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ÉCLAIRE

Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems

Seventh Framework Programme

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D3.1 NH_3 emission model for agricultural management

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PU	Public	☐
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RE	Restricted to a group specified by the consortium (including the Commission Services)	☐
CO	Confidential, only for members of the consortium (including the Commission Services)	☐

1. Executive Summary

- The objective of this task was to develop a mathematical model (general emission model) to estimate ammonia emissions from fertiliser/manure application with emphasis on the response to those conditions that are expected to change in the future (temperature, moisture, management)
- A meta-modelling approach was taken that developed meta-models for three fertiliser types (slurry, farm yard manure and the mineral fertiliser urea ammonium nitrate; UAN) using emission estimates from the process-based model Volt'Air
- In order to have a process-based model that is suitable for multiple fertiliser types and different soil conditions, it was necessary to modify Volt'Air to simulate emissions from solid fertilisers (farmyard manure, composts etc.) and to simulate emissions from applications to organic soils
- Volt'Air simulations for typical spring and summer applications were run for each fertiliser type for 522 European locations with a large range of soil and climate conditions
- The largest average emission rates were predicted by Volt'Air for FYM and the smallest for UAN. The most influential parameter in the model was the air temperature following application, which had a stronger influence on emissions than that included in other modelling approaches (e.g. the ALFAM model)
- In order to select the best meta-model formulation, the statistical performance of three meta-model types was compared. As a result of the strong temperature dependence of the simulated emissions, the best performing meta-model was based on the logistic equation (an exponential increase levelling off to a maximum value)
- Meta-models for each fertiliser type were developed with the coefficients for soil and meteorological variables determined by multiple linear regression
- Meta-models for predicting both the proportion of total ammoniacal nitrogen (TAN) emitted and the duration of the emission period were developed
- On average, the models for predicting the proportion of TAN emitted from applications of slurry, FYM and UAN deviate from the Volt'Air predictions by 16%, 8% and 24%, respectively and the prediction bias is small (less than 1% TAN)
- For slurry, FYM and UAN, the mean emission predictions of the meta-models (55%, 70%, 9%, respectively) compare well with the emission factors from the EMEP/EEA air pollutant emission inventory guidebook (55%, 79% and 10%, respectively)
- In order to extend the applicability of the meta-models to other fertiliser types, ratios of the emission inventory guidebook Tier 2 emission factors can be used

2. Objectives:

The objective of this task was to develop a mathematical model to estimate ammonia (NH_3) emissions from fertiliser/manure application with emphasis on the response to those conditions that are expected to change in the future (temperature, moisture, management). This model needs to be compatible with agricultural NH_3 emission model (Gyldenkærne et al., 2005) being developed in WP6, which will be used to provide spatially and temporally varying NH_3 emission data for the EMEP chemical transport model (WP7). In order to produce a model suitable for all conditions, it was necessary to improve the process-based model (Volt'Air), which was used as the basis of the final emission model.

3. Activities:

3.1. Modification of the Volt'Air model for the simulation of emissions from farm yard manures and composts

The process-based model Volt'Air (Génermont, 1996; Génermont and Cellier, 1997; Garcia et al., 2012) has been developed and validated to predict ammonia emissions from the land application of slurries and mineral fertilisers. The model has recently been improved for cattle slurry application: a more realistic representation of the slurry was obtained by adding a specifically parameterized slurry layer above the soil profile (Garcia et al., 2012). It was hypothesized that this concept of an additional layer would allow the simulation of various types of applied organic matter, particularly those with large solid fractions that stay on the surface of the soil (such as typical farmyard manure; FYM), with properties differing from those of the soil. In ÉCLAIRE, Volt'Air has been thus modified to be able to simulate the emissions from farmyard manure applications.

Organic fertiliser is conceptualized as an additional layer above the soil profile created at the time of the application. This layer is described by specific (i) thermal properties derived from a literature review, (ii) optical properties calculated using previous measurements (Génermont and Cellier, 1997) and (iii) hydraulic properties, from specific measurements of the water retention and hydraulic conductivity curves of a pure sample of the organic fertiliser, in order to correctly represent the infiltration of the ammoniacal nitrogen in solution through this surface matrix to the soil. The thickness of the organic fertiliser layer depends on the application rate, the dry matter content, the bulk density of the fresh organic matter, and the bulk density of the dry organic matter.

