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Organic residues valorisation by fertilisation: Coupling models to assess the impact of spreader performances on nitrogenous emissions and related environmental impacts

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Abstract

This paper proposes a generic methodological framework to investigate the link between application technique performances and related nitrogen emissions in the field. Our approach is to couple biophysical models (of N emissions) and models used to assess machinery technological performances related to distribution, application rate efficiency and soil compaction through a four-step method. We highlighted that nitrate emissions cannot be directly linked to spreader distribution deficiencies but are more dependent on weather and soil conditions. On the contrary, ammonia volatilization can be directly linked to the type of spreading operation, especially for liquid sewage sludge. Nitrous oxide emissions are linked to the spreader weight as well as the weather and soil conditions. The methodological framework introduced in this paper highlights the feasibility of coupling real technological performances of spreaders and simulation models to assess the environmental impact of spreading practices.

Introduction

Since 1992, French and European regulations encouraged energetic recovery of waste as well as organic waste valorisation through land application. Land application is only possible if organic wastes bring enough nutrients to the crops and are harmless to both the crop and to the amended soils. As manures, sewage sludges and slurries contain great amounts of nitrogen, there is a growing issue about water and air pollution caused by their application in the field. Unfortunately, up to now, nitrogenous emissions are not well modelled in life cycle assessment methods. For instance, in databases attached to Life Cycle Assessment (LCA) inventories, the emission factors commonly used to quantify NO_3 and direct or indirect N_2O emissions are global. They come from the IPCC guidelines (2006). They do not take into consideration neither the type and performance of the land application techniques nor the type of organic waste applied.

However, average emission factors were proposed in the literature according to organic waste applied and the related application techniques. These factors were established on the basis that each application technique delivers the wanted application rate of organic waste homogeneously whereas it is a great challenge to spread liquid and solid organic fertilizers both accurately and evenly. The technological performances of the application technique – such as distribution homogeneity, respect of application rate and soil compaction – have barely been taken into account in impact computation. The aim of our research is to develop a generic methodological framework to investigate the link between application technique performances and the related nitrogen emissions in the field. Our approach is to couple biophysical models (of N emissions) and models used to assess machinery technological performances related to distribution, application rate efficiency and soil compaction in order to link nitrogenous emissions (NH_3 , NO_3 and N_2O) with the spreading machine performances.

Material and Methods

The proposed methodology for assessing nitrogenous emissions based on technological performances of spreaders is done in a four-step method [1] (Figure 1).

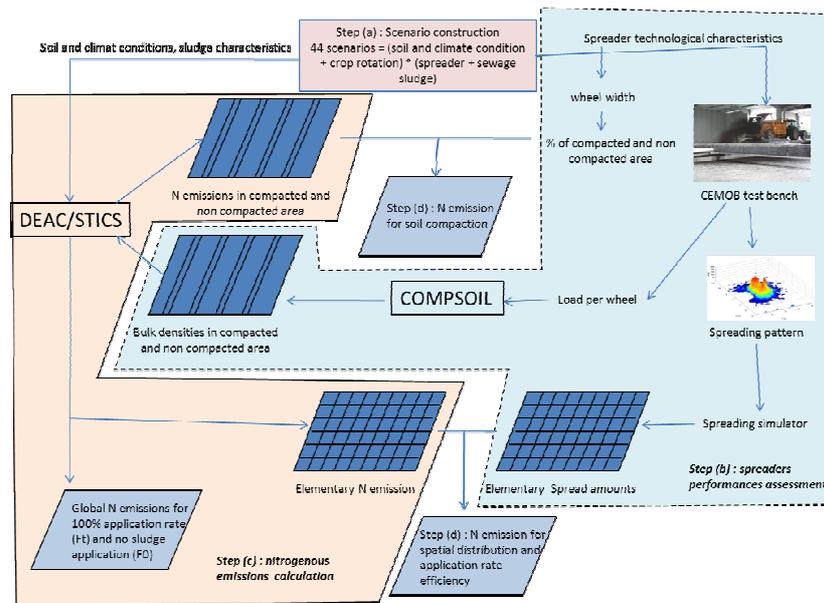


Figure 1. General framework of the method

(a) The first step consists of creating scenarios that associate a cropping system (i.e. soil and climate conditions and a crop rotation), a spreading period and a technological couple “spreading machine/sewage sludge”. Each scenario provides input data for the biophysical model.

(b) The second step consists of testing the technological performances of the spreaders. Spatial distribution and application rate efficiency are evaluated with a test bench. The test bench results are used as input data of a Matlab® simulation tool, named spreading simulator, to estimate the expected spatial distribution and application rate performances in the field. The effect of spreaders on soil compaction is assessed with the Compsoil model [2] which is parameterized with the technological characteristics of the spreaders. Through the simulation and the use of Compsoil model, respectively we will obtain (i) an application rate map and a histogram of application rate at the sub-field scale representing both the distribution and the application rate efficiency, i.e. the application rate really applied compared to the theoretical one, (ii) the bulk densities in compacted and non compacted areas representing the effect of the spreaders on soil compaction.

