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Least limiting water range and soybean yield in a long-term, no-till, integrated crop-livestock system under different grazing intensities

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ABSTRACT

Crop-livestock integrated systems possess some uniqueness in soil and plant hydro-physical properties and processes. To obtain a better understanding of these systems, it is necessary to evaluate them with indices that take into account several attributes. Our study aimed to evaluate the efficiency of the least limiting water range in determining the influence of grazing intensities on soybean yield in an Oxisol managed in a long no-till, integrated soybean-beef cattle system. We evaluated an 11 year trial located in southern Brazil, with soybean summer cropping and black oat + Italian ryegrass winter grazing and different winter grazing intensities, namely intensive, moderate and no grazing. Intensive grazing only results in the most superficial soil layer compaction. Long-term moderate grazing, on the other hand, leads to intermediate compaction, not negatively affecting surface or subsurface soil physical properties. The least limiting water range is an inadequate indicator of soil physical quality in integrated soybean-beef cattle system, provided no direct relations with soybean yields. Under normal rainfall conditions, soybean yield depend mainly on rainfall amount and distribution, rather than on soil quality.

1. Introduction

Food insecurity affects an estimated of 825 (Lobell et al., 2008) to 850 million people (Borlaug, 2007) in the world, and 60 million people in South America alone (Borlaug, 2007). Improvements in food production systems are essential for meeting the ever increasing food demand (Lal, 2009).

The state of Rio Grande do Sul, located in the Brazilian subtropical region, contributes significantly to Brazilian meat and grain production (CONAB, 2014). Despite the widespread use of no-tillage (NT) systems in Brazil (Boddey et al., 2010), more diversified food production systems, such as integrated crop-livestock systems (ICLSs), bring more flexibility to the producer (Sulc and Tracy, 2007). Advances in the understanding of ICLSs operation include a holistic perception of the system, in which the animal acts as a catalyst in the soil–plant–animal–machine–atmosphere (SPAMA) system, modifying rates and flows of systemic processes (Anghinoni et al., 2013).

Two converging issues have been reinforced topics on the long-term impacts of ICLSs in the SPAMA system: soil compaction and water availability. Isolated approaches seem inadequate to understand the synergy resulting from feedbacks (Ryschawy et al., 2012) and ecosystem functions in ICLSs (Hendrickson et al., 2008). The definition of a critical degree of soil compaction requires caution because of the difficulty in understanding compaction-crop yield relationships (Collares et al., 2008) and the lack of a “universal best soil physical condition” to plant production (Letey, 1985).

The least limiting water range (LLWR—Silva et al., 1994), a physical-water indicator generated from the non limiting water range concept (Letey, 1985), was proposed as a tool for evaluating the “physical fertility” of the soil. Soil bulk density (BD), an estimator of the LLWR, defines the conditions for plant growth, which may be favorable or critical (Silva and Kay, 1997). However, soil physical quality assessment through the LLWR has been challenged because there is not always a relationship between

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LLWR and crop yield (Gubiani et al., 2013), causing the LLWR to be an inaccurate agronomic index for compaction management.

Soil physical quality assessment through the LLWR in ICLSs depends on sward height, and on the gap between animal removal and soybean sowing in the field (Petean et al., 2010). Grazing impacts on soil organization under ICLSs conditions is not yet fully understood (Logsdon and Karlen, 2004), although moderate grazing intensities seem appropriate for environmental conditions and ICLSs production system, enabling organic carbon accumulation (Assmann et al., 2014) and not limiting soil exploration by the roots of intercrops. Grazing cycle affects the yield of subsequent crops, with post-grazing grain yields under moderate-grazing conditions being higher than observed in non-grazed areas (Moraes et al., 2014).

The concept of available water (AW) used in constructing the LLWR has been examined because of the following limitations: field capacity (FC) and permanent wilting point (PWP) (Ruiz et al., 2003), and hysteresis phenomena occurring during water absorption by roots (Reid et al., 1984). Changes in soil physical and chemical properties in ICLSs, with increased resistance to water loss by evaporation, result from partial consolidation of the soil surface during drying (Veiga et al., 2010) and operational (Reszkowska et al., 2011) and structural changes (Martinez and Zinck, 2004) due to trampling, explaining possible benefits of soil compaction (Bouwman and Arts, 2000).

Our study aimed to evaluate the efficiency of the LLWR in determining the influence of grazing and its intensity on soybean yield in an Oxisol managed for 11 years in no-till, integrated soybean-beef cattle system.

2. Materials and methods

This study was started in May 2001 and conducted in São Miguel das Missões county in the state of Rio Grande do Sul, southern Brazilian. The soil is classified as Rhodic Hapludox. The site elevation is 465 m, and the climate is characterized as humid subtropical warm (Cfa) according to the Köppen classification (Kottek et al., 2006), with an average annual temperature of 19 °C and an average annual rainfall of 1850 mm (CEMETRS, 2013). Before starting the experiment, the area had been managed since 1993 under a no-tillage system with black oat pasture (*Avena strigosa* Schreb) during winter, and a summer soybean crop (*Glycine max* (L.) Merrill). The area was first used for animal grazing during the winter of 2000. In the fall of 2001 after soybean harvest, the experiment was started with the establishment of grazing on a mixture of black oat plus ryegrass (*Lolium multiflorum* Lam.).

