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Changes in topsoil bulk density after grazing crop residues under no-till farming

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ABSTRACT

The grazing of crop residues during the winter in integrated crop–livestock systems can either increase soil bulk density (BD) by compaction or decrease BD by swelling, as a function of gravimetric soil water content (GW) during grazing. A field experiment was conducted from 2005 to 2008 to evaluate the BD response to grazing in a no-till silty loam soil (Typic Argiudoll) of the Pampas region of Argentina. Soil BD (core method), GW data and the calculated air volume (AV) were obtained from the 0–50 mm and 50–100 mm layers at different sampling times from ungrazed and grazed treatments. Over most of the study period (2006 through 2008) soil BD showed little impact from grazing, with minimal temporal variation (1.32–1.46 Mg m^{-3}). This stable behavior was ascribed to low rainfall and relatively low GW values at the time when soil was trampled by livestock and routinely trafficked by machinery. Soil BD in the upper (0–50 mm) layer was significantly ($p<0.001$) lower at the beginning of the study (2005 to early 2006), when the rainfall was higher (as was soil GW) during transit periods. Lower BD was not due to soil swelling but to air that was trapped by kneading in response to transit of livestock and machinery. Fitted straight lines indicated that this process became particularly prominent when GW was >330 g kg^{-1} in the ungrazed treatment and GW was >240 g kg^{-1} in the grazed treatments. Grazing accentuated the soil kneading process that promoted air entrapment. Our results suggest in this no-tilled silt loam soil that winter grazing of crop residues caused no deterioration of topsoil porosity in the no-tilled silty loam soil.

1. Introduction

While integrated crop–livestock systems allow the diversification of agricultural production (Franzluebbers and Stuedemann, 2008), the introduction of livestock in croplands can lead to the compaction of shallow soil. Compaction is caused by the collapse of macropores and the deformation of soil structure (Chanasyk and Naeth, 1995; Greenwood et al., 1997, 1998; Drewry et al., 2000; Singleton et al., 2000). The degree of compaction can be easily assessed by measuring bulk density (BD) (Chanasyk and Naeth, 1995; Greenwood and McKenzie, 2001). The extent to which livestock grazing affects BD is primarily controlled by the water content of the soil when animals are present. When soil is wet or very wet and livestock trampled an area, compaction is likely. The magnitude of compaction often increases when stocking rate is greater and decreases during grazing exclusion periods (Drewry and Paton, 2000; Greenwood and McKenzie, 2001; Drewry, 2006). The probability that compaction will occur decreases in integrated crop–livestock systems when no-till farming is utilized. The presence of crop stubble and debris in no-till fields protects the surface from damage and increases the soil's load-bearing capacity (Franzluebbers and Stuedemann, 2008).

Variability in soil BD is not only due to management factors, but also to natural soil characteristics (Berndt and Coughlan, 1976; Voorhees and Lindstrom, 1984; Franzluebbers et al., 1995). Soil water content is the primary natural factor in fine-textured soils, where volume changes substantially by swelling and shrinking (Jayawarardane and Greacen, 1987; Oades, 1993; Logsdon and Karlen, 2004). The degree to which BD changes with water content depends largely on the percentage of clay and the proportion of expansible minerals (e.g. smectite type of clay) (Parker et al., 1982). Changes in soil volume also occur, although to a lesser magnitude, in soils with a minimum amount of clay (i.e. >8% by weight) (Dexter, 1988). This is the case for many loamy and silty loamy soils found in many fertile plains around the world. The Pampas region of Argentina is one such region, where significant volume changes in water content were found in silty, and silty clay, loams (Taboada et al., 2004; 2008). Soil water content may be an important BD covariable that should be considered for these types of soil when studying management impacts on topsoil porosity. Silty and silty clay loams have been cultivated in the Pampas for about a century, but only in recent years has the grazing of crop residues from the previous year become more common. The impact of grazing on the BD of these soils is poorly understood, as is the interaction with water content.

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Soil BD is usually increased by grazing, as shown in the occurrence of classical, shallow compaction processes (Willatt and Pullar, 1983; Greenwood and McKenzie, 2001; Drewry, 2006). Grazing-induced declines in BD are less common and, when they do occur, are not easily explained. They have been ascribed to the intensive transit of animals on saturated soil. Drewry (2006) distinguished poaching or puddling from pugging or shearing processes. Poaching or puddling can be regarded as the opposite of soil compaction, as it can lead to lower BD through swelling (Mullins and Fraser, 1980). Pugging or shearing have been related to fingerprint marks and are associated with pasture damage. Pietola et al. (2005) observed that the trampling by livestock when soil water content was high causes kneading and homogenization of soil. As a consequence, soil BD decreases and total porosity increases in the most trampled sites. The aim of the present work was to assess, *in situ*, the influence of winter grazing of crop residues by livestock on the relationship between BD and soil water content in silty loam soils that are managed with no-till farming. The *a priori* hypothesis was that soil BD declines as a result of soil swelling during wet periods and that the process is intensified by livestock trampling.

