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Effect of fertilising with pig slurry and chicken manure on GHG emissions from Mediterranean paddies

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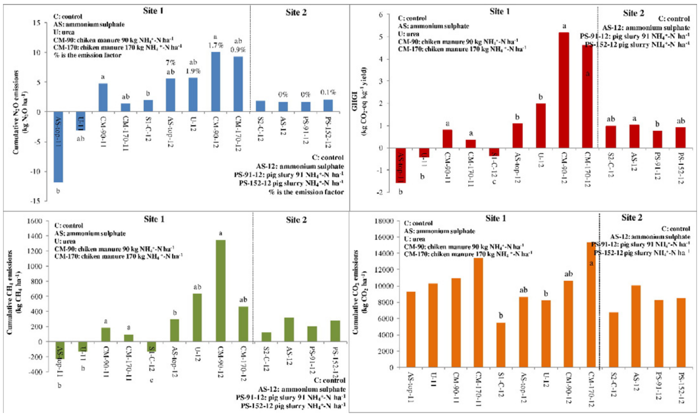
HIGHLIGHTS

- Pig slurry (~170 kg N ha^{-1}; low C/N) allows high rice yields without increasing GWP.
- Chicken manure (~170 kg N ha^{-1}; high C/N) increases GHG emissions.
- Mineral N had no effect on N_2O, while chicken manure increased CH_4 emission.
- The postharvest period was a sink of CH_4 without N_2O emissions.
- During seedling chicken manure increased GHG; mineral N and pig slurry did not.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil fertilisation affects greenhouse gas emissions. The objective of this study was to compare the effect of different fertilisation strategies on N_2O, CH_4 emissions and on ecosystem respiration (CO_2 emissions), during different periods of rice cultivation (rice crop, postharvest period, and seedling) under Mediterranean climate. Emissions were quantified weekly by the photoacoustic technique at two sites. At Site 1 (2011 and 2012), background treatments were 2 doses of chicken manure (CM): 90 and 170 kg NH_4^+-N ha^{-1} (CM-90, CM-170), urea (U, 150 kg N ha^{-1}) and no-N (control). Fifty kilogram N ha^{-1} ammonium sulphate (AS) were topdress applied to all of them. At Site 2 (2012), background treatments were 2 doses of pig slurry (PS): 91 and 152 kg NH_4^+-N ha^{-1} (PS-91, PS-152) and ammonium sulphate (AS) at 120 kg NH_4^+-N ha^{-1} and no-N (control). Sixty kilogram NH_4^+-N ha^{-1} as AS were topdress applied to AS and PS-91. During seedling, global warming potential (GWP) was ~3.5–17% of that of the whole rice crop for the CM treatments. The postharvest period was a net sink for CH_4, and CO_2 emissions only increased for the CM-170 treatment (up to 2 Mg CO_2 ha^{-1}). The GWP of the entire rice crop reached 17 Mg CO_2-eq ha^{-1} for U, and was 14 for CM-170, and 37 for CM-90. The application of PS at agronomic doses (~170 kg N ha^{-1}) allowed high yields (~7.4 Mg ha^{-1}), the control of GWP (~6.5 Mg CO_2-eq ha^{-1}), and a 13% reduction in greenhouse gas intensity (GHGI) to 0.89 kg CO_2-eq kg^{-1} when compared to AS (1.02 kg CO_2-eq kg^{-1}).

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1. Introduction

Globally, agriculture accounts for 60%, 50% and 1.1% of total anthropogenic N_2O, CH_4 and CO_2 emissions, respectively (Liu et al., 2012a). The GHG emissions from rice (*Oryza sativa* L.) and the subsequent global warming potential (GWP, 3757 kg CO_2-eq ha^{-1} $season^{-1}$) are roughly four fold those of wheat (*Triticum aestivum* L.; 662 kg CO_2-eq ha^{-1} $season^{-1}$) or maize (*Zea mays* L.; 1399 kg CO_2-eq ha^{-1}-$season^{-1}$) (Linquist et al., 2012).

