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Long-term Effect of Conventional and No-Tillage Production Systems on Nitrous Oxide Fluxes from Corn (*Zea mays* L.) Field in Southwestern Quebec

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Abstract: Problem statement: There is a growing trend in the adoption of conservation tillage as an alternative to conventional tillage farming system. Implications of this agricultural management shift with respect to nitrous oxide (N_2O) emission, which has been a topic of intense research for the past few decades, is not yet completely understood. **Approach:** This study was conducted on a 2.4 ha field located at Macdonald research farm of McGill university, Montreal, to investigate the relative impact of long-term Conventional Tillage (CT) and No-Tillage (NT) practices on soil N_2O fluxes (F_{N2O}) under grain and silage corn (*Zea mays* L.) during the 2003 and 2004 growing seasons (May-Sept). Nitrous oxide fluxes were measured using static closed chamber by taking gas samples at 0, 10, 20 and 30 min. **Results:** In both years, the N_2O fluxes were generally similar between the two tillage systems, with the exception of few sampling dates at the beginning of the growing season when N_2O emissions measured under CT were significantly ($p\leq 0.05$) greater than NT. Despite our efforts to reduce experimental error by deploying six chambers per treatment plots, spatial and temporal variations were high which might had obscured the treatment differences to be detected. **Conclusion:** An important implication of present findings was that, contrary to many reports in the literature, the adoption of NT may not add to concerns over global atmospheric N_2O concentrations. This might be due to a greater rate of N_2O reduction to N_2 in soils under NT than CT during diffusion up the soil profile because of the higher moisture content under NT system than CT.

Key words: Nitrous oxide, fluxes, tillage, corn residue, greenhouse gas

INTRODUCTION

Growing concerns about climate change has stimulated significant interest in the adoption of agricultural management practices that decrease the build-up of greenhouse gases (GHG) in the atmosphere. Consequently, sustainable soil use and management systems that improve soil's health and capacity to store GHG have attracted much attention in recent years. No-Till (NT) conservation is being recognized in many parts of the world as being a best management practice that improves soil health[1], minimizes soil erosion[2] and reduces production costs due to lower fuel consumption and labor input[2,3]. The continuing increase in acreage under NT however, raises concerns about potential trade-off between improved soil and water quality and enhanced nitrous oxide (N_2O) emission; a potent greenhouse gas (GHG) relevant to climate change.

Soil water content is an important soil property determining the amount of N_2O production from agricultural soils. The presence of crop residues on the soil surface will affect soil moisture contents, which in turn, dictates the N_2O emission rates. Soils under NT retain greater soil moisture than those under Conventional Tillage(CT)[4,5], which may enhance denitrification, with N_2O being an intermediary product. In addition to soil water content, it has long been

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established that N_2O emissions are also dependent on soil temperature, available carbon, soil pH, nitrogen fertilizer rate and time of year[6-11]. All these soil parameters are affected by soil and crop residue management practices and, consequently, the extent of N_2O emissions.

Nitrous oxide emissions have been a topic of increasing concern because N_2O has a well-documented role in stratospheric ozone (O_3) depletion and contributes to the atmospheric GHG effect[10,12-14]. Agriculture sector in Canada is estimated to be responsible for 70% of anthropogenic emissions of N_2O, most of it stemming from soils under crop production[15]. Inputs of Nitrogen (N) to agricultural soils from commercial N fertilizer applications, organic manures, or residues have been identified as major contributors to N_2O emissions from agriculture. The Global Warming Potential (GWP) of N_2O is estimated to be approximately 296 times greater than CO_2; therefore, it is important to develop sustainable agricultural systems that reduce N_2O emissions in the long term.