In order to model the heterogeneity of application of the organic fertiliser on the soil surface, the field is divided by the model into two sub-plots, one covered with a layer of organic product and one of bare soil, the respective surfaces of which depend on the application rate, and the threshold rate below which the application is uneven. Below this threshold the organic product layer thickness is kept constant, a coefficient of coverage follows a linear evolution from 0 (no application) up to 1. Above this threshold, the coefficient of coverage equals 1, and the organic product layer thickness follows a linear increase with the additional application rate. The model calculates the transfers in each sub-plot separately and then calculates a weighted volatilization flux for the whole field.

The implementation was made and tested using data sets experimentally collated as part of the QualiAgro project at INRA (Houot et al., 2009), in 1998, 2002, 2004 and 2006. The dairy cow farm yard manure application occurred in early September on bare soil. Ammonia volatilisation was measured by using the wind tunnel method (Génermont et al., 2011). We first characterized the FYM with regards to the input parameters required by Volt'Air (Table 1). The water retention and hydraulic conductivity curves of the pure FYM were measured for the 2006 FYM using the Richard's press method and Wind's method, and we used the van Genuchten model to fit the data, as explained in Garcia et al. (2012). For slurry, following Thompson et al. (2010), the critical application rate for a uniform application was chosen to be 60 m^3 ha^{-1}. In the case of FYM, due to its more solid nature, a value was chosen of 90 m^3 ha^{-1}, from field observations, leading to a coefficient of coverage of approximately 0.5. Albedo was taken as the default value for the soil, i.e. 0.2 and a roughness length of 0.01 m was used.

Table 1: Measured FYM parameters

	FYM 2006
Application rate (m^3 ha^{-1})	68.14
Dry matter content (g kg^{-1})	386
Total Nitrogen content (g kg^{-1})	8.762
Total Ammoniacal Nitrogen(g kg^{-1})	0.669
pH	8.8
CEC	7.9
Bulk density of the fresh matter	631
Bulk density of the dry matter	207
Critical application rate for uniform application	120
VG parameters	
Water content at saturation (m^3 m^{-3})	0.808
Residual water content (m^3 m^{-3})	0.330
alpha (m^{-1})	0.08
n (-)	1.52
Hydraulic conductivity at saturation (m s^{-1})	1.10e-06

Distinguishing a layer of organic fertiliser in a model of volatilization is a first step towards taking proper account of the physical and chemical processes occurring in such a matrix. For example, the assumption that the physico-chemical equilibria that take place in ideal aqueous solutions, with solute concentrations close to zero is no longer true. This study will help to better identify the efforts needed towards knowledge and modelling of adsorption parameterization and pH calculation. However, due to the lack of such knowledge, we calibrated the input parameters so that the simulated fluxes would fit the measured ones, as a first step. Thus this same dataset was used for a sensitivity analysis of both the evaporation and ammonia volatilization fluxes. It was performed on the parameters of the organic fertilisers that have to be specifically characterized: (i) analytical properties (ammoniacal N content, pH and adsorption) and (ii) physical properties (optical, thermal and hydraulic properties). The sensitivity analysis was also performed on parameters pertaining to the technical choices made for the application: application rate with a potential subsequent uneven application and incorporation characterized by its depth, its efficiency and the delay after application. The calibrated input parameters for FYM applications were then used in the development of the general emission model.

The sensitivity analysis for FYM pH shows that using the measured pH value of 8.8 leads to a large overestimation of the fluxes (Figure 1). However, the representativeness of the simulation conditions to the measurement conditions may be an important factor that needs to be studied further. Based on this limited dataset, we used a pH of 8 instead of the measured values for the development of the general emission model.

