Field Crops Research 204 (2017) 135–145

Contents lists available at ScienceDirect

Field Crops Research

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

Research paper

Effect of inhibitors and fertigation strategies on GHG emissions, NO fluxes and yield in irrigated maize

Guillermo Guardia[a,*], Max T. Cangani[b], Gemma Andreu[a], Alberto Sanz-Cobena[a], Sonia García-Marco[a], José Manuel Álvarez[a], Jaime Recio-Huetos[a], Antonio Vallejo[a]

[a] ETSI Agronómica, Alimentaria y de Biosistemas (ETSIAAB), Technical University of Madrid (UPM), Ciudad Universitaria, 28040 Madrid, Spain
[b] Faculdade de Ciências Agrárias e Veterinária de Jaboticabal, Universidade Estadual Paulista—UNESP, Jaboticabal-SP, Brazil

ARTICLE INFO

Article history:
Received 16 June 2016
Received in revised form 9 January 2017
Accepted 9 January 2017

Keywords:
GHG emission
Nitric oxide emission
Nitrification inhibitor DMPSA
Urease inhibitor NBPT
Fertigation

ABSTRACT

Abating large losses of nitrogen (N) oxides while maintaining or enhancing crop yield is a major goal in irrigated maize (Zea mays L) cropping areas. During two consecutive campaigns, the new nitrification inhibitor 2-(3,4-dimethyl-1H-pyrazol-1-yl) succinic acid isomeric mixture (DMPSA) applied with calcium ammonium nitrate (CAN) and the same fertilizer applied by drip-fertigation without the inhibitor, were evaluated and compared with CAN broadcast to the surface and irrigated with sprinklers. Concurrently, urea-based treatments such as urea-fertigation and the broadcast application of urea combined with sprinkler irrigation, with or without the urease inhibitor N-butyl thiophosphorictriamide (NBPT), were also assessed. Nitrous oxide (N_2O) and nitric oxide (NO) fluxes, grain and biomass yield and yield-scaled N_2O emissions of the different treatments were compared. Additionally, methane (CH_4) and carbon dioxide (CO_2) fluxes were measured. On average, fertigation treatments led to a mitigation of N_2O emissions with respect to sprinkler irrigation by 80% and 78% for CAN and urea, respectively. With regards to inhibitor-based strategies, the use of DMPSA and NBPT reduced N_2O losses by 58% and 51%, respectively, considering the average of both maize cropping seasons. Since no differences in grain yield were observed between fertilized treatments, DMPSA and fertigation treatments gave the lowest values of yield-scaled N_2O emissions, leading to reductions of 63%, 71% and 78% for CAN with DMPSA, urea-fertigation and CAN-fertigation, respectively, with respect to conventional management strategies (surface broadcast application and sprinkler irrigation). Low NO emissions during the first campaign masked differences between treatments, whereas during the second season, NO losses significantly decreased in the following order: conventional treatments > inhibitors > fertigation. Comparing conventional management practices, CAN significantly decreased emissions of N oxides compared with urea, but this effect was only observed in the second maize cropping season. The moisture distribution pattern in drip plots (dry and wet areas) caused a reduction of CH_4 sink (only in one of the two seasons) and respiration fluxes, in comparison to sprinkler. This study shows that the use of the new nitrification inhibitor DMPSA and drip-fertigation should be promoted in irrigated maize agro-ecosystems, in order to mitigate emissions of N oxides without penalizing grain yield and leading to similar or enhanced biomass production.

1. Introduction

With production of almost 700 Mt, maize is one of the three most important crops in the world (FAO, 2014). Thus, the intensive production of maize is of major economic relevance in regions such as USA and Canada (Corn Belt), China, Mexico, Brazil, Argentina and irrigated semi-arid areas (e.g. Mediterranean regions). Due to its high water and fertilizer (particularly nitrogen, N) demand, maize cropping has a high potential to generate large N losses, through ammonia (NH_3) volatilization, nitrate (NO_3^-) leaching and N oxides emissions (Rimski-Korsakov et al., 2012; Huang et al., 2015; Abalos et al., 2016; Cayuela et al., 2016). The latter include nitrous oxide (N_2O), a harmful greenhouse gas (GHG) (Myhre et al., 2013) which is mainly produced through the soil microbial processes of nitrification and denitrification (Firestone and Davidson, 1989); and nitric oxide (NO), which is involved in the formation of tropospheric ozone and is mainly generated through nitrification (Skiba et al., 1997). Finding management practices that lead to lower N losses

* Corresponding author.
E-mail address: guillermo.guardia@upm.es (G. Guardia).

http://dx.doi.org/10.1016/j.fcr.2017.01.009
0378-4290/

while maintaining yield is, therefore, crucial in maize cropping areas, to assure both economic and environmental sustainability of these agro-ecosystems.

