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Effect of tillage and water management on GHG emissions from Mediterranean rice growing ecosystems

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HIGHLIGHTS

- No-tillage increases N_2O emissions from rice fields.
- No-tillage decreases CH_4 emissions from flooded rice fields.
- Aerobic rice production with no-tillage is an efficient strategy to minimize GHG emissions.

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ABSTRACT

Paddy rice fields are an important source of greenhouse gases (GHG), especially methane. In the present work, we assessed the impact on GHG emissions of two main parameters of rice production: aerobic rice production was compared with traditional flooded rice production and conventional tillage (CT) was compared with short-term and long-term no-tillage (NT) management. A field experiment was performed over three years and the GHG emissions were measured during each year. Five treatments (3 replicates) were considered: **NTS7**: no-tillage over seven years and sprinkler irrigation; **NTS**: no-tillage and sprinkler irrigation; **CTS:** conventional tillage and sprinkler irrigation; **NTF**: no-tillage and flooding; **CTF:** conventional tillage and flooding. The use of sprinkler irrigation rather than flooding led to decreases in nitrous oxide and methane emissions of ~40% and more than 99%, respectively, over the 3-year experiment. The use of sprinkler irrigation compared with flooded irrigation reduced the global warming potential (GWP) about 40% and 36% in no-tillage and conventional tillage treatments, respectively. Treatment NTF decreased CH_4 emissions, relative to CTF, by ~60% over three years but the effect of NT on N_2O emissions was not clear: a decrease or no effect was mostly observed in the NT treatments, relative to CT. A decrease of ~40% in the total GHG emissions was observed in the NT treatments, relative to CT. No or small differences between NTS and NTS7 in terms of gaseous emissions were found. The short-term no-tillage and sprinkler irrigated treatment (NTS) gave lower yields than CTF in 2011 and 2012, but reached similar yields in the third year (NTS 8229 kg ha^{-1};CTF 8926 kg ha^{-1}), with average savings of 75% of the total amount of water applied in CTF. The NTS7 data showed that high yields (reaching 9805 kg ha^{-1} in 2012) and water savings are sustainable in the long term. Considering the yield-scaled GWP of the emissions, NT gave a decrease of up to 42%, relative to CT. However, the effect of water management on yield-scaled GWP depended on the soil management: yield-scaled GWP was higher with flooding when NT was used and lower when tillage was used. It can be concluded that, for aerobic rice production, NT is an efficient strategy to minimize GHG emissions while maintaining high levels of production.

1. Introduction

Rice (*Oryza sativa* L.) is the staple food of more than 60% of the

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world population (Patel et al., 2010). The total area dedicated to rice production is 180 million ha of which 90% is in Asia, while in the European Union (EU) 475 000 ha are used for rice cultivation. Spain is one of the largest rice producers in the EU, with 30% of the total production (MAGRAMA, 2013).

Rice production is also one of the main contributors to the emissions of greenhouse gases (GHG), especially methane (CH_4) and nitrous oxide (N_2O) (Datta et al., 2009; Zhang et al., 2010). The soil management practices used for rice production have a strong influence on CH_4 (Ali et al., 2009) and N_2O (Kreye et al., 2007; Ahmad et al., 2009) emissions from rice fields, which must be controlled to maintain the ecosystem balance.

Methane production in soil occurs exclusively in anaerobic conditions and depends on several soil parameters such as carbon (C) content, temperature, and bulk density (Mitra et al., 2002). Anaerobic soil conditions and a redox potential lower than −200 mV are needed for CH_4 production by methanogenic bacteria (Kreye et al., 2007). Of the close to 230 000 Mg of CH_4 that were emitted from paddy fields in the EU in 2012, 25% were emitted in Spain (FAOSTAT, 2015). Nitrous oxide production occurs via two complementary processes, nitrification and denitrification. Subsequent soil transitions from wet to dry conditions stimulate nitrification, whereas denitrification is enhanced when the soil is rewetted (Abao et al., 2000). These gaseous emissions to the atmosphere are also limited by the diffusion of gases in soil and water, as in the case of flooded rice fields. The effects of paddy fields on CH_4 emissions are well known and, more recently, their effects on N_2O emissions have been studied. Kreye et al. (2007) followed the N_2O emissions in a study considering water-saving rice production in north China and they reported an increase of N_2O emission**s** in irrigated soils compared to traditional paddy fields. Even if the amounts of N_2O emitted are significantly lower than the amounts of CH_4, the relative global warming potential (GWP) of N_2O (265 for a 100-year horizon) is significantly higher than that of CH_4 (28 for a 100-year horizon), so it is a priority to reduce emissions of this gas. Several strategies have been proposed to mitigate GHG emissions from paddy rice fields, such as improvement of land management by no- or reduced-tillage practices (Pathak and Wassmann, 2007). Tillage plays an important role in weed control and nutrient mixing but it is also responsible for soil C and nitrogen (N) losses (Soane et al., 2012). The main consequences of no-tillage (NT) practices are negligible soil perturbation and accumulation of plant residues, a source of organic matter and nutrients. This should, in the long-term, lead to a shift in the physical, chemical, and biological properties of the soil (Soane et al., 2012) that should affect GHG production and mobility along the soil column and their subsequent emission from the soil surface (Beare et al., 2009). However, few or no data are available on the long-term effect of no-tillage (direct seeding) on GHG emissions from rice fields.