2. Materials and methods

2.1. Site characteristics

The study was conducted from September 2005 to September 2008 at a farm managed with an integrated crop–livestock production system under no-till farming. The farm is located in the northern Pampean Region, called Rolling Pampa (33º 18′ 23.3″ S; 61º 58′ 2.3″ W). This region has a temperate (mean annual temperature: 17.5 ºC) 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 whole study area is covered by a fine silty, thermic Typic Argiudoll (Soil Taxonomy); Luvic Phaeozem (FAO Soil Classification).

The production farm was managed with a crop (8 years)–pasture (4 years) rotation scheme, always no-till. Soils were alternatively cropped to maize (*Zea mays* L.) from mid-October until the end of March, and soybean (*Glycine max* L., Merrill) from mid-November until the end of April. Crop residues and winter weeds (*Stellaria media* L. and *Bowlesia incana*) were yearly grazed during the winter at a nearly constant stocking rate (1.1 cow ha^{-1}). When the winter weeds had substantially diminished, livestock was moved to a nearby pasture field to preserve the agricultural residue ground cover. Herbicides (glyphosate and atrazine) were not applied during winter. After the cropping phase, composite pastures (grass-alfalfa (*Medicago sativa* L.)) were sown using no-till systems. The pasture was grazed under a rotational scheme at stocking rates as high as 30–40 animals ha^{-1}.

2.2. Field treatments and soil sampling

The experiment began 4 years after the end of the pasture period. The study area covered 45 ha of the farm, where two treatments were installed: a) grazed: livestock grazing of winter weeds and crop residues, as usual; b) ungrazed: a fenced area which prevented grazing during the winter. This fenced treatment was considered a control. The experimental design was completely randomized ($n=3$).

Soil samples were collected during the study period on three sampling dates: a) before livestock grazing (BGZ), which usually occurs after harvesting of summer crops in autumn; b) after livestock grazing (AGZ) that usually occurs at the end of winter; and c) before maize or soybean harvesting (HAR).

2.3. Analyses

Soil samples were collected at study initiation to determine: a) soil textural class (particle size analysis using the pipette method); b) clay mineralogy (X-ray diffraction); c) soil pH (1:2.5 distilled water suspension); d) total organic carbon (wet combustion analysis) (Nelson and Sommers, 1996). During the study, rainfall was measured in pluviometers placed near the experiment area.

Soil bulk density (BD) was determined by the core method. During the study, at the BGZ, AGZ and HAR sampling times, three soil cores (5 cm height, 100 cm^3 each) were randomly taken from each treatment and each plot from the 0–50 mm and 50–100 mm layers. Soil gravimetric water content (GW) was determined by oven drying the soil sample at 105 ºC to constant weight. Soil air volume (AV) was calculated using the following equation:

$$AV\,(\%) = 100–(BD\,/\,PD^{*}100)-VW \tag{1}$$

where VW is the volumetric water content of the sample and PD is the soil particle density (2.65 Mg m^{-3}).

Two undisturbed samples of about 8000 cm^3 (10 cm height) were collected with a spade at the beginning of the study (initial) and on the AGZ sampling date in 2005 and 2006 in both ungrazed and grazed treatments. After air drying in the laboratory under constant temperature conditions (25 ºC), soil samples were initially dry-sieved by vibration (4.8, 3.4 and 2 mm screen-opening sieves) and the mean weight diameter of dry-sieved aggregates was calculated. Dry-sieved aggregates were moistened to field capacity and wet-sieved (4.8, 3.4, 2, 1, 0.5, 0.3 mm screen-opening sieves) using a Yoder apparatus; the mean weight diameter was calculated. The change in mean weight diameter between dry-sieved and wet-sieved aggregates (CMWD) represents an index of soil structural instability (Burke et al., 1986).

2.4. Soil kneaded experiment

A field experiment was conducted to simulate the remolding action of cattle hooves on wet soil. Eight large cores (15 cm diameter × 15 cm height) were inserted into the soil to a depth of up to 50 mm in the grazed treatment. These cores were located as proximal pairs, one was used as a control and the other was kneaded by hand. All cores were previously wetted with distilled water and allowed to reach soil–water saturation. Once saturated, the soil of one core per pair was gently kneaded by hand for 2 min, to simulate the action of livestock trampling on wet soil. Therefore, there were two experimental treatments: control (not kneaded) and kneaded. A soil core (100 cm^3) was extracted from the center of each large core to determine soil BD, GW, VW and VA after the treatments were applied.

2.5. Statistical analysis

Trends in BD in the ungrazed and grazed treatments were analyzed as repeated measures over time. We tested three different covariance structures (VC, CSH and ARH(1)) (Littell et al., 1998). The covariance structure VC resulted in the best agreement with the Akaike information criterion (AIC; Akaike, 1974).

Different models were adjusted to describe the BD–GW and the AV–GW relationships. The similarity of models fitted for each treatment was tested through the comparison between: i) a basic model, that describes the BD–GW relationship using one function per treatment (six parameters, three per function) and ii) a restricted model, that describes the BD–GW relationship using only one function for both treatments (three parameters). Differences between the fitted basic and restricted models were analyzed using an f-test (Mead et al., 1993). The calculated parameters of each function were compared using the Student's t, which was computed as:

$$t = \left[(p_1-p_2)\,/\,(s_{p1}-s_{p2})\right] \tag{2}$$