Science of the Total Environment 619–620 (2018) 18–27

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Long-term effects of contrasting tillage on soil organic carbon, nitrous oxide and ammonia emissions in a Mediterranean Vertisol under different crop sequences

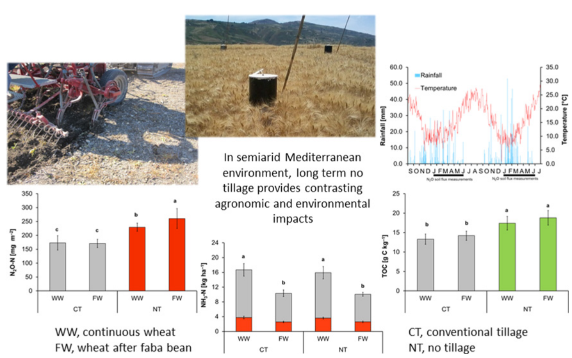
Giuseppe Badagliacca [a,b], Emilio Benítez [c], Gaetano Amato [a], Luigi Badalucco [a], Dario Giambalvo [a], Vito Armando Laudicina [a,*], Paolo Ruisi [a]

[a] Dipartimento di Scienze Agrarie, Alimentari e Forestali, Università degli Studi di Palermo, Viale delle Scienze, 90128 Palermo, Italy
[b] Dipartimento di Agraria, Università Mediterranea di Reggio Calabria, Feo di Vito, 89124 ReggioCalabria, Italy
[c] Departamento de Protección Ambiental, Consejo Superior de Investigaciones Científicas (CSIC), Estación Experimental del Zaidín (EEZ), Calle Profesor Albareda 1, 18008 Granada, Spain

HIGHLIGHTS

- Tillage effects on soil organic C and N gas emissions were assessed in two crop sequences.
- N_2O emissions, but not total NH_3 emissions, were higher in NT than CT.
- Continuous application of NT for 23 years increased bulk density, WFPS, TOC and EOC in the topsoil compared to CT.
- Denitrifying enzyme activity and nosZ gene were enhanced by long term NT.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 September 2017
Received in revised form 9 November 2017
Accepted 9 November 2017
Available online xxxx

Editor: Jay Gan

Keywords:
No tillage
Greenhouse gas emissions
Carbon stock
nosZ gene
Mediterranean environment
Wheat

ABSTRACT

This 2-year study aimed to verify whether the continuous application of no tillage (NT) for over 20 years, in comparison with conventional tillage (CT), affects nitrous oxide (N_2O) and ammonia (NH_3) emissions from a Vertisol and, if so, whether such an effect varies with crop sequence (continuous wheat, WW and wheat after faba bean, FW). To shed light on the mechanisms involved in determining N-gas emissions, soil bulk density, water filled pore space (WFPS), some carbon (C) and nitrogen (N) pools, denitrifying enzyme activity (DEA), and nitrous oxide reductase gene abundance (nosZ gene) were also assessed at 0–15 and 15–30 cm soil depth. Tillage system had no significant effect on total NH_3 emissions. On average, total N_2O emissions were higher under NT (2.45 kg N_2O-N ha^{-1}) than CT (1.72 kg N_2O-N ha^{-1}), being the differences between the two tillage systems greater in FW than WW. The higher N_2O emissions in NT treatments were ascribed to the increased bulk density, WFPS, and extractable organic C under NT compared to CT, all factors that generally promote the production of N_2O. Moreover, compared to CT, NT enhanced the potential DEA (114 vs 16 μg N kg^{-1} h^{-1}) and nosZ gene abundance (116 vs 69 copy number mg^{-1} dry soil) in the topsoil. Finally, NT compared to CT led to an average annual increase in C stock of 0.70 Mg C ha^{-1} year^{-1}. Though NT can increase the amount os soil organic matter so storing

Abbreviations: NT, no tillage; CT, conventional tillage; WW, wheat grown after wheat; FW, wheat grown after faba bean; TOC, total organic carbon; EOC, extractable organic carbon; TN, total nitrogen; WFPS, water filled pore space; BD, bulk density; DEA, denitrifying enzyme activity.