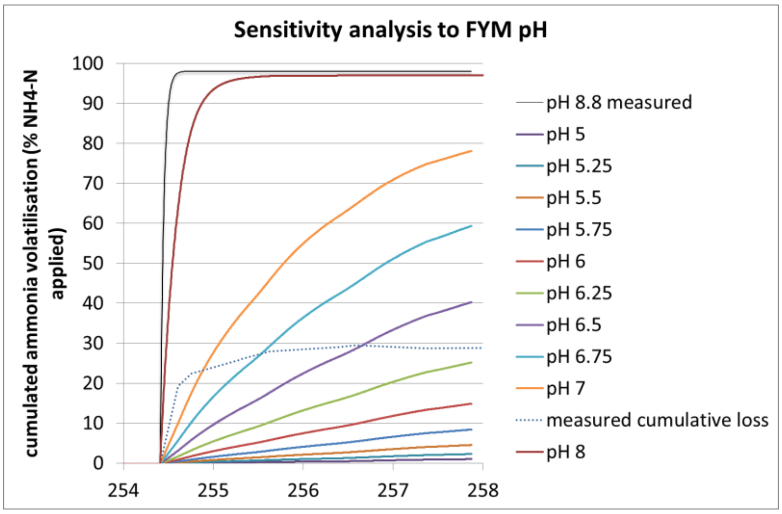

Figure 1: Simulated cumulated NH_3 losses following FYM application for different FYM pH values plus losses measured experimentally.

The sensitivity analysis to the critical application rate for uniform application rate was performed for a FYM pH of 6.5. Ammonia volatilization is very sensitive to this parameter, as a larger surface exchange produces larger fluxes of ammonia to the atmosphere (Figure 2).

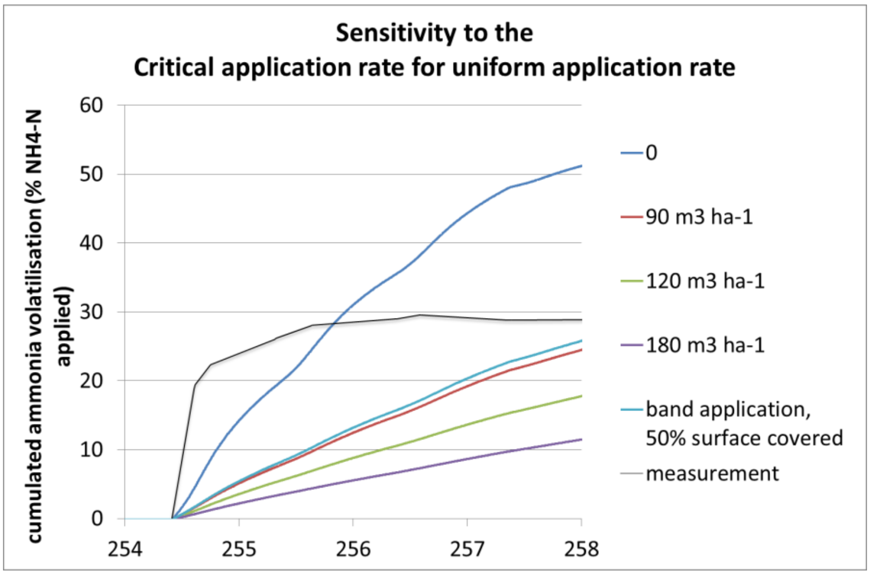

Figure 2: Simulated cumulated NH_3 losses following FYM application for different critical application rates for uniform application plus losses measured experimentally.

3.2. Modification of the Volt'Air model for the simulation of emissions from applications to organic soils

The water transfer module of Volt'Air is based on calculations for each layer using the water retention and the hydraulic conductivity models from either Clapp and Hornberger (Clapp and Hornberger, 1978) or van Genuchten–Mualem (van Genuchten, 1980). Both configurations (CH or VG) were run as a first step, but the VG one is more adapted for the case of organic fertiliser application (Garcia et al., 2012). The parameters for these models were estimated from pedo-transfer functions using, for example, soil bulk density and/or soil texture (Clapp and Hornberger, 1978; Wösten et al., 1999). Running the VG configuration led to a systematic break-down of the model at the start of the simulation for 41 sites due to the organic carbon content of those soils being very high; either 33.63 or 33.27%, instead of a few % (~1-3%) as for the other soils. We thus introduced into Volt'Air the parameterisation of organic soils as proposed by Wösten et al. (1999). With this parameterisation, very low volatilisation rates were obtained, with volatilisation continuing long after 30 days following the application. No experimental data were available to test these very low fluxes, and we decided not to account for the organic soils in the development of the general emission model. Before further development and validation of emissions from organic soils, it should be assessed (i) whether these results significantly affect the general emission model and (ii) whether organic soils are commonly used for agriculture in Europe and are really fertilised.