Although N_2O production and emission under commonly practiced cropping systems have been a topic of intense research in Quebec, Canada, and elsewhere, there are great uncertainties regarding the impact that NT has on N_2O emissions. Some studies have shown NT to produce larger N_2O emissions than CT soils[5,10], as a result of increased soil moisture content and, therefore, lower soil gas diffusivity, whereas other studies report no significant effects of tillage on N_2O emissions[16-19]. Contradictory findings may be a result of different climatic conditions and the duration of NT practice. The site of the present study had been under the CT and NT since 1991 and, thus, may provide us with a better understanding into the conflicting findings with respect to the impact of NT on N_2O emissions compared to CT under corn (*Zea mays* L.) production systems under southwestern Quebec. Corn is the dominant crop in southwestern Quebec. The objective of the present study was to quantify soil N_2O fluxes from two long-term tillage practices; NT and CT from grain corn production on a loamy sand soil under southwestern Quebec and similar environmental conditions.

MATERIALS AND METHODS

Site description and experimental layout: This study, undertaken in 2003 and 2004, was conducted on a 2.4 ha site at McGill University's agronomy research farm on Macdonald Campus, Quebec. A detailed site description, field layout, and treatment arrangements have been reported in previous studies[18,20] and only the salient aspects are stated here. The soil was mostly of the St Damase, series (Typic Endoaquent; Humic Gleysol according to FAO classification system). The upper soil layer (about 0.30 m) was a sandy loam, underlain by a sand layer (mean thickness about 0.20 m), with clay beginning at a mean depth of 0.50 m. The site was relatively flat with less than 1% slope. During the 12 years before the initiation of this study in 2003, the site had been under CT and NT with continuous corn cropping system. The site has been under alfalfa prior to 1991 when the site was converted to continuous corn production under CT and NT systems.

Treatments were CT and NT, with or without residue. Conventional tillage consists of moldboard plowing the soil after harvest, to a depth of 0.2 m, and offset disking to a depth of 0.1 m before planting in the spring. No till plots were not tilled any time. The residue (+R) treatments consist of harvesting only the kernels as grain corn, whereas the cobs, leaves and stalks are chopped by a combine and returned to the field. The no residue (-R) treatments have the entire plant harvested, and chopped as silage corn; hence minimal residue is left on the field. The surface coverage of residue retained on the soil for each treatment, as measured in 1999, was NT+R: 86%, CT+R: 10, NT-R: 53 and CT-R: 1%[20].

Treatments were laid out in a randomized complete block design replicated in three blocks. A 4-m wide strip of uncultivated land separated the blocks. The study site consists of 18 plots, half (nine plots) with residue and planted to corn harvested for grain corn, and the other half without residue and planted to corn harvested as silage. Each plot measured 18 by 80 m in length and a 2 m wide buffer strip separated each plot. Plots were drained by a subsurface drainage system installed to a depth of 1.0 m below the soil surface, and 15 m lateral spacing.

Corn (Funk 4120 hybrid) was planted in rows spaced 0.76 m apart on 21 May in 2003 and on 20 May in 2004. All plots received: at seeding, diammonium phosphate (18-46-0), banded 50 mm below and 50 mm laterally from the seeds to provide 40 kg N ha^{-1} and 102 kg P_2O_5 ha^{-1}. Ammonium nitrate NH_4O_3 (34-0-0) and muriate of potash (0-0-60) were top-dressed 2-3 weeks later to provide an additional 140 kg N ha^{-1} and 148 kg K_2O ha^{-1}. The second application occurred on 03 July in 2003 and on 18 June in 2004. The grain-corn plots were harvested with a combine that removed only grain, leaving all residues on the plots.

Nitrous oxide sampling: Nitrous oxide fluxes were measured using static closed chambers[21,22]. Chambers (0.10 m depth) were made from 25 cm diameter PVC pipe with welded lids. Bases (0.15 m depth) made from the same diameter PVC pipe were inserted into the soil (50 mm depth) to enable gas fluxes to be measured at the same position within each plot. A water-filled channel at the top of each base produced a gas tight seal with the chamber during measurements. Two frames (each measuring 0.53 by 0.53; 0.14 m height) were placed over the rows in each plot. The frames were inserted after the corn was and remained in the soil during growing season to prevent soil disturbance and also allow repeated measurement at the same location over time, thereby facilitating the characterization of temporal variation of N_2O fluxes. The frame heights extending from the soil surface were measured regularly during the growing season, to account for the variation of headspace (because of removal, re-insertion and soil settling). Frames were removed after fall plowing and reinstalled the following year after spring disking.