* Corresponding author.
E-mail address: vitoarmando.laudicina@unipa.it (V.A. Laudicina).

https://doi.org/10.1016/j.scitotenv.2017.11.116
0048-9697/

CO_2 into soil, some criticisms related to the increase of N_2O emission arise, thereby suggesting the need for defining management strategies to mitigate such a negative effect.

1. Introduction

Agricultural activities are considered as the primary source of nitrous oxide (N_2O) and ammonia (NH_3) emissions (IPCC, 2007; EEA, 2009). Nitrous oxide emissions are linked to many soil microbial processes: 1) dissimilatory reduction of nitrates and nitrites to N_2 when O_2 concentrations is decreasing (denitrification); 2) nitrification (oxidation of NH_3 to NH_2OH and then to N_2O); and 3) by nitrifiers paradoxically denitrifying (reduction of nitrites to N_2O) (Čuhel et al., 2010; Abalos et al., 2017; Kool et al., 2011). The emission of N_2O from soil is influenced by O_2 partial pressure, moisture and temperature, pH, organic C and nitrates availability (Čuhel et al., 2010; Stevenson et al., 2011). In a recent meta-analysis, Cayuela et al. (2017) indicated water regime, crop type, and N fertilizer management as the most important factors controlling the magnitude of N_2O emissions from Mediterranean agricultural lands. Similarly to N_2O, NH_3 volatilization is positively related to soil organic C and microbial biomass, soil pH, moisture, temperature, NH_4^+ concentration in the soil solution, and negatively related to soil cation exchange capacity (Cameron et al., 2013). Due to the plurality of factors influencing N gases emissions, it is not surprising that the estimates for both N_2O and NH_3 emissions from agricultural soils are extremely variable.

Tillage system, by influencing soil aeration and temperature, water content, total and labile organic C, and the supply of N (Martin-Lammerding et al., 2011; Laudicina et al., 2014), may affect the soil microbial structure and activity and hence the N gas emissions (Mutegi et al., 2010; García-Marco et al., 2016). However, knowledge of the effects of tillage system on N gas emissions from soils is still limited and often controversial, at least for the Mediterranean areas. Comparing no tillage (NT) to conventional tillage (CT; usually based on moldboard plowing), Plaza-Bonilla et al. (2014) observed, under rainfed Mediterranean conditions, higher N_2O emissions under NT in the short-term (<4 years) but similar N_2O fluxes between NT and CT in the long term (>10 years). Similar results are reported in many studies conducted in temperate, humid or sub-humid environments (Baggs et al., 2003; Six et al., 2004; Rochette, 2008; Beare et al., 2009; Kong et al., 2009; Bayer et al., 2015), where the authors ascribed these effects to the poorer water drainage and aeration, and to the resulting lower availability of O_2 and the minor diffusion of gases through the soil under NT compared to CT conditions. On the contrary, other studies reported lower N_2O emissions in NT than in CT soils, both in temperate (Chatskikh and Olesen, 2007; Omonode et al., 2011; van Kessel et al., 2013) and Mediterranean areas (García-Marco et al., 2016).

Tillage system can also have an important role in determining the amount of N lost as NH_3 via volatilization. Several authors observed higher NH_3 emissions in NT than CT soils, especially when crop residues left on soil surface are abundant and N fertilizer used is urea (Palma et al., 1998; Rochette et al., 2009). In NT systems, in fact, the lack of mixing the N fertilizer into the soil and conversely the direct contact of the N fertilizer granules with the crop residues present on soil surface increases the risk of NH_3 losses. Crop rotations that include N_2-fixing legume species within the crop sequence have been often reported as a valuable N gas emission mitigation strategy (as reviewed by Jensen et al., 2012 and Sanz-Cobena et al., 2017), mainly due to less mineral N fertilizers applied to soil. On the other hand, other authors have highlighted that, since denitrification rate is positively related to the concentration of soil nitrates (Wagner-Riddle and Thurtell, 1998), legumes can increase N_2O emissions as a result of N released from decomposition of the N-rich crop residues (Rochette and Janzen, 2005; Tellez-Rio et al., 2015a) and/or due to their poor efficiency in recovering the plant-available soil mineral N (Jensen et al., 2012; Saia et al., 2016).

