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## Assessing N emissions from organic residues spreading: study of the on-field distribution patterns influence and of emission models sensitivity

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### Abstract

Recycling organic residues by direct spreading not only brings ecosystemic services but also induces emissions on field. Estimating N-N<sub>2</sub>O, N-NH<sub>3</sub> and N-NO<sub>3</sub> emissions on field according to the technological performances of spreading machines considering different cultural systems, weather and climate conditions, various distributions on the field and different emission models was studied.

Organic residue distributions in the field were considered as Gaussian distributions using mean, bias and standard deviation. The study showed that N-N<sub>2</sub>O emissions estimated with the STICS model are rarely sensible to distribution and mostly depend on weather and climate conditions. Concerning the other types of emissions obtained with the STICS model and all the results from the IPCC method, the bias of the distribution seems to be the parameter which influences most the results. Ammonia emissions, in particular, show variability according to the scenario and the distribution pattern for all the emission models used.

### Introduction

A study conducted in 2012 between Irstea, ACTA and Arvalis-Institut du vegetal aims to analyse the sensitivity of nitrogenous emissions resulting from organic residues spreading according to different parameters: (i) the distribution of the product on the field, (ii) the type of spread products: sewage sludge, manure and slurries, (iii) the weather and climate conditions and associated cropping systems, (iv) the models used to estimate nitrogenous emissions.

Spreading scenarios were built considering different cropping system in specific weather and climate conditions and different spread products. N-N<sub>2</sub>O, N-NH<sub>3</sub> and N-NO<sub>3</sub> emissions were calculated for each scenario with 4 different models regarding the possible variability of product distribution at the on-field scale. The main parameters used in this study are summed up in Table 1.

**Table 1. Parameters used to assess the on-field emission variability**

| Parameters                     |                    | Number | Comments  |
|--------------------------------|--------------------|--------|---|
| Average/optimal distribution   | Bias               | 11     | 0.5, 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4 and 1.5  |
|                                | Standard deviation | 5      | 10, 15, 20, 25, 30  |
| Organic residues               | Sludge             | 4      | Dry, composted, limed, liquid   |
|                                | Effluents          | 7      | Cattle and poultry manure (with 2 different agronomic characteristics of each), pig slurry and cattle slurry (with 2 different agronomic characteristics) |
| Weather and climate conditions | Sludge             | 9      | Pays de Caux (Cx), Kerlavic (K11, K12, K13), Mons (Ms1, Ms2 for   |
|                                | Effluents          | 8      | sludge, Ms 1 for effluents), Montoldre (Mt1, Mt2), Poitou Charentes (Pt)  |
| Emission models                | N-N <sub>2</sub> O | 2      | STICS, IPCC   |
|                                | N-NH <sub>3</sub>  | 3      | STICS, IPCC, EMEP   |
|                                | N-NO <sub>3</sub>  | 2      | STICS, EMEP   |

### Material and Methods

The method used is based on those proposed by Pradel et al, 2012 [1]. On one side, nitrogenous emissions are calculated for different application rate classes (from 0 to 200% of the desired application rate) with the STICS (Simulateur multidisciplinaire pour les cultures standard) model

[2], IPCC and EMEP factors for 4 types of sludges and 4 types of effluent characterised by different agronomic composition. On the other side, distributions in the field were considered following a Gaussian distribution characterized by mean and standard deviation: a bias of the distribution is built based on the mean to represent the difference between the average and the desired application rate calculated in order to fulfil crop requirements. Standard deviation represents the distribution variability of the application rate classes encountered on the field (in kg per ha). Each obtained emission through simulation for each application rate classes and each organic residue is multiplied by the % of surface of each application rate classes statistically generated to obtain to total emissions at the field scale. Example of results is given in Table 3. The difference between emissions obtained for each distribution is compared to the optimum distribution represented by a bias equal to 1 and a standard deviation equal to 10 (in bold in Table 2). The sum up of these differences for all the application rate leads to a benefit or a loss compared to the reference.

