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Mitigation impact of minimum tillage on CO_2 and N_2O emissions from a Mediterranean maize cropped soil under low-water input management

Annachiara Forte[a,*], Nunzio Fiorentino[b], Massimo Fagnano[b], Angelo Fierro[a,c]

[a] Dipartimento di Biologia, Università di Napoli Federico II, Italy
[b] Dipartimento di Agraria, Università degli Studi di Napoli Federico II, via Università 100, 80055 Portici, Italy
[c] Laboratorio di Urbanistica e Pianificazione del Territorio (LUPT), Università degli Studi di Napoli Federico II, Italy

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ABSTRACT

Reduced tillage might reduce greenhouse gas (GHG) emissions from cropped soils. However the topic is somehow still controversial, since lower CO_2 emissions achieved through reduced soil mineralization might be offset by higher N_2O losses from less disturbed soil, because of higher water filled pore space. This work aimed to clarify the potential GHG mitigation benefits of minimum tillage (MT), as opposed to mouldboard ploughing (CT), for Mediterranean maize cultivations under low water input management. To this end, soil CO_2 and N_2O fluxes were monitored at high time resolution by means of a newly developed automated system of closed static chambers coupled to a field gas photoacoustic detector. Relative to CT, cumulated CO_2 emissions appeared significantly reduced in MT over three months after the autumn ploughing (by about 30%) and along the spring-summer cultivation (by about 28%), for similar maize yields. N_2O emissions from MT showed restrained averaged values relative to CT (by 40% and 18% for fallow and maize periods, respectively); however differences might not be significant. For both treatments, N_2O emission factors were lower than the 1% IPCC default value (0.40 and 0.28 for CT and MT, respectively), following the restrained irrigation water input along the drought period. Results indicate that MT reduced GHG emissions both (i) in the short-term, likely due to the increased decomposition of soil organic matter in the ploughed soil (CT), mainly concentrated within the first week after deep tillage; (ii) in the longer-term, likely through its capacity to constrain the daily soil temperature fluctuations in the drought periods along the spring-summer maize cultivation. At this stage, the low-water input management might have played a key role in mediating the response of N_2O emissions to MT treatment.

These findings suggest that minimum tillage could entail consistent GHG benefits under the drip irrigation management in Mediterranean croplands.

1. Introduction

Global atmospheric concentrations of Carbon dioxide (CO_2) and Nitrous oxide (N_2O) have markedly increased since the pre-industrial time. In fact, current values for CO_2 and N_2O (390.5 ppm and 324.2 ppb) appear 40% and 20% higher than in 1750 (IPCC, 2013). They respectively account for about 26% and 7.9% of the total greenhouse effect and are greatly affected by the agricultural sector, which contributes to about 10–12% of total global anthropogenic emissions of greenhouse gases (GHGs) (IPCC, 2007). Agricultural N_2O emissions are mainly linked to the increased fertilizer N consumption and have risen by nearly 17% from 1990 to 2005 (Smith et al., 2007), sharing about 60% of the global anthropogenic N_2O emissions (IPCC, 2007). Differently, the net CO_2 flux from soil in agricultural land is estimated to be nearly balanced (IPCC, 2007). However, soil organic carbon losses by CO_2 emissions are generally promoted by tillage, due to the enhanced microbial degradation (La Scala et al., 2006; Fagnano and Quaglietta Chiarandà, 2008; Mangalassery et al., 2014). On one hand, these C losses from long-term cultivations may have contributed to the recent global warming trend (IPCC, 2007). On the other hand, a significant potential of CO_2 sink may be recognized for C friendly managed cropped soils, through soil carbon sequestration.

* Corresponding author.
E-mail addresses: anforte@unina.it, annachiara.forte@libero.it (A. Forte).

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Conservation tillage practices (including zero and minimum tillage) have gained increasing interest among mitigation options, reducing soil derived GHG emissions and preserving at the same time crop yields (Maraseni and Cockfield, 2011; Alluvione et al., 2013; Plaza-Bonilla et al., 2014; Busari et al., 2015). They are widely recognized to: (i) preserve soil from degradation and erosion (Abdalla et al., 2013); (ii) enhance the stability of soil organic matter (SOM) aggregates (West and Marland, 2002; Li et al., 2007; He et al., 2011; Madejón et al., 2009; Abdalla et al., 2013); (iii) promote carbon sequestration and contextually reduce CO_2 emissions (West and Marland, 2002; West and Post, 2002; Abdalla et al., 2013).

Currently, there is a lack of consistency in addressing tillage effects on CO_2 emissions from soil under dry/warm climatic conditions (Abdalla et al., 2013). Additionally, zero and minimum tillage may increase water retention and anaerobic microsites which promote N_2O fluxes from soil through denitrifying activities (Lee et al., 2009; Kong et al., 2009; Maraseni and Cockfield, 2011). The enhanced nitrous oxide emissions under these conditions might also entirely offset the benefits entailed through conservation tillage management in terms of reduced CO_2 emissions and C sequestration in SOM (Maraseni and Cockfield, 2011). Also the effect of reduced or zero tillage adoption on N_2O emission is still uncertain and not well quantified both globally (Smith and Conen, 2004) and in the Mediterranean context (Lee et al., 2009; Aguilera et al., 2013; Plaza-Bonilla et al., 2014). Most of the studies, about the effect of tillage management on N_2O fluxes from soil, highlighted a trend in wet soils (both cold and warm) for enhanced cumulative losses under reduced, minimum and no-till conservation tillage as opposite to conventional ploughing, due to increased soil bulk density and water content (Lee et al., 2006, 2009; Kong et al., 2009; Steenwerth and Belina, 2008, 2010; Garland et al., 2011; Abdalla et al., 2013; Aguilera et al., 2013; Plaza-Bonilla et al., 2014).

