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Alternate Wetting and Drying of Rice Reduced CH_4 Emissions but Triggered N_2O Peaks in a Clayey Soil of Central Italy

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ABSTRACT

Reducing CH_4 and N_2O emissions from rice cropping systems while sustaining production levels with less water requires a better understanding of the key processes involved. Alternate wetting and drying (AWD) irrigation is one promising practice that has been shown to reduce CH_4 emissions. However, little is known about the impact of this practice on N_2O emissions, in particular under Mediterranean climate. To close this knowledge gap, we assessed how AWD influenced grain yield, fluxes and annual budgets of CH_4 and N_2O emissions, and global warming potential (GWP) in Italian rice systems over a 2-year period. Overall, a larger GWP was observed under AWD, as a result of high N_2O emissions which offset reductions in CH_4 emissions. In the first year, with 70% water reduction, the yields were reduced by 33%, CH_4 emissions decreased by 97%, while N_2O emissions increased by more than 5-fold under AWD as compared to PF; in the second year, with a 40% water saving, the reductions of rice yields and CH_4 emissions (13% and 11%, respectively) were not significant, but N_2O fluxes more than doubled. The transition from anaerobic to aerobic soil conditions resulted in the highest N_2O fluxes under AWD. The duration of flooding, transition to aerobic conditions, water level above the soil surface, and the relative timing between fertilization and flooding were the main drivers affecting greenhouse gas mitigation potential under AWD and should be carefully planned through site-specific management options.

Key Words: aerobic soil conditions, fertilization, global warming potential, greenhouse gas, mitigation potential, water saving

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INTRODUCTION

Agricultural soils contribute significantly to anthropogenic greenhouse gas (GHG) emissions, mainly through CO_2, CH_4, and N_2O (IPCC, 2014). Of the total anthropogenic emissions, CH_4 and N_2O have a large global warming potential (GWP) that is 34 and 298 times, respectively, greater than CO_2 over a 100-year period (Myhre *et al.*, 2013). In the European Union (EU), CH_4 and N_2O emissions account for 49% and 63%, respectively, of the GHG released from the agricultural sector, representing about 10% of the total European GHG emissions (Weiske and Petersen, 2006). However, reliable estimates are difficult and more research is needed to cover the existing knowledge gap of GHG emissions from the agricultural sector and the underlying driving processes (Franzluebbers and Follett, 2005).

With the 20-20-20 target, the EU has set itself the objective of reducing C emissions by 20% by 2020 (European Commission, 2012). Agriculture is now faced with the challenge of securely delivering sufficient food to meet the projected demands of population growth and overcoming issues such as climate change and water scarcity through sustainable agricultural intensification (Foley *et al.*, 2011). In particular, water scarcity is a major constraint globally; thus, increasing water use efficiency is essential for future rice production

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(Mahender *et al.*, 2013).

Approximately 90% of the world's harvested rice is grown under flooded conditions for the majority of the season and accounts for up to 29% of aggregate CH_4 emissions (Neue, 1997). The annual CH_4 emission from rice paddies has been estimated to be 36 Tg year^{-1}, contributing approximately 18% of the total anthropogenic CH_4 emission to the atmosphere (Stams and Plugge, 2010; Kirschke *et al.*, 2013). In the EU, Italy is the largest rice producer (FAO, 2002), where rice contributes 3.7% of the total CH_4 emissions (FAO, 2012). In this context, a sustainable intensification of rice production, ensuring sufficient yields while reducing the negative impacts on the environment, is needed. Increasing the sustainability of rice cropping systems will require the identification of agricultural practices that mitigate GHG emissions while sustaining production levels, but their development will depend on a holistic understanding of the link between management practices and key processes involved in the production of GHG.

Alternate wetting and drying (AWD) irrigation, as opposed to permanent flooding in conventionally managed rice production system, is a practice that has been shown to reduce CH_4 emissions (FAO, 2010), water use (Rejesus *et al.*, 2011), and the concentration of arsenic in harvested rice grains (Price *et al.*, 2013; Linquist *et al.*, 2015). The flooded conditions promote CH_4 production by decreasing dissolved O_2 and redox potential, thus triggering anaerobic microbial degradation chains carried out by CH_4-producing bacteria (methanogens). Methane is produced as a terminal product of anaerobic mineralization of soil organic matter (SOM) through methylotrophic, hydrogenotrophic, and acetoclastic routes, in the absence of alternative electron acceptors (such as O_2, NO_3^-, Fe(III), and SO_4^{2-}) or microbial communities capable of using those (Krüger *et al.*, 2005). Reducing the duration of flooding through AWD or mid-season drains typically reduces CH_4 emissions. For instance, Lu *et al.* (2000) reported that in southeast China, CH_4 emission was reduced by 44% by a mid-season drainage and 61% by AWD at 10-d intervals compared to continuously flooded plots. Itoh *et al.* (2011) demonstrated that prolonged mid-season drainage suppressed CH_4 emission as much as 69.5% in paddy fields in Japan. Towprayoon *et al.* (2005) reported that CH_4 emission from rice fields in the central plain of Thailand was reduced by 35% by draining paddy fields twice. Likewise, Tyagi *et al.* (2010) reported that mid-season drainage and multiple drainage suppressed CH_4 emission by 37% and 41%, respectively.

Less is known of the impact of AWD on N_2O fluxes and there are mixed results in the literature (Hussain *et al.*, 2014). Both CH_4 and N_2O are produced during different stages of soil redox potential fluctuations, and it is generally recognized that anaerobic-aerobic cycling promotes N_2O emission (Granli and Bøckman, 1994; Cai *et al.*, 1997). N_2O is a by-product of nitrification and an intermediate product of denitrification. Nitrification may trigger N_2O emissions i) by direct production under oxic conditions, ii) as an end product in nitrifier denitrification under anoxic conditions, and iii) by indirect production through supplying NO_3^- to denitrification (coupled nitrification-denitrification) (Butterbach-Bahl *et al.*, 2013). In general, draining paddies create suitable O_2 availability in the soil for N_2O production, while flooding inhibits N_2O formation and emission. Therefore, in addition to significantly reducing CH_4 emissions, field drainage may increase N_2O emissions (Forster *et al.*, 2007).

Most studies assessing the impact of AWD on rice productivity and GHG emissions have only considered CH_4 emissions (Hussain *et al.*, 2014). Moreover, to our knowledge, no data are available for European conditions and practices and further studies are needed to check the applicability of the AWD as common agricultural practice in Mediterranean area. To start overcoming this knowledge gap, this study aimed to assess how AWD practice influence the fluxes and annual budgets of CH_4 and N_2O emissions from Italian paddy soils, taking into account emission trade-offs between these two GHGs and calculating the GWP of each management practice with respect to grain yields and water savings.

MATERIALS AND METHODS

Site description and experimental design

A 2-year experiment was conducted from 2012 to 2013 on a commercial farm (Società Italiana Sementi) of dry-seeded rice fields, located at Malalbergo Municipality (44°41′32.11″ N, 11°28′55.61″ E) in Bologna Province, central Italy. Mean monthly temperature and precipitation during the experiment period followed typical patterns for a Mediterranean climate, with a mean monthly temperature of 16 °C and a mean monthly precipitation of 63 mm. The fields were in rotation with upland crops (legumes and wheat) and prior to 2012 had been planted to upland crops for 3 years (2009–2011). The soil of the study area is classified as fine-silty, mixed, non-acid, mesic Thapto-Histic Fluvaquent (Soil Survey Staff, 2010). The soil profile description is reported in Table I according to Scho-