Soil & Tillage Research 176 (2018) 85–94

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Research paper

Soil quality under conservation practices on farm operations of the southern semiarid pampas region of Argentina

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ARTICLE INFO

Keywords:
Reduced tillage
No-till
Soil properties

ABSTRACT

Field observations of no-till production plots in the southern semiarid pampas region of Argentina question the sustainability of this practice from the soil quality (SQ) standpoint when the amount of residues left by typical crop rotations is not taken into account. Our aim was to evaluate a set of management practices as they have been implemented on farm operations of the region on SQ parameters of the surface soil. The six production systems identified represent the combinations of tillage systems (no − till, NT and reduced till, RT), time since implementation (10 or 15 years), rotations (WW, winter crops; WF, winter crops with extended fallow; WS, winter and summer crops) and soil types (sandy loam or loam to clay loam) found in the agricultural operations of local producers. Composited soil samples at three successive depths (0–5 cm, 5–10 cm and 10–18 cm) were taken in 27 production plots of ~50 ha in size each, and analyzed for soil chemical, physical and biological properties. Our results showed when including sunflower as summer crops on the dominant sandy loams, that NT production plots had the lowest total organic carbon (TOC) and total nitrogen (TN), and particulate organic carbon and nitrogen (POC, PN), and showed a three-fold decrease in structural stability when compared with NT of only winter crops or with RT managed plots. Furthermore, our canonical discriminant analysis (CDA) showed structural index (SI), TOC, change in the mean weight diameter of aggregates (CWMD), and biological activity (BA) as the best SQ indicators for the study area. The quantified degradation suggests the need to reassess NT implementation in order to make NT a sustainable option for the southern semiarid pampas region.

1. Introduction

No-tillage (NT) practices represent the core concept of conservation agriculture yet its implementation disregarding residue levels and crop rotations threaten the sustainability of this practice particularly in marginal agricultural areas of developing countries (Giller et al., 2011; Pittelkow et al., 2015). Advantages in terms of cost reduction and more efficient use of water have led to widespread adoption of conservation systems, particularly NT, over the last 30 years in countries with extensive agricultural land areas such as Argentina, Australia, Brazil, Canada and Uruguay (Friedrich et al., 2012). No-till is currently implemented on over 120 million ha worldwide; 27 million ha in Argentina or about 78% of the country's total arable land (AAPRESID, 2013). As in other temperate regions of the world, the spread of NT technology is linked to its operational simplicity, reductions in fossil fuel use and erosion risk, as well as increases in carbon sequestration and water accumulation in the soil, thus contributing to climate change mitigation and adaptation (Lal et al., 2007; Strudley et al., 2008). The increased atmospheric concentration of greenhouse gases has served to intensify interest in the carbon stored in the soil as a strategy to compensate for anthropic CO_2 emissions (Lenka and Lal, 2013). Increasing total organic carbon (TOC) stocks in the soil is also desirable from the soil quality standpoint and to obtain environmentally sound and economically viable levels of production (Kahlon et al., 2013). Conservation tillage practices, in particular NT, have shown promise in raising levels of TOC in surface soil as a result of lower temperatures, higher soil water content, and lack of residue incorporation and mixing (Lal et al., 2007). Bonel et al. (2005), report similar levels of TOC in NT and reduced tillage (RT) systems with slight differences in the distribution of this C within the surface horizon. Biological parameters such as

Abbreviations: NT, no tillage; RT, reduced tillage; WW, rotation with winter crops; WF, rotations of winter crops with year-long fallows; WS, rotations with winter and summer crops; TOC, total organic carbon; TN, total nitrogen; POC, particulate organic carbon; PN, particulate nitrogen; Pa, available phosphorus; BA, biological activity; SS, structural stability; BD, bulk density; RC, relative compaction; CWMD, change in mean weight diameter of soil aggregates; SI, structural index; CDA, canonical discriminant analysis

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https://doi.org/10.1016/j.still.2017.11.001
Received 24 April 2017; Received in revised form 9 October 2017; Accepted 2 November 2017

microbial activity are strongly related to soil organic matter content and are also affected by management more rapidly than TOC, therefore they would be sensitive and early indicators of the effect of cultural practices on the microbiological environment of the soil (Álvarez et al., 1995). Higher TOC content together with the direct action of a greater density of fungal hyphae and greater biological activity under NT also contribute to improving the structural stability (SS) of the soil and decreasing bulk density (BD) (Lal et al., 2007). However, Sasal et al. (2006) and Soracco et al. (2010) report that although SS is generally greater under NT, compaction occurs in the surface horizon as a result of the vertical compression generated by agricultural machinery traffic and the non-inversion of the soil. Research by Radford et al. (2000) has shown that 30% of the soil surface is affected annually by traffic under genuine NT systems (one pass at seeding). Soil quality is strongly related to soil structure and much of the environmental damage in intensive arable lands such as erosion and susceptibility to compaction originate from soil structure degradation (Dexter, 2002).

