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N_2O emissions from protected soilless crops for more precise food and urban agriculture life cycle assessments

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A B S T R A C T

Due to population growth and the subsequent increase in the demand for food, low carbon food chain production systems are a necessity to reduce the effects on climate change as much as possible. Urban agriculture is of great interest because of its potential in reducing the indirect CO_2 emissions of a city's food supply by reducing transportation distances, the packaging required and the food losses that occur during transportation. However, intensive urban agriculture production, which often relies on the use of soilless substrates, requires synthetic fertilizers rich in nitrogen, resulting in N_2O emissions. Presently, there is a lack of studies that determine the generation of N_2O from soilless crops to properly account for their global warming potential. In this study, an open chamber system was used to quantify N_2O emissions from lettuce crops with perlite bags as their substrate in a Mediterranean rooftop greenhouse located in the metropolitan area of Barcelona (Spain). N_2O generation, through nitrifying and denitrifying reactions, was limited by assuring an aerobic environment, negligible water retention, the absence of NH_3, and controlled dosage of NO_3^- in the most favorable pH conditions for plant assimilation. The emission factor (EF) measured for the soilless lettuce crop (0.0072–0.0085 kg N_2O^{-1} per kg N^{-1}) was half the EF of the IPCC method (0.0125 kg N_2O^{-1} per kg N^{-1}) for soil crops, which is commonly used in life cycle assessment (LCA) studies to approximate direct N_2O emissions, for lack of a better method. Using a more appropriate EF for an LCA study of a tomato crop grown under similar conditions to those used to generate the EF resulted in a 7.5% reduction (0.06 kg CO_2 eq. per kilogram of tomato production) in total global warming potential. This study shows that soilless crops reduce N_2O emissions when compared to conventional crops, making urban agriculture an attractive practice for reducing GHG emissions. The results highlight the need to determine a standard method for determining an EF applicable to soilless protected crops, which, based on the parameters described here, such as the type of substrate, fertilizers and irrigation system, would allow for a more accurate environmental evaluation of soilless conventional and urban crops.

1. Introduction

High nitrogen (N) demand for food production due to an ever-growing population has resulted in an alteration of the natural N cycle in the air, on land and in the water on both regional and global levels (Galloway et al., 2004). Direct N_2O emissions from the agricultural sector represented 6% of total European greenhouse gas (GHG) emissions in 2012. The atmospheric concentration of N_2O is of great concern because N_2O is a GHG with a global warming potential (GWP) 298 times that of CO_2 for a 100-year time span (IPCC, 2013) and is also responsible for stratospheric ozone depletion (IPCC, 2014a, 2014b). By 2050, global food production is estimated to rise by 30% (Alexandratos and Bruinsma, 2012), as a consequence of an increase in the global population to 9.6 billion humans by the same year (UN, 2012). Moreover, 70% of the global

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population will be concentrated in cities (UN, 2012), requiring more energy for food transportation and packaging and resulting in further GHG emissions. Finding more sustainable ways of producing food is imperative, especially for urban areas. One way to do this is to look for agricultural systems that produce fewer N_2O emissions to reduce GHG emissions from worldwide feeding systems (Maraseni and Qu, 2016).

Urban agriculture (UA) is a potential solution to reducing the carbon footprint of urban areas (Mok et al., 2013) because it reduces food transportation distances, packaging and food loss. Rooftop greenhouses (RTGs) are a specific type of UA consisting of a greenhouse on the roof of buildings. RTGs are of great interest due to their potential to reduce the environmental impact and costs of food production, while creating jobs in cities (Cerón-Palma et al., 2012). Sanyé-Mengual et al. (2015) have analyzed the environmental performance of RTGs in comparison with conventional crop production using a cradle-to-grave, cradle-to-gate and cradle-to-consumer approach. The study's results suggest that producing tomatoes in a RTG in a *soilless system* can result in fewer GHG emissions than conventional tomato production, if the annual production rate reaches at least 24 kg m^{-2}. For lack of a more appropriate N_2O emission factor (EF) for soilless crops, the Sanyé-Mengual et al. (2015) study used the IPCC EF to quantify N_2O emissions from the N fertilizers supplied. However, the IPCC method used (IPCC, 2006) is based on data generated from *soil-based crops* and does not take into consideration the different substrate and fertilizer reduction of soilless crops, as well as solar radiation, temperature, humidity and other factors that could significantly influence the EF. Consequently, the GHG emissions may not be correctly calculated.

