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Challenges of conservation agriculture practices on silty soils. Effects on soil pore and gas transport characteristics in North-eastern Italy

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ABSTRACT

Soil air exchange is one of the most important soil functions that directly impacts on crop productivity and environment. Generally, conservation agriculture (CA) practices are expected to provide improved soil aeration but contrasting texture-related effects were found in the literature. The aim of this study was to evaluate the effect of CA practices on gas transport characteristics in the silty soils of the Veneto Region (North-Eastern Italy). In 2010, a field experiment comparing CA practices (no-tillage, cover crop and residues retention) to conventional intensive tillage (IT) system was established in four farms located in the Veneto low plain. In fall 2015, 144 undisturbed 100 cm^3 soil cores where collected at two different layers (3–6.5 cm and 20–23.5 cm) and analysed for air-filled porosity, air permeability, gas diffusivity and soil structure indices derived.

Gas transport measurements highlighted low transmission properties of the silty soils independently from agronomic management. Both air permeability and relative gas diffusivity showed poor aerated conditions being generally $< 20\ \mu m^2$ and < 0.005, respectively.

CA treatments affected the transmission properties only in the coarsest soil studied causing a reduction of air permeability in the deeper layer and relative gas diffusivity in both layers. The CA-induced reduction was related to the tillage effect on soil bulk density and suggested that CA not only affected the air-filled porosity but also continuity and tortuosity characteristics.

The poor structural stability of Veneto soils, particularly the poor soil organic carbon content, could prevent the exploitation of CA practices firstly on soil structure and in turn on gas exchanges. For these reasons further studies elucidating the mechanisms improving soil structural conditions for silty soils as those examined in this study are required.

1. Introduction

Silty soils in the low-lying plain of the Veneto region (North-eastern Italy) are Calcisols and Cambisols (WRB, 2006) characterized by a low structural stability and soil organic carbon (SOC) content, ranging from 0.5 to 1 g 100 g^{-1} (Dal Ferro et al., 2016). They have traditionally been intensively tilled to provide a correct seedbed for crop growth. During the last 50-yr period, the combination of simplified crop systems (e.g. maize monoculture), intensive tillage (IT), and lack of organic input (e.g. farmyard manure) have depleted the SOC stocks at a rate of 1.1 t ha^{-1} y^{-1} worsening the soil quality and increasing the GHGs emissions (Morari et al., 2006).

Nowadays, no-tillage is a widespread technique among the sustainable agronomic practices, often called "conservation agriculture (CA)" when associated with crop diversification and permanent soil covering by residues retention and cover-crops (Vaneph and Benites, 2001).

As in the other European countries, application of CA practices are increasing in Veneto to reduce the production costs on the one side and allegedly to regulate and support several ecosystem services on the other side (Basch et al., 2015; Kassam et al., 2015). CA has also been subsidised during the two last rural development programs of Veneto Government (Veneto, 2016, 2013).

CA is often associated with a number of soil functions such as increasing of soil biodiversity, organic matter stocks and aggregate stability or decreasing of runoff, erosion and Phosphorous (P) losses and carbon dioxide emissions (Cavalieri et al., 2009; Kay and VandenBygaart, 2002; Verhulst et al., 2010). On the other hand the absence of tillage operations may impact the crop root growth through an increase in soil strength and soil bulk density, and reduce soil porosity and gas exchange (Dal Ferro et al., 2014; Dwyer et al., 1996;

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Lipiec et al., 2006; Martínez et al., 2016; Mentges et al., 2016; Palm et al., 2014; Schjønning and Rasmussen, 2000).

The overall benefit of CA depends on soil type and climate. Soils with low structural stability and poor drainage are generally not suitable for no-tillage systems and can lead to a substantial reduction of crop yield (Soane et al., 2012). Unstable soils, especially with low organic matter content, are subjected to higher risk of compaction (Ehlers and Claupein, 1994; Van Ouwerkerk and Perdok, 1994).

Soil air exchange with the atmosphere is one of the most important soil functions that directly impacts on crop productivity and environment. Being largely controlled by pore size distribution, pore continuity and water saturation (Blackwell et al., 1990; Hillel, 1998), air transport is strongly affected by tillage management (Martínez et al., 2016; Mentges et al., 2016; Schjønning and Rasmussen, 2000). Near-surface transport of gases is primarily controlled by air permeability (k_a) (Schjønning et al., 2002; Stepniewski et al., 1994), while diffusion is the process dominating gas exchange in subsoil (Glinski and Stepniewski, 1985).

CA practices are expected to develop a more stable soil structure which would provide higher soil aeration (Horn, 2004). However, the benefits connected to CA management are also texture-related.

In sandy soils, CA practices increased pore connectivity and continuity implying higher specific permeability and diffusivity, at least at shallow depth (Martínez et al., 2016). In contrast, no-tillage systems led to lower air permeability in clay soils (Mentges et al., 2016), which was probably due to higher water retention capacity and larger pore tortuosity (Deepagoda et al., 2011). Only few studies evaluated gas transport characteristics of silt-rich and poorly drained soils. Schjønning and Rasmussen (2000) observed reduced air permeability and diffusivity where direct drilling and ploughed soil was compared in a silty soil of marine origin. In silty loess soils, Eden et al. (2012) observed a rather weak impact on soil structure after a long-term application of organic and mineral fertilizers. Authors concluded that "the high silt content prevented formation of a more resilient soil structure", despite the gradient in SOC.