In several countries such as the United States, NT is commonly used in an alternating sequence with periodic tilling in order to decrease surface compaction, interrupt the cycle of pests and diseases, and reduce production costs associated with the increased use of herbicides and other inputs (Derpsch et al., 2010). On the contrary, in Argentina, as in other Latin American countries, NT is practiced continuously in more than two thirds of the total area under agricultural production (Friedrich et al., 2012). To maximize NT benefits, adequate levels of residue cover are required; in the US, more than 70% of residue cover remain under NT practices (USDA/ERS, 2006). In the southwestern Buenos Aires province of Argentina, López et al. (2015) reported that 44% and 63% of NT plots were left with less than 30% coverage at the time of wheat planting when the previous crop was a winter or a summer crop, respectively. This brief report highlights an important gap between the definitions of conservation practices, in particular NT, and their on-farm implementation in the semiarid region. Farmers referred using NT management based mainly on the adoption of machinery associated technology (i.e. one pass seeding, herbicide and fertilizer applications) and with little attention to ground cover by crop residues after planting. In their recent meta-analysis on the effect of NT on crop yields around the world, Pittelkow et al. (2015) repeatedly observed this lack of sufficient amount of residue particularly in semiarid and arid regions of developing countries, negatively affecting crop yields. Conservation agriculture is based on three agronomic principles: minimum soil disturbance, retention of crop residues, and crop rotation. NT practice is considered the utmost agricultural management system in regards to soil conservation and retention of crop residues. Yet Pittelkow et al. (2015) found strong evidence that the contribution of NT practices to the sustainable intensification of agriculture is limited when the other two principles are deficient. Though the focus of their meta-analysis was crop yield responses under NT, we pose that the negative effects of implementing NT practices within a system that fails to generate and retain enough residues (> 30%) and to use crop rotations, will extend to soil quality (SQ) attributes in the semiarid and arid regions of developing countries such as Argentina.

Research on the impact of different tillage systems on SQ in Argentina have focused primarily on comparisons between contrasting tillage systems such as NT vs conventional tillage or uncultivated (prairie) soils of the pampa region (Bono et al., 2008; Urioste et al., 2006). Other studies on the effect of different rotations under NT on SQ included integrated cropping and grazing systems (Quiroga et al., 2009) or cropping systems that typically include soybean [*Glycine max* (L.) Merr.] and maize (*Zea mays* L.) in the rotation (Álvarez et al., 2014a; Echeverría et al., 1992; Fabrizzi et al., 2005; Noellemeyer et al., 2013). The impact of agronomic management practices on SQ attributes differs greatly depending on climate, region, and soil texture among other factors (Angers et al., 1997; Congreves et al., 2015). Quiroga et al. (1998) reported that coarse organic matter, SS and susceptibility to compaction were satisfactory indicators to segregate soils under different uses (cropping, grazing and pristine conditions) in the semiarid pampa region. However, organic matter varied with soil texture; hence the authors proposed using both criteria in the assessment of the SQ. The use of NT is still not widespread in the semiarid pampa region, though there is clear evidence of its expansion with about 10–20% of the arable land currently in NT. The extensive tillage undergone by the soils since the introduction of agriculture in the region has resulted in a weakly structured surface soil horizon highly susceptible to wind erosion and with increased risk of developing subsurface compaction in the form of plow pans (Amiotti et al., 2012). Within this region, more research is needed to better understand the impacts of management practices of no-till and reduced tillage as they are currently implemented in farmers' fields on SQ parameters. We hypothesize that: i) in the dominant sandy loam soils of this semiarid region, the use of continuous NT increases the risk of soil compaction due to low residue levels, weather conditions, and soil texture preventing increases in TOC stocks and related soil properties, commonly associated with NT use in other regions. ii) Likewise, increasing the number and type of crops (winter and summer crops) of the rotations under NT can potentially improve TOC and alleviate compaction, which will be more evident on soils with fine texture. Thus, the objectives of this work were 1) to characterize and compare management practices as they have been implemented on farm operations of the southern semiarid region regarding their effects on the SQ attributes of the surface soil, and 2) to identify those soil attributes most sensitive to changes in management practices that could indicate changes in SQ. The six production systems identified for this study represent the various combinations of tillage systems, time since implementation, rotations, and surface soil texture found in the agricultural operations of area producers participating in the study. Generating data on the impact of different management practices on the soil will contribute to re-orienting or adjusting their implementation to regional conditions in order to enhance the productive capacity and ensure the sustainability of these marginal agricultural systems.

2. Materials and methods

2.1. Characterization of the study area

The study area is located within the semiarid southwestern region of Buenos Aires Province, Argentina, comprising the middle/distal portion of the Subventania plain, a gently undulating terrain encompassing some 400,000 ha of arable land. The climate is temperate semiarid with a mean annual temperature of 15 °C and annual rainfall of 580 mm. The dominant soils, classified as Petrocalcic Paleustolls, evolved from loess deposited on an inherited petrocalcic horizon at variable depths, usually between 60 and 100 cm. Soils in the region have undergone pulses of removal and deposit of materials linked to the effects of intense winds acting over bare soil in situations of poor agricultural management. These erosive processes led to coarser textures of the surface horizons of regional soils, originally loam to clay loam. These phenomena have not affected all soils in the study region, so that surface horizons with a sandy loam texture (the dominant type) coexist alongside others that preserve the finer textural characteristic of the original loess material (Amiotti et al., 2001). Winter cereal crops of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) are usually grown continuously, in rotation with sunflower (*Helianthus annuus* L.), or with a year-long fallow in between crops; yields vary from 1500 to 3000 kg ha^{-1} for the winter crops and average sunflower yields are 500 kg ha^{-1}, all limited by water availability. Conservation practices are implemented in about 15% of the area.

2.2. Identification of farms and combinations of factors potentially affecting soil responses

In order to identify the area producers that were carrying out