Therefore, we performed a 2-year study in a typical Mediterranean environment: to verify i) whether the long-term (over 20 years) NT affects the C and N pools, and the emissions of N_2O and NH_3 from soil and, if so, ii) whether such effect varies when crop sequence varies, and iii) to gain a better insight into how agricultural management may affect N gas emissions through changes on soil physical and chemical properties. Durum wheat (*Triticum durum* Desf.) was used as focal crop.

2. Material and methods

2.1. Experimental site

The field crop trial was carried out under rainfed conditions at the experimental Pietranera farm of the University of Palermo. The farm is located about 30 km north of Agrigento (Sicily, Italy, 37°30′ N, 13°31′ E; 178 m a.s.l.). The soil was classified as Chromic Haploxerert (Vertisol) and its characteristics, determined at the beginning of the experiment (year 1991) and referring to the 0–40 cm top layer, were 525 g kg^{-1} clay, 216 g kg^{-1} silt, 259 g kg^{-1} sand, pH 8.1 (in water), 14 g kg^{-1} total organic C, 1.29 g kg^{-1} total N, 36 mg kg^{-1} available P (Olsen).

The climate at the experimental site is semiarid Mediterranean, with a mean annual rainfall of 572 mm (1995 to 2015), concentrated mostly during the autumn–winter period (September–February; 76%), and spring (March–May; 19%). The dry period occurs from May to September. Mean air temperature is 15.9 °C in autumn, 9.7 °C in winter, and 16.5 °C in spring. Climatic data from September 2013 to July 2015 was collected from the nearest weather station located 500 m far from the experimental site.

2.2. Experimental design and crop management

The experiment was set up in fall 1991 as a strip-plot design with two replications, where three soil tillage systems (conventional, reduced, and no tillage) acted as vertical treatments and three crop sequences (wheat–wheat, wheat–faba bean, and wheat–berseem clover) as horizontal ones. More details are reported in Giambalvo et al. (2012) and Amato et al. (2013). The experimental factors tested here were tillage system (conventional tillage, CT, and no tillage, NT) and crop sequence (continuous wheat, WW, and wheat after faba bean, FW). Conventional tillage consisted of one moldboard plowing to a depth of 30 cm in the summer, followed by one or two shallow harrowing (0–15 cm) operations before planting. No tillage consisted of sowing by direct drilling. Plot area size was 370 m^2 (18.5×20.0 m). In NT plots, weeds were controlled before planting with glyphosate at a dose of 533 to 1066 g acid equivalent ha^{-1}, depending on the development of weeds. Every year, WW and FW plots were broadcast fertilized with 69 kg ha^{-1} of P_2O_5 just before planting. Nitrogen fertilizer was broadcast on the soil surface at 120 kg N ha^{-1} in WW plots and 80 kg N ha^{-1} in FW plots. The total amount of N fertilizer was broadcasted as follows: 50% applied immediately before planting (as diammonium phosphate and urea) and 50% applied at mid-tillering (end of March; during this experiment, it was just before the 2nd soil sampling) as ammonium nitrate. Crop planting was always in December using a no-till seed drill with hoe openers under both CT and NT, making the appropriate sowing depth adjustments to ensure a homogeneous planting depth (3–5 cm). Durum wheat (cv. Anco Marzio) was planted in rows spaced 16 cm apart at 350 viable seeds m^{-2}. In WW