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Long-term rotation and tillage effects on soil structure and crop yield

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ABSTRACT

Tillage and rotation are fundamental factors influencing soil quality and thus the sustainability of cropping systems. Many studies have focused on the effects of either tillage or rotation, but few have quantified the long term integrated effects of both. We studied the issue using a 30-year old long-term rotation and tillage treatment experiment on a Canadian silt loam soil. Topsoil measurements were carried out for three different rotations: R1, (C–C–C–C) continuous corn (*Zea mays* L.), R6, (C–C–O(RC), B(RC)) corn, corn, oats (*Avena fatua* L.) and spring barley (*Hordeum vulgare* L.) and R8, (C–C–S–S) corn, corn, soybean (*Glycine max L.*), soybean. A red clover (*Trifolium pretense* L.) cover crop was under seeded in oats and spring barley in R6. In 2010, first year corn was grown in R6 and R8. The tillage treatments included no tillage, NT and mouldboard ploughing, MP. Topsoil structural quality was visually evaluated in early June and mid October. Minimal disturbed soil cores collected in early June were used for X-ray CT scanning and to quantify water content and porosity. Soil friability was determined on the soil samples using a drop shatter test. Crop yield was determined and correlated to the soil quality estimates. We found significant effect of both rotation and tillage on visual soil structure at both times of assessment. Poor soil structure was found for NT except when combined with a diverse crop rotation (R6). The soil core pore characteristics data also displayed a significant effect of tillage but only a weak insignificant effect of rotation. The drop shatter results were in accordance with the visual assessment data. Crop yield correlated significantly with the visual soil structure scores. We conclude that a diverse crop rotation was needed for an optimal performance of NT for the studied soil.

1. Introduction

Tillage and rotation are fundamental factors influencing soil quality, crop performance and thus the sustainability of cropping systems. Conservation tillage per se is considered one of the most effective management practices to obtain mutual benefits in terms of erosion control, carbon sequestration and reduced input of energy and labour. However, maintaining crop yields is a challenge when adopting conservation tillage in many traditional cereal-based cropping systems (Carter, 1994; Meyer-Aurich et al., 2006; Morris et al., 2010). Decreased soil physical quality, in terms of excessive compaction of the untilled topsoil, is regarded as one of the primary reasons for yield reductions (e.g. Carter, 1991; Ball et al., 1994). This is especially problematic on weakly structured soils in humid temperate climates (Munkholm et al., 2003). Many have suggested the use of controlled traffic and stimulated biological activity to mitigate the problem (Ehlers and Claupein, 1994; Munkholm et al., 2003). The latter is stimulated through the input of crop residues and the use of diverse rotations and cover crops – all such factors are included in the concept of conservation agriculture (CA), strongly promoted by FAO (www.fao.org/ag/ca). The CA concept is supported by numerous studies which usually include a limited number of factors. There is, however a shortage of studies, in which the long-term integrated effect of conservation, tillage, rotation and cover crops on soil quality have been evaluated.

Assessment of soil structure is challenging because soil is a very heterogeneous and complex medium. Visual soil evaluation methods have in recent years become a widespread tool for the integrative evaluation of soil structure as highlighted in this special issue. For topsoil structure evaluation, a number of methods are available such as the spade methods: VESS, visual evaluation of soil structure (Ball et al., 2007) and VSA, visual soil assessment method (Shepherd, 2009) as well as the "le profil cultural" profile method (Manichon, 1987). In this study we applied the VESS method because it is takes account of a range of crucial properties (soil strength, porosity and roots and biological activity), integrates over a rather large volume, is fast and easy to use and integrates the evaluation of different aspects into a single number ranging from 1

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(friable) to 5 (very compact). The numeric results, from the VESS test, allow statistical analysis of management effects and exploration of linear correlations to other factors, such as crop yield or quantitative soil physical properties. Visual soil evaluation methods are by nature, qualitative and operator dependent. A visual key in combination with text guide was developed to minimize the subjectivity when performing the VESS test. However, visual methods must be regarded as complementary to quantitative methods. In this study the VESS test was supplemented with quantification of porosity, soil friability, soil strength and detailed soil pore characteristics based on X-ray CT scanning imagery.

The objective of this study was to evaluate the cumulative effects of tillage and selected rotations on soil structure using the long-term rotation-tillage experiment at Elora Research Station (Meyer-Aurich et al., 2006). We hypothesized a positive effect of diverse rotation (including cover crop) on soil quality – especially under no tillage. A secondary objective was to link topsoil structure assessment to crop yield. We expected a positive correlation between crop yield and topsoil quality.