In situ N_2O fluxes (F_{N2O}) were measured once a day, 12 times in 2003 and 14 times in 2004. Sampling was carried out in 2004 during the early spring when the potential for large N_2O emissions was greater due to high soil-water contents to gain a better understanding of emissions during snow melt and spring thaw. Gas samples from inside the chambers were collected by inserting a syringe through a rubber septum at 0, 10, 20 and 30 min after installation. At each sampling date, a 25 mL air samples were taken and injected into a 12 mL evacuated vacuutainers (Vacuutainers brand, Beckon Dickson Company, Rutherford, NJ) to ensure over pressure of sample in the tubes. Before sampling, field standards were obtained by pre-injecting labeled vials with lab standards of N_2O (0.1, 0.5 and 1.0 ppm) and were brought to the field and acted as controls. These field standards were used to calibrate the N_2O concentrations obtained from the chambers in the field, to compensate for losses during fieldwork and storage. If there was a difference (usually a decline), the N_2O concentrations measured from the field samples were adjusted, based on the field concentrations. Vials with sampled N_2O gas were stored at room temperature in the laboratory until they were analyzed, usually no more than 1-2 weeks after being sampled from the field.

Nitrous oxide concentrations were quantified with a Gas Chromatograph (GC) fitted with electron capture detectors (Model 5890 Series, Hewlett Packard, Hewlett Packard Company, Avondale, PA). The general procedure in using the GC was to run three standard N_2O concentrations of 0.1, 0.5 and 1.0 ppm, sequentially, at the beginning of the day, and three standard N_2O concentrations of 0.5 ppm at the end of the working day, to ensure the calibration of the GC. To eliminate the chances of contamination into the detector, 20-30 mL of N_2 gas (blanks) was injected into the pre-column, to prevent contamination and carryover effects reaching the detector. The injection of blanks was performed after each standard, the field standard and during regular intervals during the field N_2O sample analysis.

A Campbell CR10 Scientific datalogger (Campbell Scientific Inc., Edmonton) was set-up on site to record air temperature and precipitation. Air temperature and precipitation were also recorded by Montreal PET International Airport, located 20 km east of the site. Soil moisture and soil temperature were measured in proximity to the N_2O gas measurement locations throughout the experimental period. All moisture contents were determined gravimetrically and then converted to volumetric soil moisture using the bulk density. Following planting, thermocouples (WatchDog Model 100 Docking Station, Spectrum Technologies, Inc.) were inserted in each plot to measure soil temperature at 0-10 and 10-20 cm depth. The thermocouples were located no more than 0.10 m from the flux measurement points. Hourly soil temperatures during the period of N_2O measurements were averaged for each sampling date.

Calculation of soil N_2O fluxes: The soil surface N_2O fluxes (F_{N2O}) were calculated from the following equation[21]:

$$F_{N2O} = dC/dt\ (V\ Mmol/A\ Vmol) \quad (1)$$

Where:

dC/dt = The rate of change of N_2O concentration
V = The chamber headspace volume (m^3)
Mmol = The molecular weight of N_2O (44 g moL^{-1})
A = The surface area covered by the chamber (0.29 m^2)
Vmol = The volume of gas at 20°C (0.024 m^3 moL^{-1})

The slope dC/dt was found by plotting time (in seconds) versus N_2O concentration (in nmol moL^{-1}). The units of N_2O fluxes (F_{N2O}) were ng m^{-2} sec^{-1}.