However, the process appears tuned by the interaction of site specific soil-climatic-crop parameters and by the short-term (a few years) or long term (>10 years) ongoing C-friendly management. As a result, N_2O emissions under conservation tillage schemes as an alternative to conventionally tilled soils can appear both: (i) increased (Baggs et al., 2003; Lee et al., 2006; Steenwerth and Belina, 2008, 2010; Kong et al., 2009; Garland et al., 2011; Plaza-Bonilla et al., 2014) and (ii) invariant or even reduced (Heller et al., 2010; Garland et al., 2011; Plaza-Bonilla et al., 2014).

Given the controversial balance between the advantages and the disadvantages of non-inversion tillage under specific pedo-climatic conditions, there is still the need to investigate the effectiveness of reduced cultivation schemes which might be promoted and widespread adopted to mitigate and reduce climatic impact of crop cultivation on a large scale.

Specifically, studies about the effect of C-friendly tillage on GHG emissions under Mediterranean conditions appear underrepresented. In these agro-ecosystems it has recently been recognized that drought can limit the N_2O fluxes during the spring-summer crops to restrained spatial and temporal hot-spots on irrigation events following fertilization, especially in the case of low-water input irrigation management (Sánchez-Martín et al., 2008, 2010; Ranucci et al., 2011; Aguilera et al., 2013; Castaldi et al., 2015). Therefore, under low optimized water supply such as drip irrigation, climate change mitigation potential of reduced tillage management may not be hindered by concomitant relevant enhanced N_2O emissions.

The objective of this study was to address the potential GHG benefits associated with the adoption of minimum tillage (MT) for drip irrigated maize in Southern Italy. The work was carried out in the wider framework of the MESCOSAGR Project, aimed to evaluate the short-term (within a three-year time frame) potential of alternative carbon friendly strategies (MT included) to sustain and increase crop yields and soil organic C in different pedo-climatic conditions. Specifically the authors hypothesized that minimum tillage would reduce emissions of GHGs compared to conventional cropping systems. To this end, field continuous N_2O and CO_2 flux chamber measurements were carried out along a typical cultivation of Southern Italy (maize for forage and silage), during both the fallow period of bare soil and the following spring-summer maize cultivation. Collected data were processed to (i) investigate discrepancies in GHG emissions patterns, analysing their dependence on soil chemical-physical key drivers and (ii) quantify the overall mitigating effect.

2. Material and methods

2.1. Study site

The field monitoring was carried out in an experimental farm of the University of Naples Federico II, located inside the Sele River Plain of Campania region in Southern Italy (40°37′N, 14°58′E, 30 m a.s.l.). The site is characterized by a typical Mediterranean climate, with long-term average yearly temperature of 15.5 °C and long-term average yearly precipitation of 908 mm (mostly occurring in autumn-winter). The soil is a typical Vertic Haploxeralf (USDA soil taxonomy; Soil Survey Staff, 2014), with a sandy-clay-loam texture: sand 47%- silt 20.1%- clay 32.9% and sand 46%- silt 24.5%- clay 29.5% for 0–15 cm and 15–30 cm soil depth, respectively. Main soil properties of the plow layer (0–30 cm) are: bulk density of 1.42 g cm^{-3}, pH of 7.4 (1 soil:2.5 water), 7.5 g organic C kg^{-1}, 0.9 g total N kg^{-1}, 31.5 mg Olsen P kg^{-1}, and 90.6 cmol exchangeable K kg^{-1}. Maize crop yields were 16 Mg d.m. ha^{-1} and 17 Mg d.m. ha^{-1}, for CT and MT, respectively (Table 1).

2.2. Experimental setup and crop management

The study focused on the cultivation of maize (*Zea mays* L), which represents a widespread crop for silage in the Campania region. To this end, in fall 2006, inside an agricultural field previously cropped with durum wheat after mouldboard ploughing, conventional mouldboard ploughing (CT, 30 cm depth) and minimum tillage (MT, by rotary harrow) trials were arranged in experimental 30 m^2 (6 × 5 m) plots, through a randomized complete block design with four replicates for each treatment. Afterwards, the CT and MT trials remained under their respective tillage management throughout fall in 2007 and 2008. In both treatments, each year (from 2006 to 2008), a maize crop was sown in spring and between maize cultivations, the soil was left bare (bare fallow period). During the maize cultivation both CT and MT treatments received two passes of rotary hoe for seedbed preparation, N, K and P fertilizers at sowing time (130 kg N ha^{-1}

Table 1
Scheduling of agronomic management practices and dry biomass yields for both treatments. Mouldboard ploughing at 30 cm applies only for CT.

Operations	Time
Main tillage in CT (mould-board plough at 30 cm)	11/10, 2007
Fertilization (130 kg N ha^{-1} as urea; 100 kg P_2O_5 ha^{-1} as triple superphosphate; 200 kg K_2O ha^{-1} as muriate of potash) and seedbed preparation (two harrowings)	05/05, 2008
Maize sowing (7.4 seeds per m^2)	06/05, 2008
Weed mechanical control by hoeing	18/06, 2008 22/07, 2008
Irrigation (362 mm total water applied)	11 applications
Harvest Total biomass (Mg d.m. ha^{-1}): 16 and 17 in CT and MT, respectively	20/08, 2008