**Table 2. % of surface receiving each application rate according to different bias and standard deviation (results shows for 3 of the 11 bias: 0.5, 1 and 1.5 and 3 of the 5 standard deviation: 10, 20, 30). The optimum distribution is given for bias 1 and standard deviation 10 (in bold).**

| Bias     | Standard deviation | Application rate classes (in %) |          |          |             |              |              |              |             |          |          |          |
|----------|--------------------|---------------------------------|----------|----------|-------------|--------------|--------------|--------------|-------------|----------|----------|----------|
|          |                    | 0                               | 20       | 40       | 60          | 80           | 100          | 120          | 140         | 160      | 180      | 200      |
| 0.5      | 10                 | 0.01                            | 2.41     | 48.3     | 46.67       | 2.61         | 0            | 0            | 0           | 0        | 0        | 0        |
| 0.5      | 20                 | 2.42                            | 13.65    | 34.58    | 34.02       | 13.17        | 2.06         | 0.1          | 0           | 0        | 0        | 0        |
| 0.5      | 30                 | 9.69                            | 15.36    | 25.48    | 24.29       | 16.12        | 6.68         | 1.86         | 0.47        | 0.05     | 0        | 0        |
| ....     |                    |                                 |          |          |             |              |              |              |             |          |          |          |
| <b>1</b> | <b>10</b>          | <b>0</b>                        | <b>0</b> | <b>0</b> | <b>0.14</b> | <b>15.92</b> | <b>68.23</b> | <b>15.56</b> | <b>0.15</b> | <b>0</b> | <b>0</b> | <b>0</b> |
| 1        | 20                 | 0                               | 0        | 0.58     | 5.93        | 24.28        | 38.68        | 24.3         | 5.69        | 0.53     | 0.01     | 0        |
| 1        | 30                 | 0.17                            | 0.94     | 3.68     | 10.7        | 20.98        | 26.36        | 21.24        | 11.15       | 3.79     | 0.85     | 0.14     |
| ....     |                    |                                 |          |          |             |              |              |              |             |          |          |          |
| 1.5      | 10                 | 0                               | 0        | 0        | 0           | 0            | 0.01         | 2.15         | 47.4        | 48.08    | 2.35     | 0.01     |
| 1.5      | 20                 | 0                               | 0        | 0        | 0           | 0.2          | 2.34         | 13.04        | 33.55       | 35.06    | 13.72    | 2.09     |
| 1.5      | 30                 | 0                               | 0        | 0.01     | 0.31        | 1.81         | 6.66         | 16.4         | 24.93       | 24.83    | 16.34    | 8.71     |

**Table 3. Example of N-NO<sub>3</sub> emissions results simulated with STICS model in Pays de Caux system for a bias equal to 1 and a standard deviation equal to 10 for different sludge (in kg N-NO<sub>3</sub>)**

|      | composted sludge | dry sludge | limed sludge | liquid sludge |
|------|------------------|------------|--------------|---------------|
| 0%   | 0                | 0          | 0            | 0             |
| 20%  | 0                | 0          | 0            | 0             |
| 40%  | 0                | 0          | 0            | 0             |
| 60%  | 0.0084           | 0.0098     | 0.0098       | 0.0098        |
| 80%  | 0.9552           | 1.2736     | 1.1144       | 1.1144        |
| 100% | 4.0938           | 5.4584     | 4.7761       | 5.4584        |
| 120% | 0.9336           | 1.2448     | 1.2448       | 1.2448        |
| 140% | 0.009            | 0.012      | 0.012        | 0.012         |
| 160% | 0                | 0          | 0            | 0             |
| 180% | 0                | 0          | 0            | 0             |
| 200% | 0                | 0          | 0            | 0             |
| sum  | 6.00             | 8.00       | 7.16         | 7.84          |