The relationship between N_2O concentrations (four values) and time (t = 0, 10, 20 and 30 min) was tested for linearity. For linear conditions, a line of best fit was plotted through these four points, giving the slope dC/dt and hence the rate. In cases where the relationship was found to be non linear, Eq. 2[21] was used to calculate the rate and soil F_{N2O}:

$$f = \frac{V(C_1 - C_0)^2}{At(2C_1 - C_2 - C_0)} \ln\left[\frac{C_1 - C_0}{C_2 - C_1}\right] \quad \text{for } t_2 = 2t_1$$

and (2)

$$\frac{C_1 - C_0}{C_2 - C_1} > 1$$

Where:

f = The measured flux (in units of mass $area^{-1}$ $time^{-1}$)
Zv = The internal volume of the chamber
A = The soil area it covers
t = Time and C is the trace gas concentration

Statistical analyses: All the F_{N2O} data were tested for a standard normal distribution. In cases where the data were not normally distributed, the F_{N2O} values were log-transformed; the results presented have been back transformed to facilitate readability. Statistical analyses were performed using the General Linear Model (GLM) procedure[23]. Differences among treatments were evaluated using protected (only if ANOVA indicates a significant F value) Least Significant Difference (LSD) comparison. Unless otherwise stated, α = 0.05 probability level was used to declare whether or not a difference is statistically significant.

RESULTS

The spring of 2003 was wetter and cooler than normal (Table 1). On average, the latter half of the 2003 growing season (July, August and September) had warmer than normal temperatures, with less than normal precipitation. August was a dry month causing soil moisture contents to drop to extremely low levels. The 2004 growing season had temperatures and precipitations that were similar to normal, except May when precipitation was greater than normal. Precipitation in July and August were slightly lower than normal, causing soil moisture to remain low during this period. The soil temperatures (0-0.10 m depth below the soil surface) were generally similar among all treatments during both seasons, except few instances when CT plots tended to be warmer than NT, particularly during June and July (Fig. 1 and 2).

As expected, the lowest soil temperatures were measured in spring and the beginning of summer, and the highest soils temperatures were recorded at the end of June to the beginning of July (Fig. 1 and 2). The soil was not covered by snow during the recording period, but experienced thawing and was saturated by runoff at the beginning of spring which contributed to wetter and colder soils during this time.

From May to early October, the N_2O emissions at the experimental site varied from 9-175 ng m^{-2} sec^{-1} in 2003 (Table 2) and from 11-290 ng m^{-2} sec^{-1} in 2004 (Table 3). In 2003, the CT-R treatment produced the highest N_2O emissions recorded during the season of 175.3 ng m^{-2} sec^{-1} on May 22, following first application of fertilizer on May 21 (Table 2). In 2004, the highest average N_2O emissions for the season of 290 ng m^{-2} sec^{-1} was recorded on April 16 prior to fertilizer application under CT-R plots (Table 2).

Table 1: Summary of climatic data for 2003 and 2004 season

Month (mm)	Mean Temperature (°C) 2003	Mean Temperature (°C) 2004	Normal mean temperature* (°C)	Total Precipitation (mm) 2003	Total Precipitation (mm) 2004	Normal precipitation*
April	6.9	4.2	5.70	79.9	76.9	74.8
May	11.3	13.4	12.90	127.5	110.5	66.7
June	17.5	18.8	18.00	106.0	70.0	82.5
July	22.1	21.6	20.80	55.0	54.0	85.6
August	21.8	21.6	19.40	11.0	79.0	100.3
September	18.3	17.7	14.50	64.5	104.0	86.5

*: Normal mean temperature and normal precipitation are based on data from 1971-2000; (Environment Canada, 2003 and 2004)

Table 2: Soil N_2O flux (ng m^{-2} sec^{-1}) for NT+R, NT-R, CT+R and CT-R in the growing season of 2003

