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Review

The potential of organic fertilizers and water management to reduce N_2O emissions in Mediterranean climate cropping systems. A review

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ABSTRACT

Environmental problems related to the use of synthetic fertilizers and to organic waste management have led to increased interest in the use of organic materials as an alternative source of nutrients for crops, but this is also associated with N_2O emissions. There has been an increasing amount of research into the effects of using different types of fertilization on N_2O emissions under Mediterranean climatic conditions, but the findings have sometimes been rather contradictory. Available information also suggests that water management could exert a high influence on N_2O emissions. In this context, we have reviewed the current scientific knowledge, including an analysis of the effect of fertilizer type and water management on direct N_2O emissions.

A meta-analysis of compliant reviewed experiments revealed significantly lower N_2O emissions for organic as opposed to synthetic fertilizers (23% reduction). When organic materials were segregated in solid and liquid, only solid organic fertilizer emissions were significantly lower than those of synthetic fertilizers (28% reduction in cumulative emissions). The EF is similar to the IPCC factor in conventionally irrigated systems (0.98% N_2O-N N applied^{-1}), but one order of magnitude lower in rainfed systems (0.08%). Drip irrigation produces intermediate emission levels (0.66%). Differences are driven by Mediterranean agro-climatic characteristics, which include low soil organic matter (SOM) content and a distinctive rainfall and temperature pattern. Interactions between environmental and management factors and the microbial processes involved in N_2O emissions are discussed in detail.

Indirect emissions have not been fully accounted for, but when organic fertilizers are applied at similar N rates to synthetic fertilizers, they generally make smaller contributions to the leached NO_3^- pool. The most promising practices for reducing N_2O through organic fertilization include: (i) minimizing water applications; (ii) minimizing bare soil; (iii) improving waste management; and (iv) tightening N cycling through N immobilization. The mitigation potential may be limited by: (i) residual effect; (ii) the long-term effects of fertilizers on SOM; (iii) lower yield-scaled performance; and (iv) total N availability from organic sources. Knowledge gaps identified in the review included: (i) insufficient sampling periods; (ii) high background emissions; (iii) the need to provide N_2O EF and yield-scaled EF; (iv) the need for more research on specific cropping systems; and (v) the need for full GHG balances.

In conclusion, the available information suggests a potential of organic fertilizers and water-saving practices to mitigate N_2O emissions under Mediterranean climatic conditions, although further research is needed before it can be regarded as fully proven, understood and developed.

Contents

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1. Introduction

Nitrous oxide (N_2O) is a powerful greenhouse gas (GHG). It is 298 times stronger than CO_2 at the 100-year time horizon and in 2005, it accounted for 6.1% of combined GHG radiative forcing (Forster et al., 2007). According to the cited authors, the atmospheric N_2O concentration rose from 270 to 319 ppb in the period 1900–2005, after having previously remained relatively stable for the previous two millennia. Agricultural emissions represent about 60% of global anthropogenic N_2O emissions. They increased by 17% from 1990 to 2005 and are projected to increase by 35–60% up to 2030 (Smith et al., 2007).

Nitrogen fertilizer applications to soils, whether organic or synthetic, result in N_2O emissions, as this gas is a by-product of the transformation of N compounds added to the soil. N_2O fluxes from soil are mainly driven by microbial activity, through nitrification and denitrification processes (Firestone and Davidson, 1989). In spite of the existence of a large body of knowledge on the mechanisms that underlie these pathways, there is still an insufficient understanding of the finer details of the process, such as how the composition of organic N fertilizers affects denitrification, nitrification and emission rates (Vallejo et al., 2006).

Besides soil emissions after fertilizer applications (direct emissions), fertilizer-related N_2O production can also result from indirect emissions. Downstream of the cropping system, N_2O is produced when N compounds, and particularly leached nitrate (NO_3^-) and volatilized ammonia (NH_3), are subsequently transformed into N_2O (IPCC, 2006a). These indirect sources can represent a significant fraction of total agricultural N_2O emissions (Garnier et al., 2009). Upstream of the cropping system, N_2O and other GHG are emitted as by-products of fertilizer production, storage and transport (Snyder et al., 2009). Although these emissions are very dependent on the methods used to obtain fertilizers, half of synthetic N fertilizer-related GHG emissions could occur in the production phase, whereas the other half occurs from the soil (Tirado et al., 2010). In 2001, fertilizer production accounted for 1% of the global energy demand; 72% of this energy corresponded to N, and a further 16% to compound fertilizers containing N (Ramírez and Worrell, 2006).

There is increasing interest in the application of organic fertilizers to soils (e.g., Hargreaves et al., 2008; Petersen et al., 2003; Singh and Agrawal, 2008; Smil, 1999), as they can contribute to climate change mitigation through C sequestration (Diacono and Montemurro, 2010), at the same time helping to tackle problems associated with waste management and meeting the nutrient and organic matter needs of agricultural soils (Tirado et al., 2010). Nevertheless, the use of organic fertilizers also has a number of drawbacks, which include the energy costs associated with transport and the land spreading of the fertilizers (Wiens et al., 2008), potential pollution with heavy metals and other toxic substances (Petersen et al., 2003), the availability of organic N sources, and GHG emissions (Snyder et al., 2009).

The type and composition of fertilizers have been shown to affect direct N_2O emissions from cropped soils (Stehfest and Bouwman, 2006), although the differences between applying organic and synthetic fertilizers are still not clear. For example, Laegreid and Aastveit (2002) analyzed several databases and found higher direct N_2O emissions from manure than from mineral fertilizers. Although there is great uncertainty in the estimation of the effect of fertilization type on indirect N_2O emissions, overall emissions could actually be slightly lower for organic fertilizers, as calculated in a top–down analysis (Davidson, 2009).

These information gaps are especially relevant for Mediterranean-type cropping systems, where an increasing