3.3. Development of the general emission model

The general emission model was developed using the process-based fertiliser emission model Volt'Air). Since the model is relatively complex, taking into account soil and meteorological conditions as well as management factors, Volt'Air cannot be applied over large spatial and/or temporal scales. Neither can the model be easily simplified to produce a faster model that gives more approximate predictions. For these reasons, a meta-modelling approach was taken that developed meta-models for three different fertiliser types (slurry, farm yard manure (FYM) and mineral fertiliser) based on simulation results for a large range of European climate and soil conditions.

Simulation input data:

Soil data: In order to run simulations for a large range of European soil type and climate combinations, the European Soil Database (ESDB, Panagos, 2006; Panagos et al, 2012) was used. After mapping soil type (FAO 1985 classification) to soil texture (USDA classification using the FAO Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2008), all adjacent map polygons with the same texture were combined, giving a total of 15773 polygons. This number is too large for running Volt'Air simulations and so the number of polygons was reduced by removing the smallest polygons until the remaining dataset covered 67% of EU land area. The soil parameters and the corresponding meteorological data from the resulting 522 polygons were used in the Volt'Air simulations. The ESDB does not include soil pH (important for Volt'Air) and so the JRC European soil pH map (Böhner et al., 2008) was used to estimate soil pH at the centroid of each polygon (Figure 3).

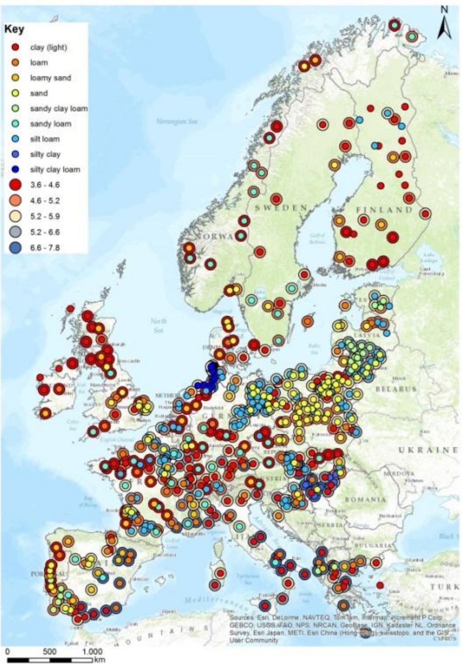

Figure 3: Map showing the spatial distribution of soil texture (small circles) and pH (large circles) used for the simulations.

Meteorological data: The hourly meteorological variables required by Volt'Air for the simulations were taken from the EMEP chemical transport model (simulation year: 2008) for the location of each of the 522 soil polygon centroids. The variables used were: air temperature, water vapour pressure, solar radiation, wind speed, rainfall and soil moisture index.

Descriptions of the simulations:

A 'typical' scenario was simulated for each fertiliser type (Table 2) using the soil and meteorological data for each of the 522 locations. The slurry and FYM parameters used are fairly typical for European situations (Hacala et al., 2001; Génermont et al., 2011; Morvan, Comm. Pers.). The mineral fertiliser used was urea ammonium nitrate solution (UAN) since this has an intermediate emission factor (0.125 kg NH_3 kg N^{-1}); between those of ammonium nitrate (0.037 kg NH_3 kg N^{-1}) and urea (0.243 kg NH_3 kg N^{-1}) in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2013). Two separate application dates were used for each location to represent spring and summer application periods giving a total of 1044 simulations (522 locations × 2 application dates). The duration of the simulations was 2 months, with the fertiliser being applied after the first month. The first month simulation thus serves to calculate the soil water content at the time of application, as a result of an initial soil water index, rainfall events and evaporation. Model output was expressed as % total ammoniacal nitrogen (TAN) volatilised at the end of the simulation. Simulation results were not included in the analyses if the volatilisation was not considered complete before the end of the simulation (using the criterion: volatilisation after 25 days < 0.95 × volatilisation after 30 days) or if an error occurred during the simulation. Simulation results for organic soils were also removed since Volt'Air has not been validated for this type of soils.