	Sampling dates											
Tillage	1May	9 May	22 May	8 June	18 Jun	24 June	16 July	31 July	15 Aug.	29 Aug.	14 Sept.	3 Oct.
NT+R	10.8a (6.9)	15.6a (7.5)	36.4a (22.1)	93.6a (47.8)	73.6a (37.9)	84.3a (25.6)	20.6a (12)	42.3a (25.5)	20.2a (10)	28.8a (8.7)	19.1a (12.5)	12.2a (9)
NT–R	13.8a (4.6)	27.4b (5.3)	152 b ((53.4)	77.9a (27)	87.9a (27.6)	54.3a (17.4)	21.7a (7.3)	30.3a (13.8)	16.3a (12.8)	21.4a (10.0)	20.5a (8.1)	14.9a (7.4)
CT+R	9.0a (7.1)	14.7a (4.8)	72.6a (40.2)	169b (30.4)	48.8b (21.4)	91.2b (16.7)	33.9a (24.2)	33.2a (15)	12.4a (6.9)	15.6a (5.6)	20ab (5.8)	19.0a (9.8)
CT–R	10.1a (6.8)	30.4b (10.6)	175b (26.8)	32.1a (5.1)	32.1b (5.1)	42.8a (9.8)	20.6a (16.7)	26.3a (19.8)	12.0a (8.4)	13.5a (4.3)	25.8b (6.9)	22.1a (13)

NT+R: No tillage with residue; NT-R: No tillage without residue; CT+R: Conventional tillage with residue; CT-R: Conventional tillage without residue. Values within the same column followed by different letters are statistically ($p \leq 0.05$) different. Values between parentheses are standard deviations (n = 6)

Table 3: Soil N_2O flux (ng m^{-2} sec^{-1}) for NT+R, NT-R, CT+R and CT-R during 2004 growing season

	Sampling dates												
Tillage	April 11	April 16	April 30	May7	May28	June 11	June 27	July 14	July 28	Aug. 13	Aug. 27	Sept. 17	Oct. 01
NT+R	118.4a	50.1a	144.3a	38.7b	31.8a	38.6a	45.4a	38.6a	28.4a	17.6a	20.7a	12.3a	20.7a
	(82.6)	(24.1)	(51.4)	(27.3)	(14.5)	(14.9)	(25.7)	(18.1)	(12.0)	(9.8)	(11.3)	(2.7)	(12.0)
NT–R	36.4b	23.9a	84.2b	63.4a	45.6a	49.0a	89.4a	37.6a	13.3a	16.1a	20.3a	16.6a	11.1a
	(22.5)	(27.7)	(48.6)	(46.2)	(11.1)	(23.7)	(74.5)	(26.0)	(7.9)	(12.7)	(6.4)	(6.1)	(3.9)
CT+R	63.8a	227.4b	145.7a	90.9a	37.7a	51.7a	35.9a	21.6a	22.9a	15.6a	12.0a	19.2a	11.0a
	(36.0)	(130.1)	(24.3)	(35.0)	(5.6)	(23.1)	(16.7)	(11.8)	(8.1)	(10.1)	(5.2)	(12.3)	(8.9)
CT–R	30.6b	290.8b	109.7b	72.9a	34.7a	43.7a	29.8a	25.5a	26.0a	18.4a	18.7a	13.7a	12.7a
	(22.0)	(117.7)	(57.4)	(50.3)	(24.5)	(21.9)	(9.9)	(19.8)	(32.0)	(8.5)	(12.7)	(5.9)	(8.0)

NT+R: No tillage with residue; NT-R: No tillage without residue; CT+R: Conventional tillage with residue; CT-R: Conventional tillage without residue. Values within the same column followed by different letters are statistically ($p \leq 0.05$) different. Values between parentheses are standard deviations (n = 6)

