represented the depth of action of soil openers typically employed in the subtropical humid climate region in Brazil.

The weight of the seed drill used in this study was approximately 2800 kg while the weight of the tractor used to pull the seeder was around 5000 kg. The speed of the machine for sowing operations was 1.4 $m\,s^{-1}$. The seeder operated with three lines, spaced by 0.60 m, for corn sowing (Fig. 1a), and with five lines, spaced by 0.45 m, soybean sowing. The row direction was the same in all crops, however, the position of the lines varied from one crop to another. The width of the shank that equipped the seeder for sowing soybean and corn was 15 mm. A set of screws (Fig. 1b) allowed the depth of operation of the shank to adjust to the desired

Fig. 1. (a) No-till seeders used to sow the crops in the experiment; (b) fixed shank opener that equipped the seeder for the sowing of soybeans (*Glicyne max* L.) and corn (*Zea mays* L.), and, in detail (S), the set of screws that allowed to adjust the desired depth of operation of the shank.