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Topsoil compaction and recovery in integrated no-tilled crop–livestock systems of Argentina

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ABSTRACT

Cattle trampling during grazing of crop residue may cause physical soil damage that may be repaired when animals are excluded. Understanding the interplay between soil deterioration and natural recovery of the soil physical condition allows for a better understanding of grazing management systems. Various soil physical properties (i.e., bulk density (BD), penetration resistance (PR), infiltration rate, structural instability) were determined up to 20 cm depth in a silty loam Typic Argiudoll and a sandy loam Typic Hapludoll of the Argentine Pampas from 2005 to 2008. Sampling was carried out before and after grazing, and at different moments of the crop cycle including harvest event. Grazing winter residues and weeds did not lead to the expected compaction processes (e.g., in average BD difference between after grazing and before grazing was from −0.072 to +0.137 Mg m^{-3} for both soils under grazing). In general, physical soil conditions improved during winter, independently of grazing. This might be related to the intrinsic soil characteristics (organic matter content, moisture, clay content) or grazing system (stocking rate, duration of grazing period), which prevented soil physical damage, suggesting that recovery forces were greater than grazing stress. Cropping to maize and soybean showed similar value or improved soil physical properties respect to the after grazing (e.g., in average PR difference between before harvest and after grazing was from +409 to −2561 kPa for both soils), acting as biotic a recovery factor. However, massive damage was harvest operation led to the highest soil deterioration (e.g., in average PR difference between before harvest and after harvest was 985 kPa).

1. Introduction

In recent years there has been a strong demand for farming systems to integrate crop and livestock production to avoid environmental problems caused by high cropping intensity and to improve soil quality and ecosystem services provided by soils, testing pastures and crop rotations (Franzluebbers and Stuedemann, 2008; García-Prechác et al., 2004; Fernández et al., 2011). A main risk of integrated crop–livestock systems is the generation of shallow soil compaction, especially in those under no-till management due to absence of mechanical disturbance (Díaz-Zorita et al., 2002; Strudley et al., 2008; Álvarez et al., 2009). A question that still remains regarding this management is the capacity of soils under no tillage to naturally reverse the soil compaction produced by this farming system. This includes how long the process takes for regeneration of topsoil compaction (if it does), and how the process operates in soils with different texture (Greenwood and McKenzie, 2001; Drewry, 2006).

Most studies on soil compaction occurrence and recovery have evaluated both processes in different soil types but in different years and in different climatic conditions, and could not compare between both situations. Drewry (2006) points out the importance of making evaluations in different soil types, but with simultaneous, short-term resilience studies. The exclusion of grazing during certain periods is an effective way to evaluate trampling effects and soil condition recovery (Warren et al., 1986b; Taboada and Lavado, 1993; Greenwood et al., 1998, 1997; Drewry, 2006). Greenwood et al. (1998) found an improvement in physical soil properties due to biological activity and wetting–drying cycles in the absence of animal trampling compaction. Soil physical condition improved when animals were completely excluded (Drewry, 2006) through exclosures (Zegwaard et al., 1998; Singleton et al., 2000; Greenwood and McKenzie, 2001).

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Some authors observed cyclical patterns in topsoil physical properties, characterized by periods of soil compaction by trampling and follow by natural recovery (Drewry et al., 2004; Monaghan et al., 2005). The initial physical condition and intrinsic soil characteristics are determinants of the recovery time of a soil (Nguyen et al., 1998; Nie et al., 1997; McDowell et al., 2004). Greenwood et al. (1998) found soil physical properties improved in 12 months in soils with 20–30% clay content. However, these changes would take longer in coarse-textured soils associated with a drier climate (Braunack and Walker, 1985).

The topsoil structural condition is the result of a dynamic equilibrium between disaggregation (e.g., slaking of aggregates, etc.) and aggregation or regeneration processes (Kay 1990; Drewry et al., 2004). In this balance, natural forces (e.g., texture and clay type, wetting–drying cycles, expansion–contraction processes, etc.), and anthropic forces (e.g., machinery movements, tillage, cattle trampling, etc.) are both involved (Kay, 1990).

In loamy soils, regeneration depends on the combined action of abiotic (i.e., wetting–drying cycles) and biotic mechanisms (Oades, 1993; Taboada et al., 2004). In silty loam soils, fragmentation of a compacted soil by wetting–drying cycles seems to be the necessary first step for regeneration (Taboada et al., 2004). Loamy soils are not completely rigid but are capable of noticeable volume changes and cracking by drying (Barbosa et al., 1999; Taboada et al., 2004). Coarse-textured soils, on the other hand, have a rigid skeleton, in which the biological stabilization is the main aggregate formation process (Oades, 1993).

