European Journal of Agronomy 98 (2018) 25–36

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Global warming potential of a Mediterranean irrigated forage system: Implications for designing the fertilization strategy

Antonio Pulina[a,b], Roberto Lai[a,b,d,*], Giovanna Seddaiu[a,b], Chiara Bertora[c], Margherita Rizzu[a,b], Carlo Grignani[c], Pier Paolo Roggero[a,b]

[a] *Dipartimento di Agraria, University of Sassari, Viale Italia 39, 07100, Sassari, Italy*
[b] *Desertification Research Centre, NRD, University of Sassari, Viale Italia 39, 07100, Sassari, Italy*
[c] *Department of Agricultural, Forest and Food Sciences, University of Turin, Largo Paolo Braccini 2, 10095, Grugliasco, (TO), Italy*
[d] *Cooperativa Produttori Arborea – Società Agricola, Strada 14 Ovest, 09092, Arborea, Italy*

A R T I C L E I N F O

Keywords:
Silage maize
Italian ryegrass
Nitrification inhibitors
Organic fertilizers
Cattle slurry
Sandy soil

A B S T R A C T

Under Mediterranean conditions, the impacts of both organic and mineral N fertilization on soil Greenhouse Gases (GHG) emission can be controversial. The aim of this study was to assess the soil GHG emissions and the net Global Warming Potential (GWP) in a Mediterranean irrigated forage system under different fertilization treatments. Three N fertilization options were compared for two years in a double-crop rotation of silage maize and Italian ryegrass for hay: cattle slurry (SL), solid fraction of slurry (SO) and mineral fertilizer with a nitrification inhibitor (MI). The soil CO_2, N_2O and CH_4 fluxes were highly influenced by the interaction between treatment and date. The maximum values of GHG emissions were observed after fertilizations, to a different extent depending on the fertilizer. In the net GWP reference year, soil respiration (SR) was higher in SO (46.26 ± 3.26 Mg ha^{-1} yr^{-1} of CO_2) than SL (30.03 ± 0.40 Mg ha^{-1} yr^{-1}) and MI (23.71 ± 0.57 Mg ha^{-1} yr^{-1}). However, the C sequestration was higher in SO than in the other treatments. The N_2O fluxes were higher in SL (11.5 ± 5.2 kg ha^{-1} yr^{-1} of N_2O) than in SO (3.4 ± 1.8 kg ha^{-1} yr^{-1}), while the MI had intermediate values (6.5 ± 1.4 kg ha^{-1} yr^{-1}). No differences were observed in cumulative CH_4 emissions. The SO resulted as a net GWP sink (-9.86 ± 3.05 Mg yr^{-1} of CO_2eq based on SR), while the SL and MI (9.79 ± 1.41 and 1.34 ± 1.87 Mg yr^{-1}, respectively, based on SR) resulted as a source. The SO seemed to have a higher potential in terms of reducing GHG emissions by maintaining adequate levels of agronomic efficiency. This study put in evidence how different organic fertilizers can have contrasting impacts on GHG emissions providing some insights on their different potential mitigation roles under Mediterranean conditions.

1. Introduction

Agriculture is responsible for about 10–12% of total anthropogenic greenhouse gases (GHG) emissions, above all through soil CO_2, N_2O and CH_4 fluxes (Smith et al., 2014). Nevertheless, agricultural sector can be pivotal for soil organic carbon (SOC) sequestration and C changes which are widely recognized as crucial for counteracting climate change (Follett, 2001; Farina et al., 2011).

Under Mediterranean conditions, the total C losses form soils can be attributed to the CO_2 efflux due to autotrophic and heterotrophic metabolic activities (Hanson et al., 2000; Follett, 2001), also referred as Soil Respiration (SR), which are regulated by the interaction of multiple factors. Although it is recognized that the soil water content (SWC) and soil temperature (T) are the main driver of seasonal C changes in semiarid rainfed environments (Davidson et al., 1998), high N inputs and irrigation can influence soil C dynamics in intensive cropping systems. The use of organic fertilizers in agroecosystems is recognized as a mean to increase the SOC stocks in the soil (Bertora et al., 2009; Maillard and Angers, 2014), but research findings on their effectiveness are often contrasting depending also on the origin and type of supplied fertilizer (Peters et al., 2011; Lai et al., 2017). The role of different organic fertilizers, as a partial or total replacement of mineral fertilizers as a mean to achieve soil GHG emissions mitigation and, at the same time, to maintain the agro-ecosystems productivity, is one of the key topics in the scientific debate on the contribution of agricultural systems to climate change mitigation (Smith et al., 2008; Sanz-Cobena et al., 2017).

