



Tillage and drainage management effect on soil gas diffusivity



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ABSTRACT

Subsurface drainage influences the gaseous exchange in soils and improves crop productivity. Thus, gas diffusivity were monitored on a long-term drainage/tillage experiment established in 1994 at the Waterman Farm of The Ohio State University, Columbus, OH, USA. Specific objectives of the present study were to compare the gas diffusion and physical properties (bulk density and water retention) of soils managed under no-till (NT) and chisel-tillage (CT) systems with subsurface drainage management. Soils of the experimental site are classified as Crosby silt loam (Fine, mixed, mesic, Aeric Ochraqualf; fine, mixed, mesic, Typic Argiaqual). Treatments included: NT with tile drainage (NT-D), NT with no-drainage (NT-ND), CT with drainage (CT-D), and CT with no-drainage (CT-ND). The research site has been under continuous corn (*Zea mays* L.) cropping system since the start of the experiment. Intact core samples ($n = 36$) from 0–10, 10–20, and 20–30 cm depths were collected during November 2011 in three replicated plots of NT and CT systems under D and ND treatments. Results from this study showed that drainage treatments significantly influencing the relative gas diffusion (D_p/D_0), is defined as the ratio of the soil gas diffusion coefficient to that in free air. The D_p/D_0 for NT soils (23.1×10^{-3}) were 26% higher than those for CT (18.3×10^{-3}). Similarly, the ratio was 22% higher for soils under D (25.0×10^{-3}) compared with those under ND (20.5×10^{-3}). The tillage by drainage interaction was also significant for the D_p/D_0 at the 0–10 cm depth. Corn yield was positively correlated with relative gas diffusion ($R^2 = 0.36$). It can be concluded from this study that NT system under drainage management can improve the gas diffusivity, enhance the soil structure and increase crop yield.

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1. Introduction

No-till (NT) system is a useful technology for soil and water conservation, increases the soil organic carbon (SOC) pool, and serves as a sink of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2) (Six et al., 2004; Triplett and Dick, 2008). The NT system also decreases labor input and increasing profitability. In 2007, more than 26 million ha (Mha) of total crop land in the U.S., representing about 16% of total cropland areas, was under NT management production of corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), wheat (*Triticum aestivum* L.), and cotton (*Gossypium hirsutum* L.) (Derpsch et al., 2010; Kassam et al., 2012). The NT system is spreading globally, but especially in South America (Derpsch and Friedrich, 2009). In general, the NT system improves soil properties, increases nutrient retention, enhances carbon (C) cycling, and moderates the flux of water and air (Blanco-Canqui and Lal, 2007). However, the soil

physical environments and GHG emissions may not always be improved under NT (Arshad et al., 2004). Further, several questions remain about processes for improvement of soil quality and emissions of GHGs (Blanco-Canqui et al., 2004). For a wide acceptance of NT agricultural system, therefore, it is crucial to understand and evaluate soil physical properties and emissions of GHGs.

Globally, 146 Mha of arable land has poorly drained soils and is in need of some drainage management to improve soil physical properties (e.g., soil aeration, water retention, aggregation) and decrease soil erosion (Randall and Iragavarapu, 1995). The low water infiltration rate, high ground water level, snow melt and heavy rains in the spring accentuate the need for drainage management to increase and sustain high agronomic productivity. If excessively wet crop land soils are not drained, crop growth is adversely affected by the lack of aeration, reduced concentration of O_2 and increased concentration of CO_2 and CH_4 (Lal and Taylor, 1969). Thus, drainage management is important to improving soil physical quality, reducing emission of GHGs, and improving crop growth. However, research data on the effects of drainage management on soil physical properties and emission of GHGs,

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especially under the NT agricultural system, are scanty (Abid and Lal, 2008, 2009). Thus, it is critical to understand the impact of NT farming and drainage management on soil physical properties.

Good soil aeration and favorable diffusivity are essential to alleviating soil-related constraints in poorly drained soils (Allaire et al., 2008), and to moderate GHG emissions (Pingintha et al., 2010). Plant roots and soil biota need O₂ for respiration which is exchanged by gaseous movement, particularly gaseous diffusion and exchange. Otherwise plants and microbes could not thrive in anaerobic soils due to the lack of O₂ and low respiration. In addition, gaseous diffusion is a crucial factor for a favorable composition of soil air and decomposition and transformation of soil organic carbon (SOC) and nitrogen (N) (Pingintha et al., 2010). The results of these processes affect emission of GHGs from cropland under NT management. Therefore, the gaseous movement in soils needs to be well understood to optimize the potential of agricultural practices (e.g., NT, minimum tillage, and tile drainage) and to reduce emissions of GHGs.