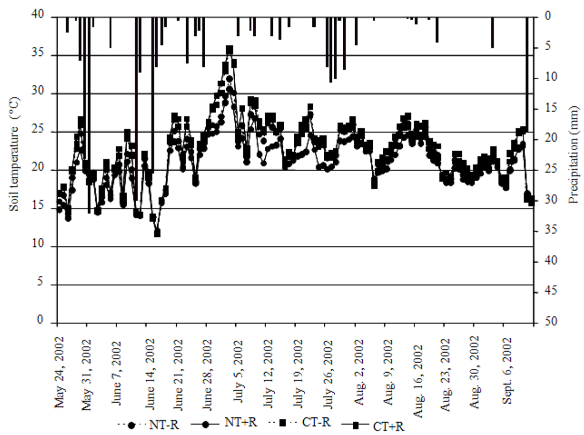

Fig. 1: Precipitation and daily soil temperature readings for 2003 at 0-0.10 m soil depth for NT-R = no-till, silage corn; NT+R: No-till, grain corn; CT-R: Conventional tillage, silage corn; CT+R: Conventional tillage, grain corn

There were a number of sampling dates where there were significant ($p \leq 0.05$) differences among the treatments during the two growing seasons. These sampling dates were May 09, 22, 08, June 18, 24 and September 04 in 2003 (Table 2) and April 11, 16, 30 and May 07 in 2004 (Table 3). It was interesting to observe that nearly in all cases, plots under CT, with or without crop residue, produced significantly greater N_2O than plots under NT. This was particularly evident in 2003 growing season following fertilizer application with the exception of September 04 sampling date (Table 2), where N_2O fluxes increased within days after fertilizer application, then declined towards background levels. Although sampling was more frequent in 2004 than 2003, we measured N_2O emissions under CT greater than NT only during spring prior to fertilizer application (Table 3).

Soil water contents were converted into percent Water Filled Pore Space (WFPS) to get a better indication of potential denitrification. From these results,

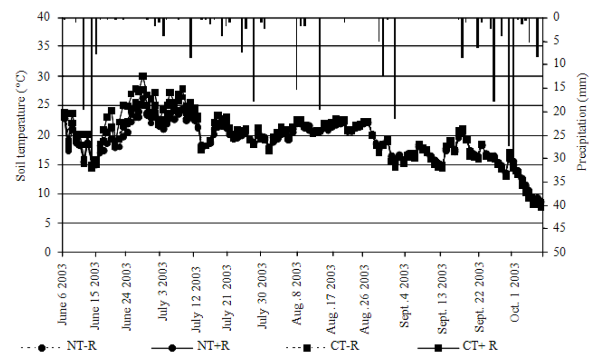

Fig. 2: Precipitation and daily soil temperature readings for 2004, at 0-10 cm depth for NT-R: No-till, silage corn; NT+R: No-till, grain corn; CT-R: Conventional tillage, silage corn; CT+R: Conventional tillage, grain corn

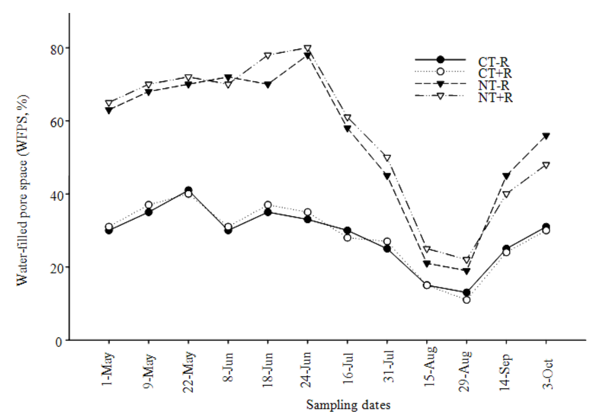

Fig. 3: Water filled pore space in 2003 from (a): 0-10 cm and (b): 10-20 cm depth for NT-R: No-till, silage corn; NT+R: No-till, grain corn; CT-R: Conventional tillage, silage corn; CT+R: Conventional tillage, grain corn

the NT under both with or without residue (+R/-R) treatments had WFPS values above 0.62 for most of the period from May 8-June 27 (Fig. 3 and 4),