In Mediterranean irrigated cropping systems, considerable amount of N inputs are usually supplied to ensure high crop production. Although an high primary productivity can enhance the C sequestration rate, favourable conditions for N_2O production are also created, which

* Corresponding author at: Dipartimento di Agraria, University of Sassari, Viale Italia 39, 07100, Sassari, Italy.
E-mail address: rlai@uniss.it (R. Lai).

https://doi.org/10.1016/j.eja.2018.05.002
Received 8 November 2017; Received in revised form 7 May 2018; Accepted 10 May 2018
1161-0301/

are in turn strongly related to water and fertilization management (Halvorson et al., 2010; Cayuela et al., 2017). The denitrification processes are mainly associated to the organic N and total C supplied with the organic fertilizers (Vallejo et al., 2006; Aita et al., 2015; Tellez-Rio et al., 2015), while the nitrification is linked to the mineral fertilizers use (Meijide et al., 2007; Hube et al., 2017). The composition of N fertilizers, particularly those organic, can vary considerably, resulting in differences in terms of N_2O emissions (Meijide et al., 2007). High organic and soluble C contents generally enhance total emissions of N_2O, while these are reduced with high C:N organic fertilizers, containing more stable C compounds (Vallejo et al., 2006). The use of nitrification and urease inhibitors is effective in reducing from 30 to 50% of the potential N_2O fluxes (Huérfano et al., 2015) in both rainfed and irrigated systems, probably due to an indirect effect on reducing denitrification (Sanz-Cobena et al., 2017).

The influence of fertilization strategies on CH_4 fluxes in Mediterranean non-flooded systems is debated. Soon after the application into the soil, organic fertilizers can result both as a source of CH_4 (Guardia et al., 2016) or sink (Meijide et al., 2010). Sanchez-Martin et al. (2010) reported opposite effects displayed by organic (sink) and mineral (source) fertilizers. Furthermore, fertilizers with high C content can induce changes in soil porosity resulting in the creation of anaerobic microsites suitable for methanogenesis (Le Mer and Roger, 2001).

Under Mediterranean irrigated and not-flooded conditions, there are few studies and contrasting findings on the influence of fertilization on the net Global Warming Potential (GWP) (e.g. Aguilera et al., 2013), which consist of the overall balance between the GHG net exchange in a cropping system (Robertson and Grace, 2004). In irrigated maize, Guardia et al. (2017) reported that the use of pig slurry compared to urea may be a good mitigation option, although a better agronomic N efficiency can be obtained when slurries are added with the nitrification inhibitors. Furthermore, Hube et al. (2017) found a significant effect of dicyandiamide in mitigating GHG emissions in an oat cropping systems. Overall, in maize-based cropping systems, the use of organic fertilizers resulted as a net GWP sink also by using green manure from barley straw (Cuello et al., 2015), wheat-straw biochar (Zhang et al., 2012) and wastewater (Fernández-Luqueño et al., 2010).

The hypothesis was that in a Mediterranean irrigated forage system the use of organic instead of mineral fertilizers is a suitable net GWP mitigation option, when the characteristics of the organic substrates allow to enhance the C sequestration and to reduce the N-reactive availability to N_2O production while maintaining a good productivity level. The aims of this study were to evaluate the impact of different sources of N as organic (cattle slurry and its solid fraction after separation) or mineral (ammonium sulphate nitrate with nitrification inhibitor) fertilizers could have on: (i) seasonal dynamics of CO_2, N_2O and CH_4 fluxes from the soil and their relationship with abiotic drivers, such as soil water content and temperature; (ii) net GWP and the GHG Eco-Efficiency, as a ratio between the net GWP and the aboveground dry matter production.