(c) The third step consists of simulating the nitrogenous emissions generated by different application rates, with biophysical models such as STICS [3] and DEAC. Bulk densities in compacted and non-compacted areas which result from Compsoil simulations are used as input data in STICS model to model nitrogenous emissions in compacted and non compacted areas.

(d) Finally, the simulated nitrogen losses provided by the biophysical models are coupled with the levels of elementary spread amounts provided by the spreading simulator and with the proportion of areas compacted and non compacted. This allows calculating the various nitrogen losses of the spreader according to its performances on spatial distribution, on application rate efficiency and on soil compaction..

Results

Nitrogenous emissions for basal assessment (F0)

The basal emission assessment, using STICS and DEAC models for N-NH₃, N-N₂O and N-NO₃ emissions, is called F0. F0 is the value obtained for a 0% application rate, simulating the impact of no sewage sludge application for the 44 scenarios. There is an important effect of the reference site for all types of emissions, regardless of the spreading operation and the spreading machine. Total nitrogen emissions for each of these groups, resulting of the sum of N-NH₃, N-NO₃ and N-N₂O values, are respectively 32, 6.8, 49.8, 82, 93.5, 19.8, 32.7 and 27.8 kg N.ha⁻¹. These emissions are due to nitrogen balance in soil coming from crop residues, nitrogen mineralization and mineral fertilizers application.

Nitrogenous emissions simulated under standard sewage sludge spreading ($\Delta F1$)

$\Delta F1$ is calculated by the difference between emissions obtained for a 100% application rate (F_t) and those obtained for a 0% application rate (F_0), simulating the impact of sewage sludge spreading for the 44 scenarios. Results shown in Figure 2 represent the additional nitrogen emitted when the sewage sludge is applied, given that it is evenly distributed over the field at the optimal recommended application rate with no compacting effect of the spreading machine. Compared to the total amount of nitrogen supplied by the sewage sludge, N-NH₃ emissions vary from 0 to 8 % (from 0 to 10 kg of nitrogen per hectare), N-NO₃ emissions from -3 to 8 % (from -3 to 10 kg of nitrogen per hectare) and N-N₂O emissions from -3 to 6 % (from -2 to 4 kg of nitrogen per hectare).

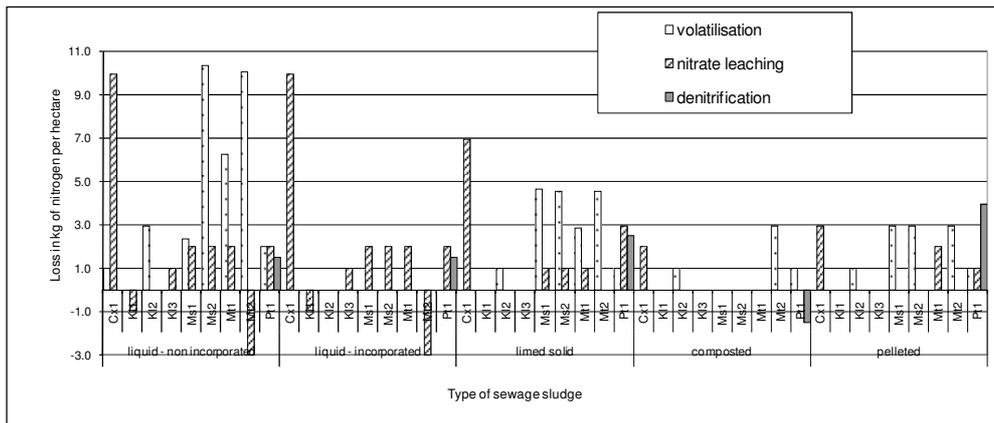


Figure 2. Nitrogen flows due to sewage sludge spreading ($\Delta F1$)

Variability of nitrogenous emissions related to spatial distribution and application rate. The additional nitrogen flow due to the spatial distribution heterogeneity is less than 4% total N applied for N-NH₃ emissions in most of the 44 scenarios (Figure 3). N-NO₃ emissions are very low, excepted for LS spreading in one weather and soil situation (19 % total N applied). Extra denitrification induced by spreading heterogeneity is not significant.

This result is explained by the limited sensitivity of models to the sewage sludge application rate, by the relatively small proportion of surface concerned by higher application rates and by the compensatory phenomenon induced by surfaces receiving lower application rates.