Similar to the Sanyé-Mengual et al. (2015) study, other life cycle assessment (LCA) studies that attempt to evaluate the environmental performance of soilless crops have the same handicap due to a lack of more appropriate EFs. For example, three soilless tomato crops grown in Spain, Hungary and The Netherlands were evaluated with LCA methodology in the European project EUPHOROS (Montero et al., 2011) using the same IPCC soil-based EF for all locations, without taking into account how the soil-less substrate and the differing climate conditions could affect the GHG emissions during the growth phase. Similarly, Torrellas et al. (2012) assessed how various degrees of fertilization affect the LCA of a soilless tomato crop grown in Southern Spain. Even though they used the IPCC EF, the study concluded that one of the most important factors in curtailing the carbon footprint of the fruit is the reduction of direct emissions to air caused by N fertilizers, further evidencing the need for a more appropriate N_2O EF for soilless crops. Payen et al. (2015) reached comparable conclusions in their cradle-to-market analysis of local versus imported tomatoes grown with soilless systems in France. They concluded that the environmental assessment is especially sensitive to both the EF used to determine the direct N_2O emissions and the transportation requirements of the fruit.

In soil-based crops, emissions of N_2O result from nitrification and denitrification reactions as shown in Fig. 1a. The inert conditions of substrates used in soilless crops and their low capacity to retain water can inhibit the microbial population growth that produces N_2O emissions through nitrification, making denitrification the main mechanism (Ruser and Schulz, 2015). Consequently, applying the IPCC EF, even as a rough approximation, could significantly overestimate the N_2O emissions from soilless crops. Furthermore, in soilless crops, N fertilizers can be exclusively provided through nitrate (NO_3^-) doses via the irrigation system, as shown in Fig. 1b, thereby limiting the amount of ammonium (NH_4) present in the substrate, which could lead to N_2O via nitrification (Gianquinto et al., 2013). In addition, an optimal NO_3^- dose, as well as favorable pH conditions (between 5.5 and 6.5) to facilitate optimal plant N assimilation, should prevent the accumulation of NO_3^- in the substrate, which would otherwise lead to N_2O via denitrification (Gianquinto et al., 2013; Savvas et al., 2013). The denitrification route shown in Fig. 1b is further limited by the fact that the high porosity of the substrate results in an aerobic environment (Ruser and Schulz, 2015). In an aerobic environment, microorganisms have enough available oxygen to continue with their activity, so the denitrification process is not necessary for obtaining the required oxygen.

There are several studies that analyze direct N_2O emission from fertilized crops, but very few that determine the EF for soilless crops (Table 1). Yoshihara et al. (2014) experimentally measured an emissions factor of 0.01–0.046 kg N_2O^{-1} per kg N^{-1} for a tomato crop grown in rockwool substrate. The study examined the change in N_2O emissions response after fertilization with different concentrations of fertilizer and found that 90% of N_2O emissions occurred within the first two hours of fertilization, with a main emissions peak at the 90th minute. Furthermore, they realized that halving the concentration of fertilization reduced N_2O emissions by more than half. A second study by Daum and Schenk (2013) estimated an emission of 0.004–0.016 kg N_2O^{-1} per kg N for a cucumber, closed-loop crop cultivated with rockwool substrate. The study found that the highest emissions rates are produced during fruit stem growth. In addition, root density increases N_2O emissions because high root respiration favors the growth of microorganisms in the substrate. Both studies provide a range for the N_2O EF that could be between 20% and 68% less than the EF published for soil crops (Bouwman, 1996) and accepted by the IPCC (2006), if efficient

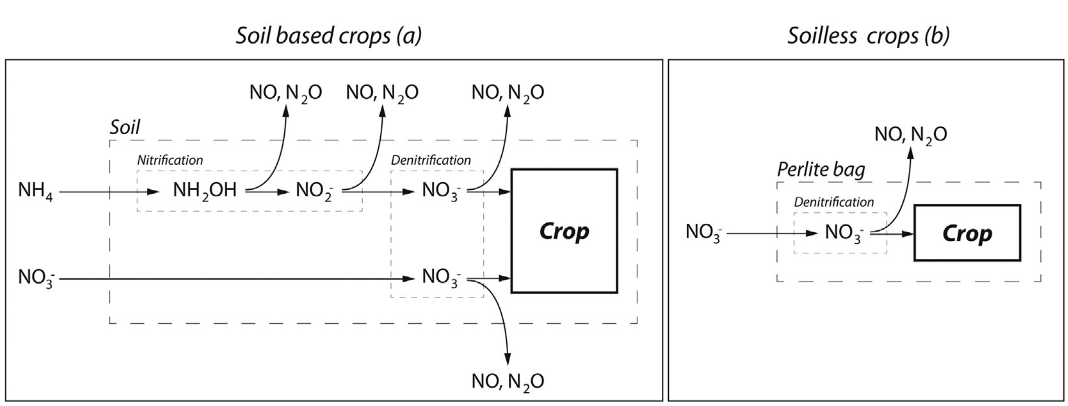

Fig. 1. (a) N_2O emissions through the nitrification – coupled – denitrification process in soil based crops, adapted from Reiner Ruser and Rudolf Schulz (Ruser and Schulz, 2015). (b) Only the denitrification process produces N_2O emissions for soilless crops.