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Effects of long-term tillage and drainage treatments on greenhouse gas fluxes from a corn field during the fallow period

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ABSTRACT

Advance tillage research suggests that tillage decreases soil fertility and adversely affects the environment. The objective of this research was to estimate the greenhouse gas (GHG) flux vis-à-vis GHG production potential at different soil depths (0–100 cm) from tillage and drainage management treatments during the fallow period (October 2009 to April 2010) in a continuous (since 1994) corn (*Zea mays*) growing field at the Waterman farm in central Ohio. The Crosby silt loam (*Aeric ochraqualf*) soil of the experimental farm has been managed with the same practice since 1994 with two tillage sub-factors: no till (NT) and chisel tillage (T) and two drainage sub-factors: tile drainage (D) and no-drainage (ND). The fallow period was from the middle of October to the middle of April. The field was under snow cover during the middle of December to the first week of March. GHG fluxes (CO_2, CH_4 and N_2O) were significantly lower during the snow cover period. This study suggests that the CO_2 flux was significantly higher from T and D plots compared to NT and ND plots. Neither CH_4 nor N_2O fluxes were influenced by tillage or drainage. The CO_2 flux from T + D treatments was significantly higher (25.98–398.65 mg m^{-2} h^{-1}) throughout the fallow period. Significantly higher N_2O flux (87.07–125.76 μg m^{-2} h^{-1}) was recorded from all treatments during the thawing period in the first week of March. Considering that the total C flux involves only the loss from the SOC stock, as much as 3.05% of the total SOC stock (1.23 Mg C ha^{-1}) was lost during the fallow period from T–D plots as CO_2 and CH_4. Analysis of soil from different soil depths suggests that the CO_2 and N_2O emissions from soil were mostly dependent on production potential at 0–10 cm and 0–30 cm of soil depths, respectively. However, there was no such trend for CH_4 emissions from soil.

1. Introduction

Climate change is strongly linked to increasing levels of specific greenhouse gases (GHGs). Methane (CH_4) and nitrous oxide (N_2O) are the important GHGs from an agricultural perspective (Smith et al., 2008). Carbon dioxide (CO_2) is the most important GHG (Sandor and Skees, 1999) from the perspective of policy makers. However, the Global Warming Potential (GWP) of CH_4 and N_2O are 25 and 298 times higher than that of CO_2, respectively (Solomon et al., 2007). Apart from fossil fuel combustion, land use change and depletion of soil carbon (C) stocks are also significant contributors to the atmospheric CO_2 (Forster et al., 2007). Agricultural soils of the world have lost >50 Pg C (Lal, 2004) and agricultural activities contribute 3% of the total annual CO_2 emission in the US (Williams et al., 2004).

The soil organic matter (SOM) plays an important role in enhancing crop production (Causarano et al., 2006), improving soil structural stability, and mitigating climate change (Hao et al., 2002) by stabilizing atmospheric CO_2 concentration. However, when the soil is tilled, SOM is decomposed rapidly due to changes in water, air and temperature in the soil. Decrease in SOC (~58% of the SOM) concentration minimizes soil resilience, degrades soil quality, reduces soil productivity and buffering capacity of the soil (Lal and Bruce, 1999). Breakdown of soil aggregates and exposure of the SOC accentuates microbial decay of soil C and N which leads to emission of GHGs (e.g. CO_2, CH_4 and N_2O). However, about 60–70% of the historic loss of SOM can be restored with the adoption of recommended management practices (RMPs) (Lal et al., 1998). Conversion to conservation tillage (CT), and diverse crop rotations based on legumes and cover crops in the rotation cycle are some RMPs which could help in the restoration of SOM in degraded soils.

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Research on the effect of NT on N_2O emission has generated mixed results. Some studies have reported stimulation of N_2O emissions from NT (MacKenzie et al., 1997; Ball et al., 1999; Baggs et al., 2003; Marland et al., 2001), others have reported inhibition (Drury et al., 2006; Rochette et al., 2008) and still others have reported no impact (Choudhary et al., 2002; Elmi et al., 2003). Thus, the net effect of tillage on N_2O emission is inconsistent and not widely quantified (Li et al., 2005).

Drainage and irrigation constitute important aspects of water management, and emissions of GHGs from soil. Lantz et al. (2001) reported higher SOC loss from poorly drained soils in Ohio. However, Abid and Lal (2008) reported higher SOC concentration in un-drained compared with drained soils. Crop residue mulch in NT improves water infiltration rate in the soil compared to the tillage plot (Paltineanu and Starr, 2000). Surface mulch in NT soil decreases radiation load on the soil, and also the heat loss during the night. The undrained-NT system increases water content of soil, which in turn decreases soil temperature during spring and summer. The net effect is less diurnal soil temperature variation and GHG emission.

Most studies on GHG emissions from different tillage practices are focused on the annual emission from the field, but the emission during the fallow period have not been elaborated. The wet and dry cycle during the fallow period may affect the GHG emissions from the soil, which leads to a change in the cumulative annual estimation of GHGs.