## Results

### *Nitrogenous emission variability according to bias and standard deviation*

Between 3960 and 9240 data were generated. Variability analysis were done regarding the bias with the standard deviation equal to 10 and the standard deviation with bias equal to 1. These variability analyses were studied according to the different weather and climate conditions and the different organic residues [3]. Three different observations can be done:

1. If the sum of the nitrogenous emissions (in grey in Table 3) **is constant and equal to zero**, no variation was observed because no emission was generated by the organic residue spreading whatever the bias and the standard deviation used. This was observed using STICS model for N-N<sub>2</sub>O emissions in Kerlavic system for all the effluents, N-N<sub>2</sub>O emissions in all the systems except for Kerlavic and Poitou Charentes for all the sludges and N-NH<sub>3</sub> emissions for Kerlavic system for all the sludges.
2. If the sum of the nitrogenous emissions (in grey in Table 3) **is constant and different from zero**, no variation was observed whatever the bias and the standard deviation used because the emissions are the same whatever the application rate classes. This was observed using STICS model for N-N<sub>2</sub>O emissions in Kerlavic system for all the sludge, N-NO<sub>3</sub> emissions for 1 to 5 system regarding the sludge, N-N<sub>2</sub>O emissions in 3 systems for all the effluents and N-NO<sub>3</sub> emissions for Kerlavic and Mons systems for poultry manure.
3. If the sum of the nitrogenous emissions (in grey in Table 3) **is variable regarding the bias and the standard deviation**, we observe that for all the bias and standard deviation for all the systems and the organic residues using IPCC and EMEP factors, emissions are proportional to the nitrogen content of the organic residues. In those cases, the variability is not significant. Using STICS model, N-N<sub>2</sub>O emission variability for sludges is significant for one system for a bias at least inferior 0.8 and superior to 1.2. N-NH<sub>3</sub> emission variability is significant for numerous biases for limed and liquid sludges and for composted sludge in 3 systems and dry sludge in 5 systems and for all tested effluents. N-NO<sub>3</sub> emission variability is only significant for the bias for sludge spreading. No significant variability was observed for N-NO<sub>3</sub> emissions whatever the bias and the standard deviation studied.

*Comparison of nitrogenous emission variability according to the model used*

The following tables represent the minus, maximum, average and standard deviation for each studied nitrogenous emission regarding the organic residues and the emission model used.

When the “distribution” factor is studied, sum of emissions are more sensitive to bias than standard deviation whatever the studied emission model. The variability of the sum of emissions is significant in numerous spreading scenarios for sludge and effluents for N-NH<sub>3</sub> and in some cases for N-NO<sub>3</sub>. STICS N-NO<sub>2</sub> emissions are barely sensitive to this factor. When the “organic residues” factor is studied, a classification is possible for N-NH<sub>3</sub> and N-NO<sub>3</sub> emissions in case of sludge spreading scenarios. This is less clear for effluents, no classification can be established.

**Table 4. Minus, maximum, mean and standard deviation (SD) of emission sums, benefits and loss compared to the reference for N-N<sub>2</sub>O regarding products and emission models**

| Emission type  | Organic product | N-N <sub>2</sub> O (UN/ha) |       |           |       |       |
|--|-----------------|----------------------------|-------|-----------|-------|-------|
|  |                 | Sludges                    |       | Effluents |       |       |
|  |                 | Models                     | STICS | IPCC      | STICS | IPCC  |
| Sum of emissions   | Minus           |                            | 0,00  | 0,13      | 0,00  | 0,27  |
|  | Maximum         |                            | 37,51 | 3,17      | 55,48 | 5,63  |
|  | Mean            |                            | 3,33  | 1,70      | 23,70 | 2,56  |
|  | SD              |                            | 9,17  | 0,77      | 19,32 | 1,12  |
| Benefits (+) and losses<br>(-) compared to the<br>optimal distribution | Minus           |                            | -3,46 | -0,39     | -1,26 | -1,26 |
|  | Maximum         |                            | 3,35  | 0,41      | 0,78  | 1,26  |
|  | Mean            |                            | 0,01  | 0,00      | 0,00  | 0,00  |
|  | SD              |                            | 0,49  | 0,17      | 0,10  | 0,55  |