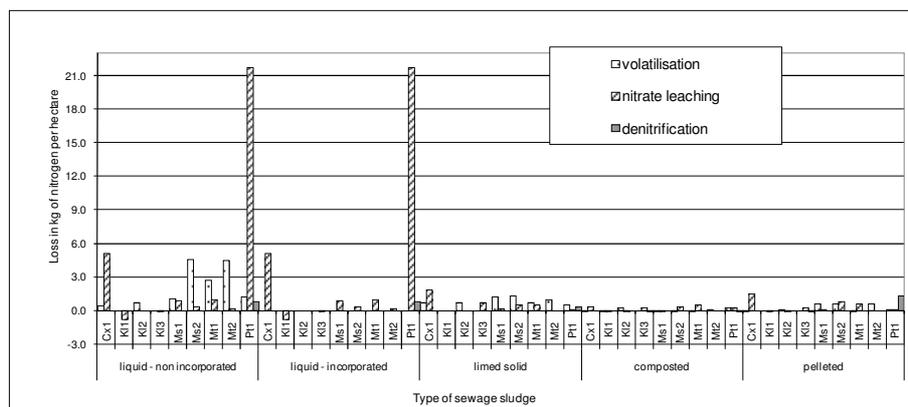


Figure 3. Nitrogen flows due to spreader performance on spatial distribution and application rate

Nitrogenous emissions variability related to soil compaction

Our results show that soil compaction induced by the spreading machine had no significant impact on ammonia volatilization (Figure 4). Indeed, the compaction effect of the machine does not lead to a sufficient reduction of the infiltration for the liquid sewage sludge and has no effect for non-liquid

sludges. Soil compaction has a logical negative effect on nitrate leaching. In compacted areas, a part of the nitrates are likely to be removed with runoff. Besides, denitrification losses (represented by nitrous oxide emissions) are the most affected ones by soil compaction; especially in sensitive locations where the water filled pore space (WFPS) often reaches the trigger threshold for activate the denitrification process.

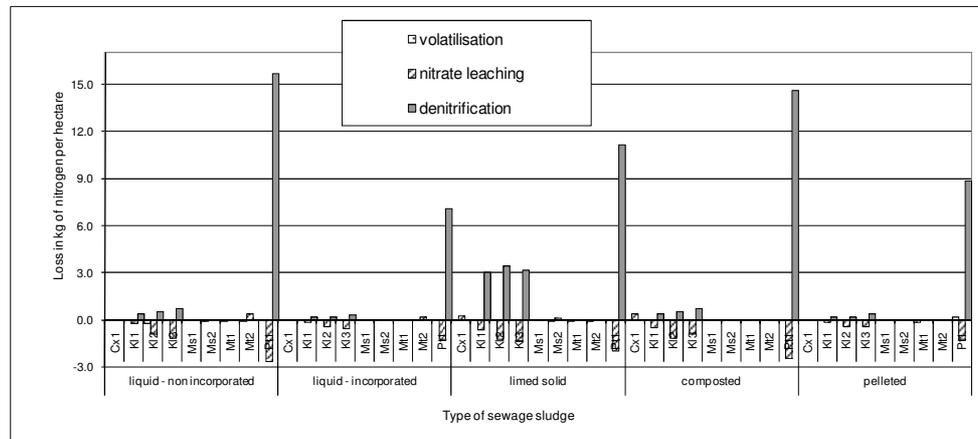


Figure 4. Nitrogen flows due to spreader performance on soil compaction

Conclusion and perspectives

The aim of this paper was to propose a methodological framework to refine the inventory of nitrogenous emissions linked to sewage sludge spreading, by introducing in particular spreading and spreaders' characteristics. The methodological framework introduced in this paper highlights the feasibility of coupling real technological performances of spreaders and simulation models to assess the environmental impact of spreading practices.

Our method can be used to assess the environmental impacts of the organic waste valorisation through land spreading operation and to assess the impact of spreader performances in different conditions. This method can help spreader manufacturers in improving the technological performances of their spreader through ecodesign or in providing farmers with advices on the better use of their spreader depending on the conditions of use.

Finally, as it highlights the variability in nitrogenous emissions, this method can also be used to assess the variability in Life Cycle Assessment Inventories of spreading operations. Indeed, environmental assessment of agricultural practices implying fertilization and spreading processes through Life Cycle Assessment generally comes up against difficulties in estimating nitrogenous emissions. As a simplification, it is common to use standard emissions factors (IPCC-tiers 1 or data coming from the literature). The limits of this simple approach result in standardization of the LCA results as well as a standardization of the recommendations to improve the fertilization and spreading practices. Giving a range of nitrogenous emissions values instead of using one single value based on emission factors such as IPCC-tiers 1 ones will allow recommendations in fertilization and spreading practices improvement adapted to the local weather and climate conditions. As a perspective, this method can also be used to conduct spatialized LCA of fertilizing and spreading operations.

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