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Direct nitrous oxide emissions in Mediterranean climate cropping systems: Emission factors based on a meta-analysis of available measurement data

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A B S T R A C T

Many recent reviews and meta-analyses of N_2O emissions do not include data from Mediterranean studies. In this paper we present a meta-analysis of the N_2O emissions from Mediterranean cropping systems, and propose a more robust and reliable regional emission factor (EF) for N_2O, distinguishing the effects of water management, crop type, and fertilizer management. The average overall EF for Mediterranean agriculture (EF_{Med}) was 0.5%, which is substantially lower than the IPCC default value of 1%. Soil properties had no significant effect on EFs for N_2O. Increasing the N fertilizer rate led to higher EFs; when N was applied at rates greater than 400 kg N ha^{-1}, the EF did not significantly differ from the 1% default value (EF: 0.82%). Liquid slurries led to emissions that did not significantly differ from 1%; the other fertilizer types were lower but did not significantly differ from each other. Rain-fed crops in Mediterranean regions have lower EFs (EF: 0.27%) than irrigated crops (EF: 0.63%). Drip irrigation systems (EF: 0.51%) had 44% lower EF than sprinkler irrigation methods (EF: 0.91%). Extensive crops, such as winter cereals (wheat, oat and barley), had lower EFs (EF: 0.26%) than intensive crops such as maize (EF: 0.83%). For flooded rice, anaerobic conditions likely led to complete denitrification and low EFs (EF: 0.19%). Our results indicate that N_2O emissions from Mediterranean agriculture are overestimated in current national greenhouse gas inventories and that, with the new EF determined from this study, the effect of mitigation strategies such as drip irrigation or the use of nitrification inhibitors, even if highly significant, may be smaller in absolute terms.

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1. Introduction

More than half of the global Mediterranean climate zone is located on the Mediterranean Sea Basin (Aschmann, 1973); the remainder is on the Pacific coast of North America, south-western Australia, the Cape region of South Africa and the central coast of Chile (Olson et al., 2001). One of the most distinctive features of Mediterranean climates is the summer drought and relatively mild temperatures in winter. However, annual precipitation is variable, between 275 and 1000 mm, such that Mediterranean climate regions range from semi-arid to humid.

In Mediterranean climates, precipitation and temperatures are suitable in winter for cultivating a variety of rain-fed crops including cereals, grain legumes, oilseeds and horticulture (Andrews et al., 2002). Cultivation of perennial crops is common in Mediterranean climate areas. Some of these crops are resistant to summer droughts, including olives, almonds, and grapes, while others are cultivated under irrigation, such as citrus and other fruit trees. Agriculture in Mediterranean climates regions, therefore, provides a high diversity of crops.

Agricultural soils are regarded as the primary source of anthropogenic N_2O emissions (Smith et al., 2008). Despite the cultural and economic importance of Mediterranean agriculture (Grigg, 1974), the number of field studies analyzing N_2O emissions from Mediterranean agricultural lands is much smaller than from other temperate areas (Stehfest and Bouwman, 2006). Recent reviews and meta-analyses of N_2O emissions do not include data from Mediterranean studies (e.g. Kim et al., 2013; Lesschen et al., 2011; Shcherbak et al., 2014). Estimating N_2O emissions and N_2O emission factors (EF, the percentage of fertilizer N applied that is transformed and emitted on site as N_2O) is essential for assessing the impact of agriculture on greenhouse gas (GHG) emissions for a particular area. Current national emission inventory methods use a direct EF for N_2O, with a default value of 1% or 1.25% (depending on the country) of the N input from manure and mineral fertilizer (IPCC, 2006). However, many studies have concluded that the response of direct N_2O emissions to N input is non-linear (Kim et al., 2013; Philibert et al., 2012; Shcherbak et al., 2014), and other recent studies highlighted the important role of environmental and management factors in determining N_2O emissions and EFs, such as climate, soil characteristics, type of fertilizer and time of application, crop type, and irrigation system (Aguilera et al., 2013a; Bouwman et al., 2002; Gerber et al., 2016; Leip et al., 2011; Lesschen et al., 2011). For example, Aguilera et al. (2013a) suggested using a lower EF for Mediterranean areas than for other temperate regions, especially in rain-fed systems.