Table 2: Summary of the application parameters used in the three scenarios

	Slurry	FYM	UAN
Application rate	60 m^3 ha^{-1}	60 t ha^{-1}	100 kg N ha^{-1}
Total ammoniacal Nitrogen content	0.862 g kg fresh matter ➔ 52 kg NH_4-N ha^{-1}	0.53 g kg fresh matter ➔ 32 kg NH_4-N ha^{-1}	25% of total N as NH_4-N + 50% of total N as Urea-N
pH	7.0	8.0	5.77
Dry mater content (%)	4.69	20.0	(aqueous solution)
Application method	Splash plate	Broadcast	Uniform application
Application dates	First day of April and September	First day of April and September	First day of April and September

4. Results:

4.1. Volt'Air simulation results

Volt'Air predicted a large range of emissions for each fertiliser type in response to the different soil and climate combination (Table 3). The largest average emission rates were predicted for FYM and the smallest for UAN. The most influential parameter in the model was the air temperature following application, as shown in Figure 4. This influence is also apparent in the spatial distribution of emissions (Figure 5).

Table 3: Summary of the distribution of volatilisation rates (%TAN) for each fertiliser type

	Slurry	FYM	UAN
Min	0.2	4.2	0.01
Mean	54.4	69.6	9.7
Median	54.5	71.9	4.5
Max	97.6	94.1	82.9
n	778	953	824

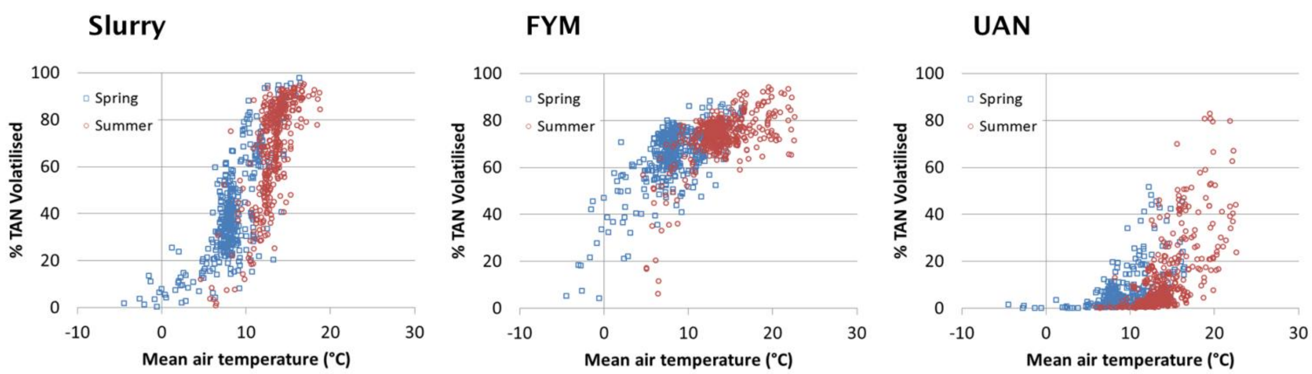

Figure 4: Air temperature dependence of the emissions for the three fertiliser types.

