Estimating Nitrous Oxide (N_2O) emissions from the application of N fertilizers to soils at higher resolution in Ireland

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Introduction

This paper aims to define a high-resolution model to estimate nitrous oxide (N_2O) emissions from agricultural soils in the Republic of Ireland. N_2O emissions from the management of agricultural soils represented 10% of the total national GHG emissions in 2020 (Duffy et al., 2022). The current methodology for quantifying N_2O emissions uses a general equation based on the Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and national emissions factors differentiated by fertilizer type (Tier 2). Although this method approximates the sector's emissions, it does not consider two crucial environmental factors, namely soil characteristics (pH, texture, drainage) and climate (precipitation and temperature). By taking into account these factors, N_2O emissions can be quantified with increased granularity.

Background

This research follows the methodology proposed by the Intergovernmental Panel on Climate Change (IPCC) for agricultural soils (category 3.D.1). N_2O is primarily emitted from ecosystems as a by-product of nitrification and denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas. N_2O is a gaseous intermediary in the reaction sequence (IPCC, 2006). The methodology measures direct and indirect N_2O emissions, where the direct N_2O emissions take into account the nitrogen inputs from synthetic fertilizer, animal manure, sewage sludge, crop residues, mineral soils, urine and dung deposited by grazing animals, and managed/drained organic soils, and the indirect N_2O emissions includes emissions from atmospheric deposition and nitrogen leaching and run-off. N_2O emissions are calculated by accounting for the amounts of each input and multiplying them by their respective emission factor (Duffy et al., 2022).

High-resolution model to quantify N_2O emissions

The high-resolution model modifies the emissions factor of the direct N_2O emissions equations by adding soil characteristics and climate (environmental factors) by using indices. The soil characteristics indices are soil pH, texture, drainage, soil type and soil moisture, and they are defined considering the results obtained in previous research in Ireland and the EU (Hafner et al., 2019; Harty et al., 2016; Krol et al., 2016; Murphy et al., 2022; Rahman et al., 2021; Roche et al., 2016). Regarding climate, there are two indices, one for the annual precipitation and the other for air temperature. The precipitation index is a linear function that affects emissions directly. The air temperature index is the difference between the highest and average temperature of the year. The assumptions of the climate indices are defined according to the information registered from 2010 to 2019 by the Irish Meteorological Service (Met, 2022).

In order to compare the high-resolution model, a baseline model was estimated to follow the current methodology in Ireland. This model was proposed in the 2020 Sustainability Report to show the GHG emissions at farm level in Ireland (Buckley, C. & Donnellan, T., 2021).

Data

This paper draws on the Teagasc National Farm Survey (NFS) 2018, representing the agricultural sector by type of farm and region in Ireland. The NFS is part of the EU Farm Accountancy Data Network and provides highly detailed activity data for 900 farmers annually, and farms can be spatially referenced. In this survey, it is possible to identify the primary type of soil and its main characteristics for each farm according to the soil classification suggested by Gardiner and Radford (1980). Also, georeferencing allows overlaying the sample farms on climate data rasters at high-resolution (2.5 km horizontal grid) obtained from the Met Éireann (Gleeson et al., 2017).

Results

Results indicate that the high-resolution model quantified 2.2% less N_2O emissions compared to the baseline model. This reduction in the quantification is mainly due to a decrease in the estimated fertilizer emissions of 3.9% and a drop of 1.5% in urine and dung emissions when environmental factors are included. The differences between the baseline and high-resolution models are heterogeneous around the country due to the soil characteristics and climate conditions. The variance by farms ranges from -33% to 38%. Farms with a reduction in the quantification of N_2O emissions have fewer quality soils, lower soil moisture and less variability in temperature and precipitation. In contrast, farms with an increase the in the quantification of N_2O emissions have a better quality of soils, high soil moisture and more variability in temperature and precipitation.

We confirm that the difference is statistically significant through a quantile regression of the difference between the baseline and high-resolution model. Furthermore, climate conditions have a statistically significant impact on N_2O emissions in the high-resolution model. The results of the environmental factors show that the climate has a higher effect on N_2O emissions than soil characteristics, and this impact is different throughout all the distribution of N_2O emissions at farm level. The total effect of the climate is 21%, while soil characteristics are 11%. The temperature and soil moisture variables are the ones with the most significant variability throughout the country, and they are the ones that best explain the differences in the high-resolution model.

Conclusions

This paper's results contribute to improving the accuracy of N_2O emission measurement on agricultural soils. In addition, it shows the importance of having disaggregated data on agricultural activity and climate. The environmental factors have a statistically significant effect on N_2O emissions, mainly soil moisture and temperature. The evidence from this study suggests that climate conditions have a higher impact than soil characteristics on N_2O emissions. This is important because the soil characteristics would be constant over time. In contrast, the climate conditions will show far greater variability.

The design of a high-resolution emissions estimation process allows analysis of different agricultural practices and could assist in targeting appropriate mitigation measures spatially. For instance, to define the cost of carbon at the farm level, it would be essential to consider the emission levels incorporating environmental factors by type of farm.

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