More research is needed to understand and optimize the potential of sustainable agronomic practices (Eden et al., 2012; Farooq and Siddique, 2015; Nakajima and Lal, 2014; Thorbjørn et al., 2008), especially concerning the application of CA systems. Moreover, the number of CA experiments in Europe over a wide range of soils, fertilizer applications and climate conditions with crops grown within rotations is still limited and requires expansion (Soane et al., 2012).

The aim of this study was to evaluate the effects of CA practices on soil pore and gas transport characteristics in the silty soils of the Veneto low plain. The hypothesis tested in this study is that CA could enhance soil functions related to aeration of the soil. More specifically greater organic matter content, at least at shallow depth, is hypothesized to yield higher macropore volume and connectivity, and in return improve gas exchange conditions. We studied air permeability, gas diffusivity, and derived indices of soil structure in a field experiment including four farms in which CA practices (no-tillage, cover crop and residues retention) were applied and compared to conventional IT.

2. Materials and methods

2.1. Experimental sites

A field experiment was set up in four farms located in Veneto Region (North-eastern Italy) (Fig. 1). Farm 1 (F1) was situated along the Adriatic coastline in a reclaimed environment (45° 38.350′N 12° 57.245′E, −2 m a.s.l.), the soil was Endogleyic Fluvic Cambisols (WRB, 2006) with a texture ranging from silty clay loam to silt loam (Table 1). The parent materials were calcareous silt sediments from Tagliamento and Piave rivers. Farm 2 (F2) was located in a low ancient plain originated from calcareous silt deposits of Brenta river (45° 34.965′N 12° 18.464′E, 6 m a.s.l.) and presented Endogleyic Calcisols (WRB, 2006) with a silty clay loam/silt loam texture. Farm 3 (F3) was located in a low recent plain at the Venice lagoon border (45°22′48.62"N 12° 9′47.84"E, 1 m a.s.l.) with Haplic Cambisols soils (WRB, 2006). The loamy texture was originated from the calcareous deposits of Brenta and Bacchiglione rivers. Farm 4 (F4) was located westward in the south low recent plain of the Po river (45° 2.908′N 11° 52.872′E, 2 m a.s.l.). It was characterized by a Gleyic Phaeozems (WRB, 2006) and silty clay loam or silt loam texture.

The climate in the region (years 1981–2010) was subhumid with mean annual rainfall around 829 mm in F1, 846 mm in F2, 859 mm in F3 and 673 mm in F4. In the median year, rainfall was highest in autumn (302, 241, 246 and 187 mm for F1, F2, F3 and F4, respectively) and lowest in winter (190, 157, 170 and 129 mm). Temperatures increased from January (average: 3.5, 3.0, 2.7 and 3.1 °C respectively) to July (average: 23.3, 23.3, 23.2 and 23.6 °C respectively). Reference evapotranspiration (ETo) was 860, 816, 792 and 848 mm, with a peak in July (4.9, 4.6, 4.6 and 4.8 mm d^{-1}). ETo exceeded rainfall from May to September in F1, F2 and F3 and from May to October in F4.

2.2. Experimental treatments

Experimental treatments were established at each farm in 2010 in order to compare conventional IT and CA. Experimental fields were rectangular (about 400 m length x 30 m width) with an average size of 1.2 ha. Main management operations are shown in Table 2. IT consisted of traditional tillage practices based on mouldboard ploughing (35 cm mean) with crop residues incorporation followed by secondary tillage (i.e. disk harrowing) while CA included sod seeding (direct drilling), residues retention on soil surface and use of cover crops. The crop rotation (four-year) was the same in both treatments: wheat (*Triticum aestivum* L.), oilseed rape (*Brassica napus* L.), maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.). From 2014 a simplified three-year crop rotation wheat-maize-soybean was applied. In CA, cover crops were also grown between the main crops: sorghum (*Sorghum vulgare* Pers. var. sudanense) during spring-summer while a mixture of vetch (*Vicia sativa* L.) and barley (*Hordeum vulgare* L.) during autumn-winter. Conversely, in the IT treatment the soil remained bare between the main crops (Table 2).

In IT, base dressing fertilizer was applied 1–2 weeks before the sowing while subsurface band fertilization was applied at the sowing in CA. In both management systems mineral fertilization was integrated by side dressing in maize (1 treatment) and wheat (2 treatments) (Table 2). There was no additional fertilization for cover crops while pesticide applications depended on crop requirements and were the same for both treatments. Before spring seeding, N-(phosphonomethyl) glycine was applied to suppress the winter cover crop in CA while sorghum suppression was achieved mechanically, through shredding.

2.3. Soil sampling

Sampling took place simultaneously in both treatments and at all four farms in October 2015 after soybean harvesting and before tillage operation in the IT treatment. In each field, three sampling plots (1 m × 5 m) were delimited, and soil samples were collected in the inter-row at three points and two layers, 3–6.5 cm (L1) and 20–23.5 cm (L2). Soil cores were collected by carefully removing the top soil to the intended depth, hammering sharp-edged steel cylinders into the soil, gently removing the bulk soil, and fixing lids at each end. At the same positions disturbed soil samples were also collected for particle size analyses. Samples were then stored at 2 °C before analyses. A total of 144 undisturbed 100 cm^3 soil cores (60.6 mm Ø, 34.8 mm H) and remoulded samples were collected according to the factorial combination of 4 farms × 2 layers × 2 treatments × 3 plots × 3 replicate cores.