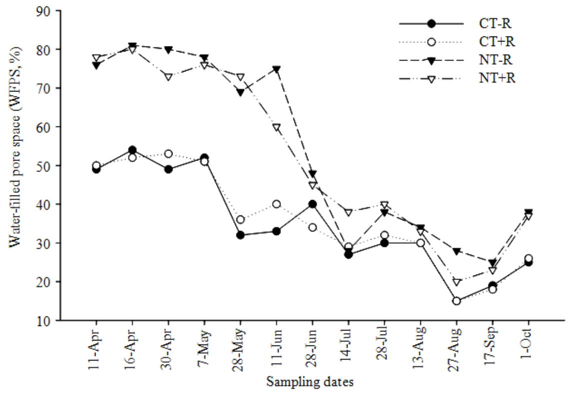

Fig. 4: Water filled pore space in 2004 from 0-20 cm depth for NT-R: No-till, silage corn; NT+R: No-till, grain corn; CT-R: Conventional tillage, silage corn; CT+R: Conventional tillage, grain corn

indicating conducive soil conditions for dentrification process to occur. The CT (with and without residue) treatments had WFPS levels below 0.62 for the 2003 growing season. Soil moisture for the 2004 season (Fig. 4) for all the treatments exhibited the same pattern as the 2003 season; high spring values, declining in August and rising again in September. Apparently this lack of difference was due to overall higher precipitation amounts received in 2004 (Table 1).

DISCUSSION

Soil temperature during the growing season was not affected significantly ($p \le 0.05$) by the tillage system. This finding is consistent with the recent report by[24] who found growing season soil temperature not being different between NT and CT, except the month of May, when soil temperatures tended to be warmer in CT soils compared with NT soils. As will be discussed in the coming sections, the slightly warmer temperature in early spring might have contributed the burst of N_2O emissions in 2004. This is a suggestion that N_2O emission was not consistently responsive to fertilizer application alone. It was interesting to note that both peak values of emissions occurred in CT in the early days of spring (April 16, 2004), probably because both CT-R and CT+R warmed more rapidly than wetter NT soils (WFPS 80%), causing the burst of N_2O under CT. However, it is not possible to verify this plausible explanation since soil temperature probes were not installed until field operations were complete. After June, treatment differences were minimal (all treatments had similar values below 42 and 91 ng m^{-2} sec^{-1} in 2003 and 2004, respectively). The slight peak on June 27 in 2004 appears to have resulted from heavy rainfall event immediately after second fertilizer application (Fig. 2). Nitrous oxide fluxes decreased to background levels as the growing season progressed, regardless of the timing of the second fertilizer application.

The N_2O fluxes are known to be strongly episodic in nature and a few peak values can contribute significantly to overall N_2O production. We recognize that peak values that can contribute significantly to the overall N_2O production might not have been captured with the kind of sampling frequency in most studies, including ours. Increasing sampling frequency during the seasons of high potential N_2O production, as well as setting up more chambers in each treatment may help to determine the extent to which N_2O emissions estimates can be improved by a given temporal sampling protocol. From practical point of view however, the work we report is labor-intensive and more frequent sampling was not feasible given the resources available.

It is worth noting that trends of N_2O fluxes for CT were generally similar to, but of greater magnitude, than those under NT for both growing seasons (Table 2 and 3). Results from more humid regions (or periods) have generally produced greater emissions under NT than CT systems[16]. In contrast, results obtained from a corn field in southwestern Quebec showed greater denitrification rates under NT soils than under CT, not only during spring but also during entire growing season[25]. This has led them to recommend that corn production should be carried out under CT, if mitigating N_2O emission were a priority.