Flooded rice emits both N_2O and CH_4 due to the negative soil redox potential and different bacterial communities (Kögel-Knabner et al., 2010; Arends et al., 2014) as reported in both instantaneous and annual estimates (Brumme et al., 1999; Groffman et al., 2000). However, periods of N_2O consumption have been reported in many field studies (Brumme et al., 1999; Chapuis-Lardy et al., 2007; Van Groenigen et al., 2015; Wrage et al., 2004).

Anaerobiosis favours the activity of methanogens which in the presence of organic matter, substantially contribute to CH_4 emissions (Banik et al., 1996). Fertilisation management, mainly the type of N fertilisers, is a key factor in the control of N losses to the atmosphere and GHG emissions from paddy fields (Gogoi and Baruah, 2012; Maris et al., 2016). Urea is prone to large gaseous losses, particularly due to ammonia volatilisation (Mikkelsen et al., 1978) and denitrification to N_2O and N_2, though reports on N_2O emissions are contradictory (Lindau et al., 1991; Zou et al., 2005), possibly due to the influence of location and management practices (Zhao et al., 2011). Recent rice field studies suggest that high NH_4^+-N may stimulate CH_4 oxidation reducing its emissions (Bodelier and Laanbroek, 2004; Banger et al., 2012) by roughly 30 to 50% (Xie et al., 2010; Yao et al., 2012). It has been stated that when fertilising with ammonium sulphate the competition of sulphate-reducing bacteria for hydrogen reduces CH_4 emissions. Nitrogen fertilisation may also increase CH_4 and CO_2 emissions due to increased rice biomass which can facilitate gas transport through rice plants (Dick, 1992; Iqbal. et al., 2009; Singh et al., 1999; Wilson and Al-Kaisi, 2008), as well as enhance carbon substrate availability for methanogens (Lu et al., 2000; Schimel, 2000). Lindau et al. (1991) found that urea addition increased CH_4 emissions by approximately 40 to 75% compared to control. According to Hou et al. (2000), efforts to reduce the overall GWP of rice should focus on reducing CH_4 emissions. However, both CH_4 and N_2O need to be considered, as many strategies that reduce CH_4 emissions tend to increase N_2O emissions and vice-versa (Cai et al., 1998; Ma et al., 2007; Zou et al., 2005).

Soil CO_2 emissions are increasingly important as they integrate all the components of soil CO_2 production, including rhizosphere respiration and soil microbial respiration (Iqbal. et al., 2009), one of the primary fluxes of C between soil and atmosphere. Almaraz et al. (2009) did not observe any significant effect of mineral fertiliser application on cumulative CO_2 emissions.

Nowadays, urea and ammonium sulphate account for about 90% of the total N fertiliser applied to rice cultivation in the world (Food and Agriculture Organization, 2013). The autonomous regions of Aragon and Catalonia hold about 42% of the Spanish pig herd (MAGRAMA, 2014), Catalan pig farms representing 29% (IDESCAT, 2016). Furthermore, in Catalonia, the Montsià (Ebro Delta) county concentrates 32% of the poultry farms of this region, with approximately 2 million heads producing 51,786 t manure $year^{-1}$ (MAGRAMA, 2014). The use of pig slurry (PS) and chicken manure (CM) as fertiliser to winter cereal and maize is the most common recycling method. It is a challenge to apply PS and CM at an optimised dose also to rice crops, this not yet being common.