When the “weather and climate condition” factor is studied, no classification can be done for N-NO<sub>2</sub> and N-NH<sub>3</sub> emissions but a classification is possible for N-NO<sub>3</sub> emissions estimated with STICS model. We observe that cropping system is less sensitive than the weather and climate condition in the generation of nitrogenous emissions. When the emission model factor is studied, orders of magnitude are different between STICS and IPCC for N-N<sub>2</sub>O emissions where STICS emissions are greater than

IPCC ones. IPCC and EMEP models used for N-NH<sub>3</sub> emissions lead to greater values than STICS model ones. These differences are linked with the type of model (national inventory for IPCC and EMEP and cropping system for STICS).

**Table 5. Minus, maximum, mean and standard deviation (SD) of emission sums, benefits and loss compared to the reference for N-NH<sub>3</sub> regarding products and emission models**

| Emission type  |         | N-NH <sub>3</sub> (UN/ha) |       |       |           |        |        |
|--|---------|---------------------------|-------|-------|-----------|--------|--------|
| Organic product  |         | Sludges                   |       |       | Effluents |        |        |
| Models   |         | STICS                     | IPCC  | EMEP  | STICS     | IPCC   | EMEP   |
| Sum of emissions   | Minus   | 0,00                      | 2,64  | 0,80  | 0,00      | 3,85   | 3,85   |
|  | Maximum | 15,56                     | 31,57 | 10,52 | 98,63     | 62,41  | 53,55  |
|  | Mean    | 1,92                      | 15,99 | 4,65  | 10,82     | 29,84  | 23,89  |
|  | SD      | 2,80                      | 6,47  | 1,82  | 18,26     | 12,55  | 11,21  |
| Benefits (+) and losses (-) compared to the optimal distribution | Minus   | -5,24                     | -5,51 | -2,51 | -32,98    | -17,73 | -19,18 |
|  | Maximum | 5,19                      | 5,72  | 2,61  | 33,24     | 17,71  | 19,17  |
|  | Mean    | -0,01                     | 0,01  | 0,00  | 0,00      | 0,01   | 0,01   |
|  | SD      | 1,04                      | 2,32  | 0,95  | 6,39      | 7,56   | 5,20   |

**Table 6. Minus, maximum, mean and standard deviation (SD) of emission sums, benefits and loss compared to the reference for N-NO<sub>3</sub><sup>-</sup> regarding products and emission models**

| Emission type  |         | N-NO <sub>3</sub> <sup>-</sup> (UN/ha) |       |           |        |
|--|---------|--|-------|-----------|--------|
| Organic product  |         | Sludges                                |       | Effluents |        |
| Models   |         | STICS                                  | IPCC  | STICS     | IPCC   |
| Sum of emissions   | Minus   | 0,02                                   | 4,14  | 1,36      | 3,85   |
|  | Maximum | 91,00                                  | 70,01 | 82,92     | 100,93 |
|  | Mean    | 27,17                                  | 38,34 | 18,97     | 43,89  |
|  | SD      | 32,28                                  | 16,97 | 25,56     | 21,26  |
| Benefits (+) and losses (-) compared to the optimal distribution | Minus   | -13,48                                 | -8,26 | -1,13     | -26,59 |
|  | Maximum | 15,07                                  | 8,57  | 0,59      | 26,56  |
|  | Mean    | 0,02                                   | 0,01  | 0,00      | 0,02   |
|  | SD      | 1,80                                   | 3,49  | 0,11      | 11,49  |

## Conclusions

This sensitivity analysis on the sum of emission was a qualitative one. It would be interesting to analyse the robustness of what we observed using some statistical tools. Only theoretical distribution was used in this study but realistic distribution in the field is obviously different and cannot be therefore characterized by a bias and a standard deviation. A second study, based on this observation, was conducted in 2012 [4].

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