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Critical bulk density for a Mollisol and a Vertisol using least limiting water range: Effect on early wheat growth

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ABSTRACT

The least limiting water range (LLWR) integrates crop growth-limiting values based on easily measurable parameters such as soil water content and bulk density (BD) and has been validated as a valuable soil physical quality indicator for a wide range of soils, crops and management systems. When the LLWR is zero, the soil achieves the critical bulk density value (BDc). Another methodology to assess the level of soil compaction and its effect on crop growth is the shear strength (SS) of the soil. The aims of this work were: i) to obtain critical bulk density values for a Mollisol and a Vertisol using the LLWR and assess their effects on early wheat growth, and ii) to evaluate the variation in early wheat growth as affected by the increases in BD and SS. An experiment in pots containing disturbed soil from an Aquic Argiudoll and a Typic Hapludert was carried out. Soil cores obtained from agricultural paddocks were mechanically compacted to 1.1, 1.2, 1.3, 1.4 and 1.5 Mg m^{-3}. Wheat was grown on half of the pots for two months, and, after that, both shoot and root biomass were measured. LLWR and SS were evaluated in the remaining non-sowed cylinders as a function of the increase in BD. Critical bulk density was 1.44 Mg m^{-3} and 1.37 Mg m^{-3} for the Mollisol and the Vertisol, respectively. Although both soils fit in the same textural class (silty clay loam), the Vertisol has clay dominated by smectite mineralogy. In the Mollisol, wheat growth was limited when BD > 1.4 Mg m^{-3} due to the lack of aeration rather than to the high penetration resistance. The response of early wheat growth to increasing BD differed clearly between soils. In the Vertisol, early wheat growth was not affected by BD due to volumetric changes. The greater differences in volumetric changes between soils were recorded at lower BD values, being higher at 1.2 Mg m^{-3} (16.8%) and lower at 1.4 Mg m^{-3} (2%). Soil shear strength was significantly correlated with BD and was sensitive to soil water changes. Bulk density values higher than 1.35 Mg m^{-3} had high SS values. This measurement also allowed us to obtain a critical value for crop growth, but only for the Mollisol (50 kPa). LLWR and BDc were useful to determine a threshold for early wheat growth only in the Mollisol. These findings provide an interesting platform for the management of soils with similar textural classes and different clay mineralogy, particularly when they are present in the same paddock across the landscape.

Contents

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1. Introduction

Soil degradation is the loss of actual or potential productivity as a result of natural or anthropogenic factors (Lal, 1994). Many reports have highlighted the role of soil compaction as one of the most important causes of soil degradation (Dexter, 2004; Hamza and Anderson, 2005). Water supply, soil aeration, temperature and soil strength on plant roots are negatively affected by soil compaction (Håkansson, 1994; Lipiec et al., 1991; Soane and Van Ouweerkerk, 1995). In addition, soil compaction triggers physiological and morphological alterations in plants, which may lead to reductions in crop growth and yield (da Silva and Kay, 1996; da Silva et al., 1994; Gupta and Allmaras, 1987; Letey, 1985; Sadras et al., 2005).

In order to quantify trends in soil evolution and rates of change across soil type or soil management, soil quality indicators are needed. These indicators can reveal limitations to root growth, seedling emergence, infiltration or water movement within the soil profile by monitoring soil functioning if acceptable ranges or thresholds are established. Based on the concept introduced by Letey (1985), da Silva et al. (1994) proposed the least limiting water range (LLWR) as an indicator of soil structural quality for crop growth. The LLWR integrates crop growth-limiting values based on easily measurable parameters such as soil water content and bulk density (BD) and has been validated as a valuable soil physical quality indicator for a wide range of soils, crops and management systems (Betz et al., 1998; Chan et al., 2006; da Silva and Kay, 1997; Imhoff et al., 2001; Lapen et al., 2004; Leão et al., 2006; Mc Kenzie and Mc Bratney, 2001; Tormena et al., 1998). When the LLWR is zero, the soil achieves the critical bulk density value (BDc) (Imhoff et al., 2001; Leão et al., 2006; Tormena et al., 1999), which indicates that restrictive density affecting root growth and crop yield has been reached (Reichert et al., 2009).