Some potential strategies have been suggested for reducing N losses in maize areas. These involve: i) the substitution of synthetic fertilizers by organic ones, which has been shown to penalize crop yields (Abalos et al., 2016; Guardia et al., 2016); ii) the use of urease inhibitors (Sanz-Cobena et al., 2012); iii) the use of nitrification inhibitors (NIs) (Migliorati et al., 2014); iv) the use of water-saving irrigation strategies such as drip irrigation (Guardia et al., 2016) and v) the split application of N fertilization in order to improve the synchronization of N supply to maize demand (Quemada et al., 2013). The last two mitigation options could be combined through drip-fertigation systems, which can be technically achievable in maize areas without yield penalties (Couto et al., 2013), as well as improving weed management. Several field studies have demonstrated that drip irrigation reduces emissions N oxides (Sánchez-Martín et al., 2008; Sanchez-Martín et al., 2010). With regards to fertigation, Kennedy et al. (2013) reported that the integrated management of a processing tomato field (including fertigation) emitted less N_2O and had greater crop yield than the conventional system (furrow irrigation and seeding fertilization) as a result of lower substrate (mineral N) availability. By contrast, Vallejo et al. (2014) highlighted the potential of drip-fertigation to give higher N_2O emissions when compared with basal fertilization and drip irrigation, but with low emission factors in both cases. So far, no studies have been published about the effect of drip-irrigation on losses of N oxides in maize cropping areas.

The use of urease inhibitors such as N-butyl thiophosphorictriamide (NBPT) is an effective strategy to mitigate NH_3 volatilization (Bittman et al., 2014), but some studies have pointed out their potential for also reducing N_2O (Sanz-Cobena et al., 2012) and NO losses (Abalos et al., 2012). The use of nitrification inhibitors has been described as a useful tool for enhancing N use efficiency and, therefore, abating N losses (Akiyama et al., 2010; Qiao et al., 2015; Gilsanz et al., 2016), which can also improve crop yields (Abalos et al., 2014a). To date, studies have mainly focused on dicyandiamide (DCD) and 3,4 dimethylpyrazol phosphate (DMPP), which have been extensively evaluated under several climatic conditions. Conversely, no studies have yet evaluated the effectiveness of new inhibitors such as 2-(3,4-dimethyl-1H-pyrazol-1-yl) succinic acid isomeric mixture (DMPSA) on abating yield-scaled N oxide emissions. This new inhibitor was developed to be used with basic reaction fertilizers (e.g. calcium ammonium nitrate, CAN), which cause DMPP to be unstable.

Since cost appears to be the main barrier for a broad adoption by farmers (Timilsena et al., 2015), the comparison of the mitigation potential of inhibitors and drip-fertigation, as well as the yield response, needs to be carried out. Other potential cost-effective mitigation strategies, such us changing the N source (e.g. replacing urea by CAN) could be of interest in maize cropping areas with large nitrification losses, such as low C-content semi-arid soils (Aguilera et al., 2013; Zhang et al., 2016).

The main objectives of this experiment were to evaluate the effect of 1) urease (NBPT) and nitrification (DMPSA) inhibitors and 2) mineral fertilizers (CAN and urea) applied by drip-fertigation; compared with conventional management (CAN and urea without inhibitors applied at dressing in sprinkler-irrigated maize) in mitigating N_2O and NO losses. The response of crop yield and N uptake to these treatments was also assessed. Additionally, the modification of soil moisture content and its distribution through the soil profile as a result of different water-management systems may affect CO_2 (Borken and Matzner, 2009) and CH_4 fluxes (Tate, 2015), so they were also measured. Our hypothesis was that alternative management practices (inhibitors and drip-fertigation) could mitigate GHG and NO losses while enhancing crop yields.