There are three characteristics of Mediterranean regions that are fundamental to understanding why soil N_2O emissions from these regions are idiosyncratic and in-turn why the adoption of EFs which differ from other climate regions should be considered. Firstly, due to limited availability of water irrigation is a prerequisite for the cultivation of many annual crops during summer, whereas mild, humid winters enable annual crops to be rain-fed. Different EFs are therefore needed for irrigated and rain-fed crops. Secondly, soils in the Mediterranean zone generally have a neutral to alkaline soil pH and very low concentrations of organic C (Aguilera et al., 2013b; Verheye and de la Rosa, 2005). These conditions influence denitrification rates and N_2O/N_2 ratios (Li et al., 2005; Šimek and Cooper, 2002). Thirdly, soils in Mediterranean regions are rarely exposed to freeze–thaw cycles, which cause high N_2O emissions, especially in fertilized soils (Schouten et al., 2012; Tenuta and Sparling, 2011), which lead to high EFs.

The aim of this study was to improve our understanding of soil N_2O emissions from Mediterranean cropping systems by (i) summarizing available field data of soil N_2O emissions; (ii) proposing a more robust and reliable regional EF; and (iii) identifying controlling factors of N_2O EFs (soil type, climate variability, irrigation and N fertilizer management) as a basis for developing soil N_2O mitigation strategies for regions with Mediterranean climates.

2. Methods

2.1. Selection of studies and data extraction

There are varying definitions to demarcate Mediterranean climate regions worldwide, which are typically based on climate and plant associations. We chose the widely used delineation of

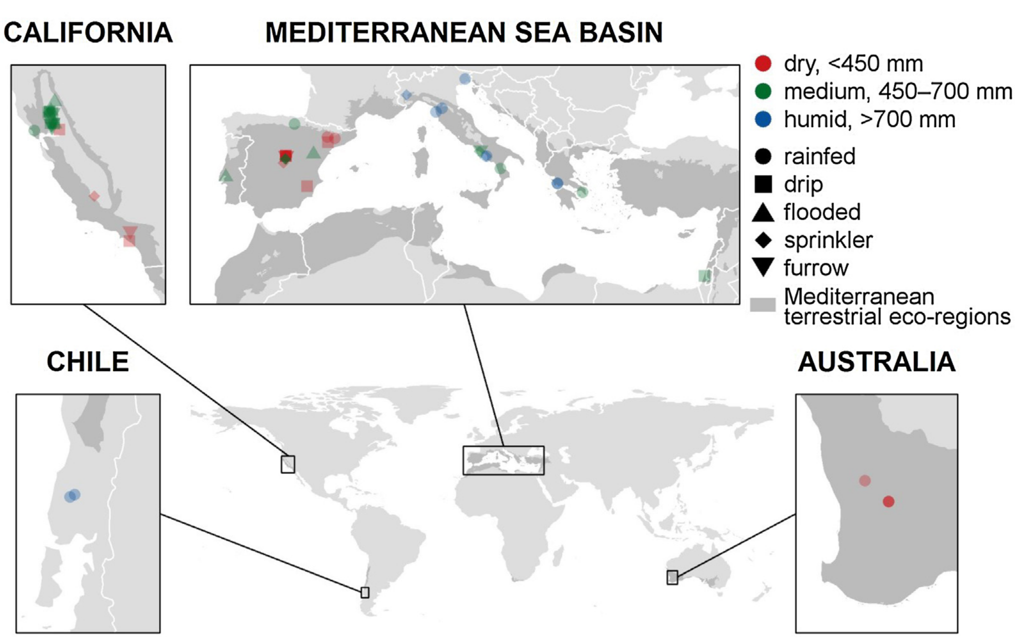

Fig. 1. Location of the study sites included in the dataset. The dark gray area delimits the Mediterranean biome from the collection of ecoregions mapped by the World Wildlife Fund (Olson et al., 2001).

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