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Research article

Potential role of compost and green manure amendment to mitigate soil GHGs emissions in Mediterranean drip irrigated maize production systems

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

[a] Dipartimento di Biologia, Università degli Studi di Napoli Federico II, Campus MS Angelo, via Cinthia, 80126 Napoli, 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

Organic fertilization can preserve soil organic matter (SOM) and is foreseen as an effective strategy to reduce green house gases (GHGs) emissions in agriculture. However, its effectiveness needs to be clarified under specific climate, crop management and soil characteristics. A field experiment was carried out in a Mediterranean drip irrigated maize system to assess the pattern of soil CO_2 and N_2O fluxes in response to the replacement of a typical bare fallow–maize cycle under urea fertilization (130 kg N ha^{-1} y^{-1}) (CONV) with: (i) bare fallow-maize cycles under two doses of compost (COM1 and COM2, 130 and 260 kg N ha^{-1} y^{-1}, respectively) and (ii) a vetch-maize cycle, with vetch incorporation as green manure (130 kg N ha^{-1} y^{-1}) (GMAN).

Along the maize period (MP), reduced daily N_2O emissions were detected in organic treated soils compared to CONV, mainly in the first stages of the cultivation, thanks to the slow release of available nitrogen from the organic substrates. Cumulative N_2O fluxes (kg N_2O-N ha^{-1}) in MP scored to 0.24, 0.14, 0.12 and 0.085 for CONV, COM1, COM2 and GMAN, respectively, with significantly lower emissions in GMAN respect to CONV. CO_2 fluxes partially reflected the ranking observed for maize yields, with cumulated values (Mg CO_2-C ha^{-1}) of 2.2, 1.5, 2.1, 2.1 for CONV, COM1, COM2 and GMAN, respectively, and significantly lower in COM1 respect to the other treatments.

During the fallow period (FP), compared to CONV (0.77 Mg CO_2-C ha^{-1} and 0.25 kg N_2O-N ha^{-1}), enhanced GHG fluxes were detected in COM treatments (about 0.90 Mg CO_2-C ha^{-1} and 0.37 kg N_2O-N ha^{-1}, as averaged values from COM1 and COM2), likely driven by the slow prolonged mineralization of the added organic matter. GMAN showed comparable CO_2 (0.82 Mg CO_2-C ha^{-1}) and N_2O emissions (0.30 kg N_2O-N ha^{-1}), in consequence of restrained post-harvest residual N coupled with the counteracting effect of vetch uptake.

Respect to the total yearly GHG emissions in CONV (about 194 kg CO_2 eq ha^{-1} y^{-1}), the overall results showed commensurate slightly higher GWP in COM treatments (+11% as averaged value from COM1 and COM2). The yield-scaled global warming potential (GWP) resulted 60% higher and nearly doubled for COM2 and COM1 respectively, according to the lower COM yields, markedly dampening at halved compost dose. GMAN appeared the best performing organic treatment, with lower GWP (−27%) and competitive yields respect to CONV.

All treatments showed N_2O emission factors consistently lower compared with the default IPCC 1% value.

1. Introduction

In the recent scientific debate on Greenhouse Gases (GHGs) mitigation strategies, solid organic amendments are foreseen as effective sustainable tools able to preserve soil fertility and enhance

* Corresponding author.
E-mail address: anforte@unina.it (A. Forte).

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soil carbon sequestration of atmospheric CO_2, at the same time potentially constraining soil GHG emissions in agroecosystems (Aguilera et al., 2013; Alluvione et al., 2010; Diacono and Montemurro, 2010; Franzluebbers, 2005; Freibauer et al., 2004; Gregorich et al., 2005; Lal, 2004; Li et al., 2013; Smith, 2004; Su, 2007; Tuomisto et al., 2012).

Currently, GHGs from the agriculture sector contributes to about 10–12% of total global anthropogenic GHG emissions (IPCC, 2007). Nitrogen input is a major driver of agricultural N_2O-N losses (Tuomisto et al., 2012), contributing to about 60% of the global anthropogenic N_2O emission (IPCC, 2007). Otherwise, the net CO_2 flux from cropped systems is assumed to be nearly balanced (IPCC, 2007), even if croplands can be both a source and a sink for CO_2 depending on the specific agronomic management (La Scala et al., 2006; Mangalassery et al., 2014; Tuomisto et al., 2012).

Organic fertilizations through compost and legume green manure can maintain the organic C levels in arable soils, increase soil C sequestration and sustain crop production by recycled and biologically fixed nitrogen (Alluvione et al., 2013; Grignani et al., 2007; Li et al., 2013; Melero et al., 2007; Tejada et al., 2008; Triberti et al., 2008).

Composting (of municipal solid waste-MSW, sewage sludge, green waste, etc.), highly recommended by the European policy on waste management (2008/98/EC), can both reduce the use of artificial fertilizers and preserve or enhance soil fertility increasing organic C and total N (Fagnano et al., 2011; Mantovi et al., 2005; Ros et al., 2006; Smith, 2004; Tuomisto et al., 2012). Moreover the use of compost can: (i) protect stabilized SOM (Lynch et al., 2006; Piccolo et al., 2004; Spaccini et al., 2002) and (ii) increase aggregate stability (Diacono and Montemurro, 2010; Spaccini and Piccolo, 2012). Green manure from legume intercrops: (i) enhance soil aggregate stability and protect soil from erosion (Gómez et al., 2009); (ii) promote N retention both in the fallow and cash crop periods (Cherr et al., 2006; Gabriel and Quemada, 2011).