Field measurements of GHG emissions are typically limited to the rice crop. Some authors have pointed out the need to quantify annual rather than seasonal emissions (Fitzgerald et al., 2000; Liang et al., 2007) because of the importance of emissions during fallow periods. Furthermore, according to some Chinese studies (Ma et al., 2012) the rice seedling period (SP) had a GWP (of N_2O and CH_4) equivalent to the GWP of the rice crop, though there are few such studies (Ma et al., 2013). The cumulative N_2O emissions of the rice SP ranged from 0.24 to 0.62 kg N_2O-N ha^{-1} and that of CH_4 from 21.8 to 162.2 kg CH_4 ha^{-1} in Chinese systems (Liu et al., 2012a; Ma et al., 2013). In China, the rice seedlings are generally grown in nursery patches for 30–40 days before being transplanted into paddy fields, while in Mediterranean areas rice is mainly sown on site. Greenhouse gas emissions estimates should reflect the specific conditions of the different countries and the agricultural practices involved (IPCC, 2007).

In the European Union about 475,000 ha are devoted to rice (*Oryza sativa* L.) with a total production of 3.2 Mt of rice grain (1.8 Mt white rice). The European Union (EU) is a net steadily growing rice importer (some 809,400 t $year^{-1}$). Italy is the largest producer, with 52% of the total, followed by Spain with 28%. In Spain, the rice sector has a 259.03 million euros worth production (estimated for 2015). Spain is a net rice exporter (about 137,231 t $year^{-1}$ net exports). In Spain, rice paddies are localised in saline areas with environmental restrictions (Deltas and marshlands belonging or close to natural parks), and with waterlogged soils. This is also the case in some other Mediterranean areas such as Valencia (Spain) or the Camargue (France) regions. The main rice producing region in Spain is Andalucia (36.7% of the Spanish rice producing area; MAGRAMA, 2015), Catalonia together with Aragon hold 24.7% of the Spanish rice area, followed by Extremadura (22.4%) and Valencia (13.8%). The Ebro Valley extends over 85,362 km^2 in NE Spain, including Aragon and Catalonia. It is one of the most intensively irrigated river basins in Europe (0.8 million ha of irrigated land; Wriedt et al., 2008). Soils near the rivers are classified as Fluvisol Eutric (FAO, 1974), while in the rest of the irrigated areas the most common soil types are Xerosol Gypsic and Xerosol Calcic. These soils are often salt-affected (CHE, 2008). About 86% of the cultivated Ebro Delta is, at present, under rice cultivation due to the presence of saline groundwater over large areas (Casanova, 1998), and to environmental policies (EU Regulation 1765/92; NATURA 2000 network and the Ramsar Convention).

Sowing density ranges from 160 to 200 kg seed ha^{-1}. On site, mechanical sowing (rice is not transplanted) takes place from April 15th to May 15th. A water layer of 3 to 5 cm is kept on the field after sowing. Later on it is increased to 10 to 15 cm. Flooding is constant throughout the rice cycle (with water running in and out of the fields at all times), except for the time when some agricultural practices (fertiliser side-dressing, pesticide treatments) require drainage. In early September, water is drained and rice can be harvested up to mid-October.

The objective of this study was to compare the effect of organic N fertilisers (pig slurry (PS) and chicken manure (CM)) with urea and ammonium sulphate on the emissions of N_2O, CH_4 and CO_2 from the rice paddy during the rice crop and for the postharvest (fallow) period, as well as for the seedling period.

Two contrasted sites in the Ebro Valley were studied, with different organic fertilisers available (CM or PS) and with different mineral N applied at sowing time (urea or ammonium sulphate). Both fertilisation strategies (mineral and organic) were designed to include a similar background applied NH_4^+-N dose (from 90 to 170 kg NH_4^+-N ha^{-1}) but to differ widely in organic-C application (CM had a high C/N ratio and PS a low one).

2. Materials and methods

2.1. Site description and experimental design

The experiment was carried out at two rice paddies located at two different sites in the Mediterranean Ebro Valley (NE Spain). Soils of the two sites are representative of Mediterranean and Spanish soils under rice. Site 1 is representative of the alluvial soils from deltas and river terraces and similar landforms: they are from moderate coarse textures up to moderate fine textures (Casanova et al., 2002). Salinity is highly variable and they have an organic matter content around 2%.