2. Materials and methods

2.1. Study site and experimental design

The field experiment was conducted in a private farm located in the Arborea district (Sardinia, Italy) (3 m a.s.l., 39°47′45″N, 8°33′25″E), characterized by an intensive dairy cattle livestock system, representing the most important human activity of the area (Nguyen et al., 2016). The area was designated as Nitrate Vulnerable Zone, therefore it is subjected to the European Directive 91/676/EEC prescriptions. The climate is Mediterranean: the mean annual temperature (1959–2012) is 16.7 °C. The average annual rainfall is 568 mm, 73% of which occurs between October and March, with an annual aridity index (rainfall/reference evapotranspiration) of 0.49 (semi-arid area). The soil has been classified as *Psammentic Palexeralfs* (USDA, 2010), and the average slope in the field was lower than 0.5%. Soil characteristics are reported in Table 1.

Table 1
Soil physical and chemical characteristics measured at the beginning of the experiment (June 2014).

Parameter	Soil depth (m)		
	0.0 ÷ 0.2	0.2 ÷ 0.4	0.4 ÷ 0.6
Clay ($g\,kg^{-1}$)	20.0	19.7	17.8
Sand ($g\,kg^{-1}$)	955.9	956.7	957.0
Silt ($g\,kg^{-1}$)	24.2	23.7	25.2
Bulk density ($kg\,m^{-3}$)	1.44	1.45	1.46
Drained upper limit (moisture at −23 kPa, $m^3\,m^{-3}$)	0.19	0.21	0.21
Field capacity (moisture at −33 kPa, $m^3\,m^{-3}$)	0.06	0.05	0.05
Wilting point (moisture at −1500 kPa, $m^3\,m^{-3}$)	0.02	0.02	0.01
Soil organic matter ($g\,kg^{-1}$)	15.2	13.0	10.7
Total N ($g\,kg^{-1}$)	1.08	1.02	0.85
Phosphorus ($mg\,kg^{-1}$ of Olsen P)	93.4	115.4	135.3
Potassium ($mg\,kg^{-1}$ of K)	70.7	69.4	85.7

The typical forage cropping system is based on the double-crop rotation of silage maize (*Zea mays* L.), grown from June to September, and a winter hay crop, typically Italian ryegrass (*Lolium multiflorum* Lam.), grown from October to May. Two double-crop rotations of silage maize and Italian ryegrass from June 2014 (maize seeding) to May 2016 (ryegrass mowing) were considered in the present study. In particular, the first year ryegrass and the second year maize were considered as a reference year (November 2014–November 2015) for the net GWP calculation. The experimental design was a completely randomized design with four replicates and the plot size of 5.2 m × 19.2 m. Three different N fertilization treatments were compared: i) cattle slurry (SL); ii) solid fraction of cattle slurry (SO), obtained after mechanical separation; iii) mineral fertilizer (MI), using ammonium sulphate nitrate with nitrification inhibitor 3,4-Dimethylpyrazole Phosphate (DMPP) (ENTEC® 26, EuroChem Agro). For each treatment, the target N rate was 130 $kg\,ha^{-1}$ for ryegrass and 315 $kg\,ha^{-1}$ for maize, which correspond to the expected N uptake by the studied crops (Demurtas et al., 2016).

The irrigation was performed with a sprinkler system, and it was managed by the farmer. In the first cycle of maize crop, the supplied water volume was 4505 $m^3\,ha^{-1}$, while in the second year the water supply was 3498 $m^3\,ha^{-1}$. Furthermore, a supplemental irrigation was carried out in the first cycle of ryegrass crop after sowing (318 $m^3\,ha^{-1}$) and during the spring (1113 $m^3\,ha^{-1}$).

Details on the cropping system management along the experiment are reported in Table 2.

2.2. Measurements

2.2.1. Weather, fertilizers and soil

Air temperature (°C), rainfall (mm), relative humidity (%), radiation ($MJ\,m^{-2}\,d^{-1}$) and wind speed ($km\,h^{-1}$) were daily measured using a weather station (WatchDog 2000 Series, Spectrum Technologies Inc., IL, USA) placed in close proximity to the experimental field. Reference evapotranspiration (ET_0) during the observed period was calculated according to the Penman-Monteith model (Allen et al., 1998: equation n° 6). Along the two-years experiment, the average air temperature was 17.3 °C. The average maximum air temperature occurred in July (30.4 °C and 30.2 °C in the first and the second year, respectively), while the average minimum temperature occurred in February (5.3 °C) and in December (5.1 °C) in the first and in the second crop cycle, respectively. The total rainfall was 870 mm, of which 518.9 mm in the first crop cycle (88% from October to March) and 351.1 mm (78% Oct–Mar) in the second. The average ET_0 of the two years was