However, the effective nexus between potential increase in C storage and decrease of soil GHG emissions is still controversial (Li et al., 2005). For instance, depending on the specific pedo-climatic context and the relative substrates composition in easily biodegradable or recalcitrant C compounds, organic fertilizers may contextually enhance soil CO_2 emissions (Ding et al., 2007; Li et al., 2013) and N_2O fluxes (Aguilera et al., 2013; Rochette et al., 2007) respect to mineral fertilization management in maize cultivation systems. Taking into account that N_2O global warming potential (GWP) is 265 times greater than CO_2, N_2O emissions might be enough elevated to negate some of the beneficial effects of organic amendments on soil properties (Heller et al., 2010).

The controversial topic need to be further specifically addressed in the Mediterranean environment (Aguilera et al., 2013). In this climatic areas the high summer temperatures coupled with low precipitations strongly influence nutrient and water availability, crop development, and microbial activity. As a result, the pattern of soil GHG emissions (especially N_2O fluxes) is strongly driven by the interaction of N fertilization with irrigation water inputs (Aguilera et al., 2013; Ranucci et al., 2011; Sánchez et al., 2001; Vallejo et al., 2004). In this regard the irrigation management appeared able to tune the potential of N_2O mitigation by organic fertilization, with the slowest progression of N_2O fluxes under low water input regimes (Aguilera et al., 2013; Sánchez-Martín et al., 2008, 2010a).

However, the overall effectiveness of organic fertilization might be limited by: (i) the effect of post-harvest residual mineral N leading to potential relevant N_2O-N losses during the fallow intercrop period (Aguilera et al., 2013); (ii) lower agronomic yield relative to the conventional mineral management, with a consequent levelling of the environmental benefits (including GHG mitigation) of alternative organic fertilizers respect to synthetic ones (Diacono and Montemurro, 2010; Meier et al., 2015; Tuomisto et al., 2012). In this regard crop-specific and yield-scaled GHG emissions appear necessary for a proper assessment of potential tradeoffs between reduced synthetic N input, yield performance and GHG emissions (Aguilera et al., 2013; Meier et al., 2015; Sanz-Cobena et al., 2014; Venterea et al., 2011).

Currently, there are only few studies investigating the effect of compost from MSW and cover crop green manuring (vetch included) on CO_2 and N_2O emissions in Mediterranean maize cropping systems. Cumulated nitrous oxide losses during the maize crop season under fertilization with composted MSW resulted lower in comparison to the conventional management with synthetic fertilizer, however no information were available for the intercrop period (López-Fernández et al., 2007; Meijide et al., 2007). Differently the net GHG benefit of maize managed with cover crop green manuring (as alternative to synthetic fertilization), referred to a whole year time window, appeared less marked, due to potential counteracting GHG emission patterns along the different main crop and intercrops periods (Guardia et al., 2016; Sanz-Cobena et al., 2014).

The objective of this work was to address the effect of compost fertilization (at two levels) and vetch green manuring (versus conventional fertilization with urea) on soil area and yield-scaled CO_2 and N_2O emissions in a Mediterranean drip-irrigated maize cultivation system, along both the main spring-summer crop and the intercrop periods. This, in order to achieve a deeper evaluation of the potential GHG mitigation for the investigated organic fertilized crop production systems, which is a major driver of their whole foreseen sustainability.

2. Materials and methods

2.1. Study site

The experimental farm was located in the coastal plain of the Sele River, Southern Italy (40°37′N, 14°58′E, 30 m above sea level) which is characterized by Mediterranean climate, with dry summer and precipitation mostly occurring in autumn-winter. See Alluvione et al. (2013) for further details.

Soil at the study site is a Vertic Haploxeralf (USDA soil taxonomy; Soil Survey Staff, 2014), with a sandy-clay-loam texture. Main soil properties of the plowed layer (0–30 cm) are: sand 46.5% silt 22.3% clay 31.2%, bulk density 1.42 g cm^{-3}, pH 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}.

2.2. Experimental design and crop management

The study focused on maize cultivation (*Zea mays* L) under drip irrigation since: (i) maize for silage is widespread in the Campania region and in non-zootechnics farms could be potentially interested in the use of compost or green manure as alternatives to mineral fertilization; (ii) drip irrigation is a diffused water-saving management in Southern Italy (Natali et al., 2009), currently contemplated for maize cultivation in the study area (Regione Campania, 2014).

Soil GHGs monitoring were conceived in the framework of the wider MESCOSAGR project, which aimed to assess, in the short term (within a three-year time frame window), the effectiveness of alternative C friendly strategies in increasing soil organic matter and supporting proper N fertility for maize yields, under different soil properties and climatic conditions.

An agricultural field previously cropped with durum wheat was converted to maize cultivation in fall 2006 subject to alternative N fertilizer managements: (i) a conventional bare fallow–maize cycle