Another methodology to assess the level of soil compaction and to estimate its effect on crop development is the soil shear strength (SS), which is related to BD. Some authors have reported that SS values are closely related to the structural conditions of the soil, such as macroporosity and soil strength (Ball and O'Sullivan, 1982; Carter, 1990). Soil shear strength depends on the cohesive forces between the soil particles and on the frictional resistance produced when the soil is forced to slide over the soil along some shear plane (Draghi and Hilbert, 2006; Hillel, 2005; Léonard and Richard, 2004). As a consequence, SS may be fairly variable according to soil granulometry, mineralogy, and organic and water content.

A pot experiment with soil samples of A horizons from two types of soils (a Mollisol and a Vertisol) was designed to: i) obtain critical bulk density values using the LLWR, and assess their effects on early wheat growth, and ii) evaluate the variation in early wheat growth as affected by the increases in BD and SS.

2. Materials and methods

2.1. Study site and soil

The study was carried out at the Paraná Experimental Station of the Instituto Nacional de Tecnología Agropecuaria (INTA) in Entre Ríos province, Argentina, (31° 51′ S and 60° 31′ W). The region has a sub-humid (annual rainfall ≈ 1000 mm) and temperate climate (annual temperature ≈ 18.3 °C). Winter temperatures are rarely below 0 °C. Predominant soils of the area are Mollisols and Vertisols. Typical, representative soils of our region are Aquic Argiudol (Mollisol) and Typic Hapludert (Vertisol) (Soil Survey Staff, 1999), frequently associated in the regional landscape (Plan Mapa de Suelos, 1998).

2.2. Sample preparation

A completely randomized laboratory experiment was carried out with soil cores (three replicates, n = 60) starting in November 2007. Sixty cylinders (0.085 m high, 0.15 m in diameter) of PVC, 30 for each soil type, with perforated bottoms were filled with soil samples belonging to an A horizon from an fine, illitic, thermic Aquic Argiudoll of the Tezanos Pinto Series (Mollisol) and from a very-fine, smectitic, thermic Typic Hapludert of the Febré Series (Vertisol) (Table 1). Soil samples were extracted from fields conducted under no tillage for at least ten years, during the winter fallow period. Soil samples were air-dried, sieved (2 mm) and placed into the cylinders, to reach a 7-cm high soil column in each cylinder.

Soil samples were compressed with a rammer, by thin layers to assure bulk density homogeneity. Five compaction levels were obtained: 1.1, 1.2, 1.3, 1.4 and 1.5 Mg m^{-3} using different soil weights by volume unit. After that, soil samples were oven-dried at 60 °C for 3 days. Then, distilled water was gradually added with a sprinkler to achieve gravimetric water content at field capacity (θ_{FC}), i.e. 31.5 and 34.5% water content for the Mollisol and the Vertisol, respectively. Careful attention was paid to minimize hydraulic charges and rapid transfer through cracks and the soil–border interface.

Four wheat seeds per cylinder were planted in half of the cylinders (n = 30). Soils were kept at θ_{FC} at laboratory temperature (25 ± 3 °C) during the two-month experiment. Soils were kept at θ_{FC} by daily water additions using a fine spray sprinkler on the soil surface until reaching the desired weight in each pot. Hoagland nutritive solution was added three times a week also using a sprinkler, previous to water additions. Two plants per cylinder were finally the adjusted stand after stage 1 (Zadoks et al., 1974). Two months after the beginning of the experiment, shoots were removed, oven-dried at 60 °C and weighed. Roots were measured washing the soil contained in the cylinder with distilled water and sodium hexamethaphosphate (100 g l^{-1}), oven-dried at 60 °C and weighed. The root/shoot ratio was calculated for each cylinder.

2.3. Soil measurements

The remaining 30 cylinders, which were not cultivated, were allowed to dry by surface evaporation at room temperature (20–25 °C) in the laboratory until soil water near permanent wilting

Table 1
Background soil properties of the Mollisol and the Vertisol studied.

Soil	pH (1:2.5)	OC %	Clay	Sand	Silt	Textural class
			g kg^{-1}			
Mollisol	6.3	2.65	274	63	663	Silty clay loam
Vertisol	7.6	2.74	317	82	601	Silty clay loam

OC: organic carbon.