Under controlled conditions[26], reported significantly higher N_2O emissions under NT compared with CT. Other researchers noted that N_2O fluxes under NT were not different than those under CT[16]. The reason for these differing findings could be to the fact that wetter soils under NT produce higher denitrification rates, with N_2 becoming the major or sole product of denitrification[27,28]. Similarly, Rolston *et al*.[29] found that, with increasingly anoxic conditions (i.e., higher WFPS), the percentage of N_2O during denitrification decreases, while the production of N_2 is favored, particularly when a source of readily available C is present[30] found that under NT, denitrification was increased when compared with CT. They postulated that the difference was in part due to the presence of a greater amount of oxidizable C in the surface soils under NT.

Since source of carbon is one of the primary requirements for N_2O production, it is possible that N_2O production through denitrification process is more likely to be limited in soils under CT than NT[31]. reported that although soil organic C changes in response to management practices could be relatively rapid, it still took about 10 y to obtain stable management effects. By the time our N_2O measurements were made in the present study, it had been 12 y after NT was implemented and, therefore, it is plausible that the soil processes associated with a change in cropping practice (changes in organic matter, pH, aggregate stability) have stabilized and reaching or approaching equilibrium state. It is worth noting that previous study from this site showed that the differences in Dissolved Organic Carbon (DOC) between NT and CT tillage systems were not consistently significant at any soil depth[18].

Despite somewhat contradictory findings, the general consensus is that because of higher moisture and organic matter content, and higher microbial populations, NT tends to produce higher denitrification rates, depending on prevailing climatic conditions at the time of measurements. For example[14] suggested that NT management in periods or regions that are relatively warm and wet may result in N_2O emission rates similar or less than those under CT and NT and may thus be a viable means to reduce N_2O emissions. These authors documented that in drier periods or regions, N_2O emissions were greater under NT because of increased soil moisture content.

The large variability of N_2O fluxes might have obscured significant differences being detected. Although precautions were taken to lower experimental errors, such as using a high quality septum on the vials, and analyzing the gas samples within a week of sampling, nevertheless, N_2O emissions remained highly variable as evidenced by large standard deviations (Table 2 and 3). High spatial and temporal variations in N_2O emissions were also found by several other researchers[32-34], particularly during the spring thaw period. Also, in studies using micrometeorological flux towers, the Coefficient of Variation (CV) due to spatial variability in N_2O fluxes during spring was high, ranging from 30-180%[35]. Large CV's have been attributed to lag times in N_2O release from different areas of the same field[36]. At this site, the particular uneven soil moisture patterns in spring were thought to contribute to the high F_{N2O} standard errors measured in spring. This pattern of uneven moisture distribution in spring at the site creates non-homogeneous moisture conditions, which will cause uneven N_2O fluxes[37]. Similarly, correlation analysis did not show statistically significant relationship between N_2O fluxes and soil temperature in this study either (data not shown).

Soil water content influences denitrification (evolution of N_2 and N_2O) significantly. Previous study from the same site of this study[18], reported that soil water contents (i.e., WFPS) were higher under NT filling more soil pores with water, which would have increased volume of anaerobic zones within soil profile, creating conditions conducive to denitrification processes. They explained that soil moisture conditions under NT (WFPS>70%) might have allowed complete denitrification to N_2 and the soil acted as a sink for N_2O. Similarly, Grundmann *et al.*[38] showed that denitrification is most apt to occur when soil wetness, or the WFPS, is above 0.62 (or 62%)[39] determined denitrification to be highest at, or above, 60% WFPS. found that all of the N_2O emitted at 70% WFPS was produced during denitrification, but nitrification was the process producing N_2O at 35-60% WFPS.

CONCLUSION

No-till conservation is commonly practiced in order to reduce soil erosion and energy consumption in North America. To gain better understanding, we investigated the effects of CT and NT on N_2O emissions using long-term plots. Observations of N_2O emissions over two growing seasons demonstrate that NT system did not contribute significantly greater atmospheric N_2O than CT as suggested by some in the literature. We interpret these results that denitrification in the NT treatments might have been producing more N_2 than N_2O. Further research is required under different conditions to determine if NT favors N_2 production. If so, then NT maybe a Best Management Practice (BMP) to mitigate N_2O emissions in agricultural soils.

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