The treatments included different sward heights, namely 10, 20, 30 and 40 cm, distributed in a randomized block experimental design with three replicates. Intense and moderate grazing intensities were used, corresponding to grazing sward heights of 10 and 20 cm, respectively, in addition to non-grazed plots (NG) used as a reference. The choice of these two grazing intensities was based on observations over the years using this protocol, that is, high (10 cm) and moderate (20 cm) intensities chosen to represent inadequate and adequate management, respectively, for maintaining the energy flow balance in this food production system (Anghinoni et al., 2013). Grazing cycles prior to the beginning of this study were assessed to characterize the influence of grazing intensity under the initial assessment conditions (Kunrath, 2014).

Neutered male steers (crossbred Angus, Hereford and Nellore) approximately 12-months old entered the pasture system weighing approximately 200 kg to simulate a cattle fattening or finishing system. During the grazing cycle cattle feeding was forage-based, and they were only furnished with mineral salt. A continuous grazing system was adopted (with a minimum of three remaining steers = test steers), and grazing began when the forage height reached approximately 20 cm (approximately 1.5 Mg of dry matter ha^{-1}). Therefore, each grazing cycle was carried out from the first half of July to the first half of November. Pasture heights were controlled every 14 days by the Sward stick method (Barthram, 1986), which consists of a graduated stick measuring system with a "marker" that slides up and down until the first forage leaf blade is reached. In each plot, approximately 100 randomized readings (points) were conducted. The average pasture height resulted from managing the grazing intensity (stocks) by adding or removing steers from each plot as required.

The samplings were conducted in all treatments only in the first block due to the plot size (averaging 1.8 ha) and the necessity of other monitoring assessment (the current study is part of a broader study regarding also soil moisture and plant physiological parameters). Soil samples were collected on November 2°, 2011, at depths of 0–5, 5–10, 10–20, 20–30 and 30–50 cm in the 10, 20, 30 and 40 cm treatments, one day after removal of the animals from the experimental area, and in the NG reference area.

Trenches were dug after animals' removal from the field, and four undisturbed soil samples were collected per soil layer (totaling 100 samples), using soil core rings with 0.057 m diameter and 0.04 m height. Subsequently, the samples were wrapped in plastic wrap, packed in styrofoam boxes and transported to the laboratory, where soil penetration resistance (PR, MPa), BD ($g\,cm^{-3}$) and volumetric water content (Θ_V, $m^3\,m^{-3}$) were determined.

2.1. Soil analyses

To determine the LLWR, soil samples were saturated and equilibrated to water tensions (Ψ_s) of 0.001, 0.006 and 0.01 MPa in sand columns (Reinert and Reichert, 2006) and to 0.03, 0.1, 0.5 and 1.5 MPa in Richards' chambers (Klute, 1986). For each tension, 14 samples were collected from 0 to 5, 5–10, 10–20, 20–30 and 30–50 cm soil layers, from the areas of different grazing intensities including the 10, 20, 30 and 40 cm heights and the NG area, and grouped to produce a wide range of BD values. The samples were removed from tension equipment after drainage, weighed, and subjected to PR testing.

Soil samples PR was measured at a constant penetration speed of 10 mm min^{-1} with a bench top, electronic penetrometer with a metal rod with basal area of 129 mm^2, base diameter of 12 mm, and angle of 30° (Reinert et al., 2007). The BD and Θ were calculated after the soil mass drying at 105 °C for 24 h. The PR, BD and Θ data were fitted to Busscher's model (1990): $PR = aBD^b\Theta^c$, where a,b and c are the fitting coefficients.

Soil water retention curve (WRC) was obtained from the same samples used to measure soil PR. Thus, water content of soil samples was measured without changing soil structure during the penetration test. The WRC model was fitted to the Θ, Ψ and BD data, $\Theta = \exp(d + eBD)\Psi^f$, where d, e and f are the fitting parameters. The LLWR was determined as described by Leão et al. (2005). For the upper limit, a Θ value of 0.01 MPa (Θ_{FC}) was used for Ψ or for an air-filled porosity of 10% (Θ_{AFP}). For the lower limit of the PR, a Θ value of 2 MPa (Θ_{PR}) was used, and for the permanent wilting point moisture (Θ_{PWP}), 1.5 MPa was used. The LLWR was calculated as the difference between the upper and lower limits of water contents for the considered physical parameters. The upper limit is the lowest value of Θ considered for the FC or for AFP of 10%, and the lower limit is the highest value of Θ for a PR of 2.0 MPa or for PWP. The penetration resistance and water retention models were fitted using PROC REG (SAS Institute, 1999).

Soil particle size analysis was performed with the pipette method after soil dispersion with 1 mol L^{-1} NaOH. The H_2O_2 treatment was not performed to remove organic matter from soil.