2. Materials and methods

2.1. Site description

The study was carried out at "El Encín" field station in Madrid (latitude 40° 32′N, longitude 3°17′W). The soil was a Calcic Haploxerept (Soil Survey Staff, 1992) with a sandy clay loam texture (clay, 28%; silt, 17%; sand, 55%) in the upper horizon (0–28 cm) with vermiculite as a dominant clay mineral. Some relevant characteristics of the top 0–28 cm soil layer are as follows: total organic C, $8.1 \pm 0.3\ g\ kg^{-1}$; pH_{H2O}, 7.6; bulk density, $1.4 \pm 0.1\ g\ cm^{-3}$; and $CaCO_3$, $13.2 \pm 0.4\ g\ kg^{-1}$. At the beginning of the experimental period, the NH_4^+ content was 1.0 mg NH_4^+–N kg soil^{-1}; the NO_3^- content was 15.9 mg NO_3^-–N kg soil^{-1}; and the dissolved organic C (DOC) content was 50.8 mg C kg soil^{-1}. The site has a semiarid Mediterranean climate with a dry and hot summer period, and the mean annual temperature and rainfall (over the last 10 years) in this area are 13.2 °C and 460 mm, respectively.

Rainfall and temperature data were obtained from a meteorological station located at the field site (CR23X micro logger, Campbell Scientific, Shepshed, UK, equipped with a Young® tipping bucket rain gauge (RM Young Company, Michigan, USA). The soil temperature was monitored using a temperature probe (SKTS 200, Skye Instruments Ltd., Llandrindod Wells, UK) inserted 10 cm into the soil. The mean hourly data were stored on a data logger (DataHog, Skye Instruments Ltd., Llandrindod Wells, UK).

2.2. Experimental design and management

A total of 24 plots (7 m × 6.5 m) were selected and arranged in a split plot design with 8 irrigation-fertilization combinations: (i) Urea-sprinkler irrigation (U-S), (ii) CAN-sprinkler irrigation (CAN-S), (iii) Urea + NBPT (UTEC®) with sprinkler irrigation (UI-S), (iv) CAN + DMPSA with sprinkler irrigation (CAN + NI-S) (v) Urea applied by drip-fertigation (U-D), (vi) CAN applied by drip-fertigation (CAN-D), (vii) Control without any N fertilizer with sprinkler irrigation (C-S), (viii) and with drip irrigation (C-D).

The experiment was conducted during two consecutive cropping seasons, 2014 and 2015. In both of them, a cultivator pass was performed before seeding (15th and 13th April in 2014 and 2015, respectively). Maize (*Zea mays* L. FAO class 600) was sown on 7th May and 17th April in 2014 and 2015, respectively, with a plant density of 7.50 plants m^{-2}. A basal fertilization was applied on 30th April 2014 and 14th April 2015, spreading by hand 50 kg P ha^{-1} and 150 kg K ha^{-1} as $Ca(H_2PO_4)_2$ and K_2SO_4, respectively, in all plots.

For treatments U-S, CAN-S, U-I and CAN-NI 180 kg N ha^{-1} were spread by hand onto the surface of the plots on 17th June (both years). The fertigation in the corresponding plots (U-D and CAN-D) was split into two applications of 90 kg N ha^{-1} at 6 and 10–12 pair of leaves stage (180 kg N ha^{-1} in total). A non-electric proportional dispenser (Dosatron DI16-11GPM, Dosatron International Inc., Bordeaux, France) was used to inject the correct rate of N fertilizer in each fertigation event. This system used the water pressure (0.3–6 bar) as a driving force to suck up the fertilizers from the tank and mix them homogeneously with the irrigation water. This process took place in a mixer section to assure the correct application rate, independent of the water flow or pressure variations.

In the plots with drip irrigation, a system was used that had one pressure-compensated irrigation line for each pair of maize lines. Consequently, each plot had half of the surface between rows with drip lines ("wet area") and half without drip lines ("dry area"). Each line had 20 emitters (nominal discharge of 4 L h^{-1}), 0.33 m apart. Irrigation was carried out three times per week with a total of 48 and 44 irrigation events during 2014 and 2015, respectively. In