In integrated crop–livestock production farming systems (ICL), soils alternate periods under pasture with cropping periods. Compaction by trampling can be mitigated by the protection of crop residues, which increase the soil bearing capacity and contribute to reducing damage, caused by cattle transit (Franzluebbers and Stuedemann, 2008).

This study reports the results of a 4 years field study in which the variation of soil physical properties was comparatively analyzed in ungrazed and grazed situations of a silty loam Typic Argiudoll and a sandy loam Typic Hapludoll under no till farming. This approach allowed us to identify and explain anthropogenic and natural effects on soil compaction and regeneration processes. The impact of winter grazing on soil properties are expected to be determined due to soil type, water status during grazing, and amount of residues present.

2. Materials and methods

2.1. Study sites, experimental design and sampling procedure

The study was conducted at two sites located in the northern Pampean Region, in a Typic Argiudoll (33°18′23.3″S; 61°58′2.3″W) and in a Typic Hapludoll (34°03′45.6″S; 62°25′19.4″W). This region has a temperate (mean annual temperature: 17.5 °C) and humid (mean annual precipitation: 1044 mm) climate. Most rainfall occurs in the spring and summer (September–March) and is often low during the winter.

The study was carried out in production farms under integrated crop–livestock systems, based on eight-year corn (*Zea mays* L.)-soybean (*Glycine max* L. Merrill) crop rotation and four years under grass-alfalfa pastures grazed at 5 cow ha^{-1} (average 420 kg cow^{-1}, mean pressure ca. 200 kPa) mean stocking rate. During the cropping period, maize or soybean residues and winter weeds, such as “chickweed” (*Stellaria media* L.) and “hoary bowlesia” (*Bowlesia incana* Ruiz & Pav.) were continuously grazed at of 1.1 cow ha^{-1} mean stocking rate. Livestock was temporarily removed from the fields during heavy rainy periods and definitely removed when ground cover by residues was lower than 60%.

The experiment started four years after a pasture period, i.e., in the middle of a cropping period. The experimental design was completely randomized, with three replicate plots per treatment. Treatments included: (1) grazed (G): grazing of crop residues and winter weeds; and (2) ungrazed (UN): cattle were excluded by electric fences during winter, while normal crop cycles continued. Sampling was carried out over a period of four years (2005, 2006, 2007, 2008) at the following times: (a) before grazing (April–May); (b) after grazing (September–October); (c) during the vegetative stage of maize or soybean; (d) during flowering; (e) before harvest (March). The first sampling year (2005) corresponded to a maize crop, followed by soybean in 2006 and maize in 2007, with the last sample after grazing in 2008.

2.2. Soils characteristics and rainfall during the experiment

The experiment was conducted on two soil types: (a) silty loam Typic Argiudoll; and (b) sandy loam Typic Hapludoll. Table 1 shows total organic matter content (TOM) (determined by the Walkley and Black method at 0–5 cm and 5–20 cm); soil pH (1:2.5, soil: water), and particle size distribution (determined by the pipette method at 0–20 cm layers; Soil Conservation Service, 1972).

Rainfall during the experiment is presented in Fig. 1. In general, lower precipitation was observed during grazing period and the highest precipitation occurred at the end of crop production at the time of harvest operation.

2.3. Determinations

2.3.1. Soil bulk density

Bulk density (BD) was determined with 100 cm^3 cylinders (Burke et al., 1986) before grazing, after grazing and before crop harvest. Four replicates at two depths (0–5 and 5–10 cm) were taken in each experimental unit.

2.3.2. Penetration resistance and soil water content

Soil penetration resistance (PR) was measured before and after grazing, and during the vegetative stage, flowering and before harvest of the crop. Five measurements per experimental unit were taken from 0 to 20 cm depth at 2.5 cm-intervals using a static digital penetrometer (Field Scout SC-900®) with a 30° tip angle. Soil water content (WC) was determined in composite samples at 0–5; 5–10; 10–20 cm depth. The PR and WC data helped establish relationships for the correction of PR, expressing PR at an average WC value for the whole experiment.

2.3.3. Infiltration rate

Field infiltration rate (IR) was determined by the method developed by the Soil Quality Institute (1999). A 15 cm-diameter cylinder was introduced to an 8 cm depth. A 2.54 cm sheet of distilled water was applied to homogenize soil moisture, another

Table 1
Soil characteristics of two soil types: Typic Argiudoll and Typic Hapludoll. Total organic matter at 0–5 cm and 5–20 cm depth; pH, clay, silt and sand content at 0–20 cm depth.

	Typic Argiudoll	Typic Hapludoll
Organic matter content (g kg^{-1})		
0–5 cm	52	34
5–20 cm	31.8	20.2
0–20 cm		
pH (1:2.5)	6.36	6.10
Clay (g kg^{-1})	21.8	11.7
Silt (g kg^{-1})	68.1	39.5
Sand (g kg^{-1})	10.1	48.8