We hypothesized that there would be significant emissions of GHGs from corn cropping soils during the winter fallow period, correlated with the intermittent wet and dry periods of the soil. Therefore, the present study was conducted to estimate GHG (CO_2, CH_4 and N_2O) emissions from soil during the entire winter fallow period from long-term continuous corn cropping fields with different tillage and drainage management practices. The GHG production potential at different soil depth was studied to understand the resilience of SOC at different soil depths, and their relationship with GHG emissions from the surface soil.

2. Materials and methods

The field study was conducted on long-term experimental plots at the Waterman farm of the Ohio State University, Columbus, OH, USA (40°02′00″ N; 83°02′30″ W). The long-term experiment was started in 1994 on the Crosby silt loam (fine, mixed mesic, Aeric ochraqualf; sand 220 g kg^{-1}, clay 220 g kg^{-1}, silt 560 g kg^{-1}) soil (USDA, 1996). The site was under a continuous corn system since the establishment of this experiment in 1994. The crop residues were left on the ground after harvest. The crop was seeded during the month of May–June and harvested toward the month of September–October. The experiment consisted of two factors, tillage and drainage. The tillage factor had two sub-factors; NT and chisel tillage (T). The drainage factor also had two sub-factors; tile drainage (D) and no drainage (ND). The tile drainage system is a network of below-ground pipes. These below-ground pipes facilitate drainage of excess water and promote aeration.

The experiment was laid out in a completely randomized block design with three replications of four treatment combinations: chisel tillage–drainage (T–D), chisel tillage–no drainage (T–ND), no till drainage (NT-D) and no till no drainage (NT-ND). Each plot size was 24.7 m × 24.7 m and separated with 6.4 m buffer. Only spring disking was made on the tilled plots and tile drainage was installed in the drainage plots since the beginning of the experiment in 1994. Nitrogen (N) fertilizer was applied at 202.5 kg N ha^{-1} at the start of the growing season in spring. Herbicide Roundup® (Monsanto, St. Louis, MO, USA) was applied three times during the cropping period. Crop residues were left on the soil surface in NT and incorporated into the soil in the T treatments. The same cultural practices have been followed each year since 1994.

Table 1
Total porosity (%) of soil at different soil depths.

Treatment	Soil depth (cm)			
	0–10	10–20	20–50	50–100
T–D	42.15	40.68	38.41	25.16
T–ND	42.87	40.25	39.65	22.15
NT–D	45.85	43.58	42.25	25.84
NT–ND	45.68	43.76	41.88	26.25

Mean of three replicate observations.

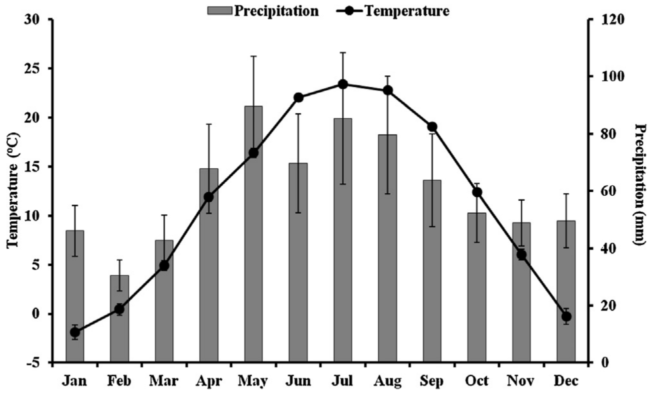

Fig. 1. Average monthly temperature and precipitation over the study area since the starting of the experiment (1994–2010). Error bar indicates SE.

Total porosity of the soil at different soil depths were measured before the starting of the experiment (Table 1). Mean monthly average temperature and precipitation of the region since the beginning of the experiment in 1994 are given in Fig. 1 (OARDC, 2010). This experiment was conducted during the fallow period from October (11th) 2009 to April (15th) 2010. Daily average ambient temperature and precipitation during the study period was collected from the weather station installed inside the experimental farm (Fig. 2). The field was covered with snow from the middle of December to first week of March. The period before the start of snow cover was regarded as 'pre-snow cover period' (P1); whereas the period after the melting of snow during March was regarded as 'post-snow cover period' (P2).

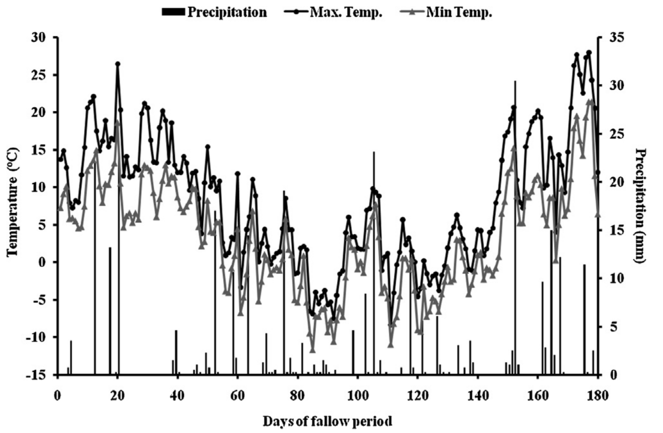

Fig. 2. Daily ambient temperature and precipitation during the period of study (October 2009–April 2010) at the experimental site of Ohio (40°02′00″ N; 83°02′30″ W).