2. Materials and methods

2.1. The experiment

Samples were taken from the long-term rotation and tillage trial (initiated in 1980) at the University of Guelph's Elora Research Station near Elora, Ontario, Canada (43°39′N, 80°25′W). The soil is mapped as Woolwich silt loam and classified as a Grey Brown Luvisol (CSSC, 1998) or Albic Luvisol (WRB, 2006). The particulate size distribution is on average: 16, 44, 40 and 2.13 g 100 g^{-1} of clay, silt, sand and organic carbon, respectively. The 30 year average rainfall (1970–2000) was 920 mm, and the average monthly temperatures for January, April and July are −7.6, 5.9 and 19.7 °C, respectively (Table 1). The 2010 growing season had monthly temperatures similar to long term averages. Although annual precipitation in 2010 was lower than long term averages, rainfall received during the 2010 April–September growing season exceeded long term average precipitation and distribution was very good.

The experimental design is a randomized split plot with four replicates. The main plot treatment is rotation and the plot treatment is tillage. Seven four-course rotations are included in the trial. In this study we used rotation R1, (C–C–C–C) continuous corn (*Zea mays* L.), rotation R6, (C–C–O(RC), B(RC)) corn, corn, oats (*Avena fatua* L.) and spring barley (*Hordeum vulgare* L.) and rotation R8, (C–C–S–S) corn, corn, soybean (*Glycine max* L.), soybean. A red clover (*Trifolium pretense* L.) cover crop was underseeded in oats and spring barley in R6. In 2010, first year corn was grown in R6 and R8. The tillage treatments included no tillage (NT) and conventional tillage with mouldboard ploughing (MP). Mouldboard ploughing (20 cm) was carried out on November 18, 2009. Secondary tillage in MP consisted of two passes of a field cultivator and packer within 1 day of crop seeding. The tillage plots are 7 × 17 m and 8 rows of corn were sown in each of the studied plots on May 7, 2010. The corn crop was harvested at full maturity on October 19 and the yield was recorded.

2.2. Visual evaluation of soil structure

Topsoil structural quality was visually evaluated according to the visual soil structure evaluation (VESS) method described by Ball et al. (2007) and further refined by Guimarães et al. (2011). The topsoil (0–20 cm) is evaluated according to aggregation, porosity and root growth and graded on a scale from Sq1 to Sq5 where 1 is best. Two assessments were carried out per plot in R1, R6 and R8, i.e. 48 observation points. The soil was sampled in the centre of the plot between rows 2 and 3 and rows 6 and 7 to avoid traffic zones. The evaluation was carried out on June 4 2010 when the corn was in the 6 leaf tip stage and repeated just before harvest on October 18 2010. The average gravimetric water content was 26% and 29%, respectively at testing in June and October. This corresponds to a matric potential around field water capacity at assessment according to soil water retention data from the Elora site (Parkin, unpublished data).

2.3. Penetration resistance

Penetration resistance was measured, at approximately field capacity, with a RIMIK cone penetrometer (Agridry Rimik, Toowoomba, Queensland, Australia) to a depth of 50 cm on May 21, 2010. All measurements employed a 20.27 mm diameter, 30° semi-angle cone. Penetration resistance was recorded at each 25 mm increment. Five determinations were made per tillage plot in all the studied rotations, i.e. 2(tillage) × 3(rotations) × 4(blocks) × 5(replicates) = 120 determinations.

2.4. Soil core sampling

Two minimally disturbed soil cores (Ø = 6.4 cm, height = 8.0 cm) were taken at 10–20 cm depth in R1 and R6 on May 28 2010. In all, 32 samples were taken. The samples were taken at the same location as for VESS test. Immediately after sampling, the samples were stored in a refrigerator at 5 °C until CT scanning. The samples were also stored in the refrigerator between X-ray CT scanning and the drop shatter test. The CT images from two samples were lost and data analyses were, therefore, carried out on a total of 30 samples. Samples were weighed before CT

Table 1
Average monthly temperature and monthly total precipitation, Elora, Ontario, Canada for 2008, 2009, 2010.

	Temperature (°C)				Precipitation (mm)			
	2008	2009	2010	30-yr Av.	2008	2009	2010	30-yr Av.
January	−4.7	−11.7	−7.2	−7.6	98.5	66.1	27.2	56.4
February	−8.6	−6.1	−5.8	−6.9	57.4	82	24.4	50.8
March	−5.2	−0.7	2.2	−1.3	85.5	72.7	41.3	72.1
April	7.5	6.1	8.7	5.9	64.6	106.2	47.5	78.3
May	9.8	11.4	13.8	12.3	86.1	79.3	99.9	79.9
June	17.6	15.8	16.8	16.9	81.6	69.2	184.1	76
July	19.1	16.5	20.2	19.7	131.3	79.5	89.4	88.5
August	17.2	17.8	19.4	18.6	120.7	92.1	12.1	95.9
September	14.8	14.5	14.0	14.1	119.3	53.7	117.8	92.1
October	7.2	6.8	8.3	7.9	68.4	91.5	52.6	69.2
November	0.7	4.6	3.0	2.4	103.1	37.3	50.8	86.3
December	−5.5	−4.5	−6.1	−4	100.4	65.8	21.1	77.7

Source: Meteorological Services Canada (2011).