Aerobic rice production has been proposed as an efficient solution to save water since it minimizes water inputs during rice growth and strongly decreases water losses by percolation and evaporation (Nie et al., 2012). Furthermore, aerobic rice production generates lower CH_4 emissions, relative to flooded rice (Nie et al., 2012; Kato and Katsura, 2014), but it often increases N_2O production (Towprayoon et al., 2005). The intermittent irrigation of rice fields, with alternate aerobic and anaerobic periods, is another management option for reducing CH_4 emissions (Zheng et al., 1997; Huang et al., 2004). However, improper irrigation could lower rice production due to increased water stress. Several authors (Wang et al., 2002; Bouman et al., 2005) found that aerobic rice systems can reduce water requirements by up to 44%, in comparison with conventional systems, with attainable yields greater than 8 Mg ha^{-1} (Kato and Katsura, 2014). Aerobic rice production is now used at the farm scale in Spain and in several other countries and this practice should increase during the coming decades (Bouman et al., 2007).

To the best of our knowledge, there is no information available about GHG emissions from rice fields in Mediterranean countries in relation to sprinkler-irrigated aerobic systems combined with different soil management regimes such as no-tillage and conservation agriculture practices. Despite the fact that Spanish rice production is very small in comparison with global production, the results obtained in the present study should be of interest to other rice producers in Europe or in countries with similar edaphoclimatic conditions.

The aim of the present work was to evaluate the effects of irrigation and tillage practices on CH_4, N_2O, and CO_2 emissions from rice fields in Mediterranean conditions. In the present work, we hypothesized that: 1) sprinkler-irrigated rice production would lead to lower GHG emissions than traditional flooding systems; 2) NT would decrease CH_4 and CO_2 emissions relative to traditional cultivation; 3) the effect of NT on GHG emissions would be more significant in the long-term.

2. Material and methods

2.1. Site description

A field experiment was conducted between 2011 and 2013 on a Hydragic Anthrosol (FAO, 2006) located in Extremadura, southwest Spain (39° 06′ N; 5° 40′ W). This site has a Mediterranean climate (rainfall < 480 mm, hot and dry summers). The temporal variations in gaseous emissions presented here refer exclusively to the second year of the experiment (2012) since similar patterns were observed in 2011 and 2013. The evolution of temperature and precipitation during this time period is shown in Fig. 1. Historically, the experimental field (2000 m^2) was cropped with rice using traditional practices (deep plowing and waterlogging), but part of the field had been dedicated to sprinkler-irrigated rice with no-tillage (direct seeding) for the seven years prior to the current experiment.

2.2. Field experiment

An agricultural field was divided into 200-m^2 experimental

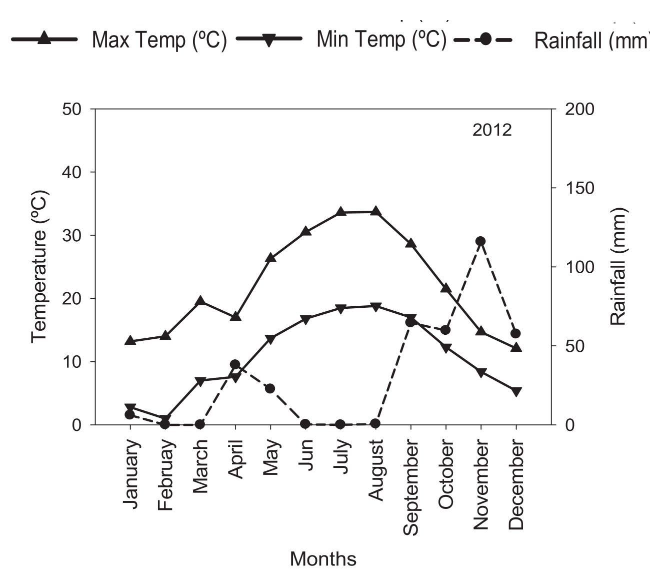

Fig. 1. Mean rainfall and temperature pattern registered at field location during the rice growing period in 2012.