Gaseous diffusion is one of the main processes associated with gaseous movement in soils (Marshall, 1959; Moldrup et al., 2004; Osozawa and Kubota, 1987; Taylor and Abrahams, 1953; Werner et al., 2004). Gaseous movement is affected by soil structure (e.g., soil texture, clay mineral, macro and micro pores, bulk density, total porosity, aggregation, and pore size distribution), and water content (Ball et al., 1988; Moldrup et al., 2001; Schjonning et al., 2003; Tuli et al., 2005). Further, gaseous diffusion depends on the continuity of soil porous media through the gas exchange process, more directly than any other soil physical properties (Ball et al., 1997). Yet, there has been little research conducted under field conditions on these issues. Schjonning (1989) and Kessavalou et al. (1998) studied the relationship between soil pore characteristics by gas diffusivities on long-term reduced tillage experiments (Kessavalou et al., 1998; Schjonning, 1989; Schjonning and Rasmussen, 1989). Yet, the effects of soil gas diffusion in NT managed cropland soils must be thoroughly understood because relative gas diffusivity is an indicator of aerobic microbial activity (Schjonning et al., 2003).

Thus, the overall goal of this research was to assess differences in soil gas diffusion over a range of NT and drainage managements. Specific objective of this study was to quantify the impacts of the NT and drainage management systems on gaseous diffusivity in soil. The hypothesis tested in this study was that NT treatment and subsurface drainage of poorly drained soils improve gaseous diffusion, decrease bulk density, improve soil structure, increase SOC concentration, and increase crop productivity.

2. Materials and methods

2.1. Site description and soil sampling

The experimental site is located on the Waterman Farm of The Ohio State University, Columbus, OH, USA (44°02'00" N, 83°02'30" W). Soils of the site are classified according to US Soil Taxonomy (Soil Survey Staff, 1996) as Crosby silt loam (Fine, mixed, mesic, Aeric Ochraqulf). The research site was established in 1994 (Abid and Lal, 2008). The field layout consists of two tillage treatments and two drainage treatments with three replications. Two tillage managements included: NT and chisel-tillage (CT), and two drainage managements included: tile drainage (D) and no-drainage (ND). Therefore, treatments included: NT with D (NT-D), NT with ND (NT-ND), CT with D (CT-D), and CT with ND (CT-ND). The CT treatment consisted of fall chisel plowing to a depth of approximately 20 cm, and spring disking to prepare the seedbed for planting. The NT system has not been disturbed or plowed either before or after the establishment of the research site 18 years ago. Corn (*Zea mays*) has been continuously cultivated on this site since the experiments started in 1994. The tile drainage was installed in the spring of 1994 and, it consists of perforated plastic tubing (Sullivan, 1997). The tubing is 10 cm in diameter and was installed at about 100 cm depth from the soil surface. On the east side of each drainage plot, a sump was constructed for the collection of sub-surface drainage water. Each plot area is 750 m² (27.4 m × 27.4 m) and plots are separated by 6.1 m grassed drive-ways on all sides (Abid and Lal, 2008). This research site has 12 plots and is laid out as a randomized block design. Nitrogen (N), potassium (K), and phosphorus (P) fertilizers were applied at the rate of 168 kg N ha⁻¹, 1, 224 kg K ha⁻¹, and 112 kg P ha⁻¹, respectively.

Soil samples were obtained from middle of all plots at 0–10, 10–20 and 20–30 cm depths during November 2011. The undisturbed soil core samples were taken with the steel-type soil core sampler ($L = 5.0$ cm, $\Phi = 4.8$ cm) by using a double cylinder hammer driven core sampler (Grossman and Reinsch, 2002). In total, 36 undisturbed soil core samples were obtained from the research site. In addition, approximately 500 g of bulk soil samples were also taken at each of those 36 points (Table 1).

2.2. Soil bulk density and soil water retention

Soil bulk density (ρ_b) was measured as the weight to volume ratio of oven dry (105 °C) soil (Grossman and Reinsch, 2002). Bulk soil samples were air dried for 1 week. Total porosity (f_t) was

Table 1
Soil texture, pH, electrical conductivity (EC) for the 0–10, 10–20, and 20–30 cm depths maintained under no-till (NT) and chisel-till (CT) system with tile-drained (D) and non-drainage (ND) management.

Treatment ^b	Soil texture (%)								
	Sand			Silt			Clay		
	0–10 cm	10–20 cm	20–30 cm	0–10 cm	10–20 cm	20–30 cm	0–10 cm	10–20 cm	20–30 cm
NT	58.0a	55.4a	55.1b	29.7a	26.4b	27.0a	12.3a	18.2a	17.9a
CT	57.4a	56.2a	56.7a	31.8a	33.0a	27.2a	10.8b	12.6b	16.1b
D	56.5b	55.9a	53.9a	31.8a	30.6a	31.6a	11.7a	13.5b	14.5b
ND	58.9a	55.7a	56.7a	29.7b	27.5b	22.3b	11.4a	16.8a	21.0a
Treatment ^a	pH			EC ($\mu\text{S cm}^{-1}$)					
	0–10 cm	10–20 cm	20–30 cm	0–10 cm	10–20 cm	20–30 cm			
	NT	6.70a	6.40a	6.56a	240a	205a	154a		
CT	6.03b	6.15a	6.22a	169b	205a	123a			
D	6.46a	6.28a	6.38a	237a	244a	156a			
ND	6.27a	6.27a	6.40a	172b	166a	121a			

^a Means with different letters within a column, tillage treatment and drainage are significantly different at $P < 0.05$.

^b NT-D, no-tillage with tile drainage treatment; NT-ND, no-tillage with no drainage treatment; CT-D, chisel tillage with tile drainage treatment; CT-ND, chisel tillage with no drainage.

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