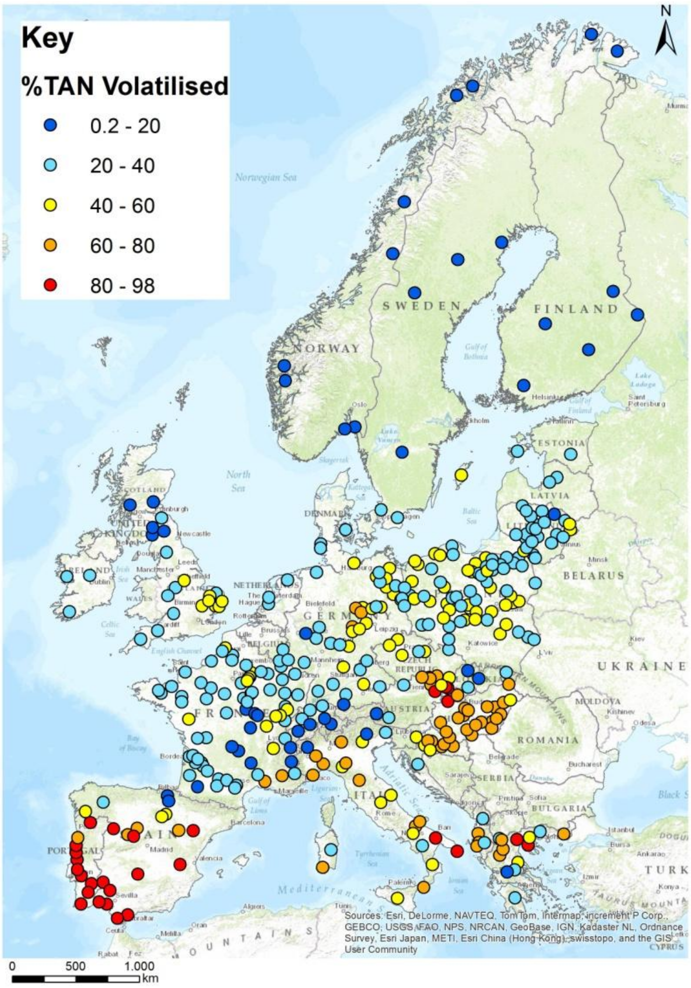

Figure5: Map showing the spatial distribution of NH_3 emissions for spring application of slurry as predicted by Volt'Air.

Meta-model development

Three different meta-model formulations were tested to evaluate which of them best recreated the response of Volt'Air to the soil and meteorological variables. Two of the formulations (MLRT and LR) take advantage of the strong dependence of the emissions on air temperature by using the logistic equation, whose characteristic is an exponential increase with a theoretical asymptotic maximum (100% of TAN volatilised in the case of Volt'Air), as shown in Figure 6.

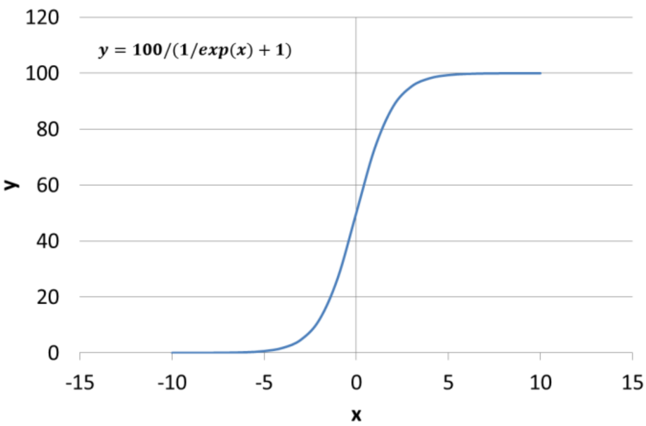

Figure 6: The form of the logistic equation.

The forms tested were:

1. MLRL: Multiple linear regression of the logarithm of the cumulated emission after 30 days (%TAN):

$$\ln(\%TAN) = a_0 + a_1x_1 + a_2x_2 + \cdots a_mx_m,$$

where $a_0 \cdots a_m$ are model coefficients and $x_1 \cdots x_m$ are the soil and meteorological variables.

2. MLRT: Multiple linear regression of the transformed cumulated emission after 30 days (%TAN). The transformation makes use of the logistic equation. The resulting meta-model has the form:

$$ln\left[\frac{1}{(100-\%TAN)-1}\right] = b_0 + b_1x_1 + b_2x_2 + \cdots b_mx_m,$$

where $b_0 \cdots b_m$ are model coefficients and $x_1 \cdots x_m$ are the soil and meteorological variables.

3. LR: Logistic residual model. This formulation fits a logistic curve to the temperature response of the cumulated emission after 30 days (%TAN) and then fits the residuals using multiple linear regression of the remaining soil and meteorological variables.

The values of the model coefficients were determined using the stepwise multiple linear regression procedure of the R programming language and removing coefficients that were not statistically significant ($p > 0.01$).

Each formulation was tested for each fertiliser type and compared with the emission predictions of Volt'Air. A cross-validation (by leave one out cross validation) was carried out to assess meta-model performance and the robustness of the coefficients. The comparison made use of the following evaluation metrics, as well as the coefficient of determination (adjusted R^2):

Metric	Formula
Root mean squared error	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(o_i - p_i)^2}$
Relative root mean squared error	$RRMSE = \frac{RMSE}{\overline{o}}$
Mean absolute error	$MAE = \frac{1}{n}\sum_{i=1}^{n}\lvert o_i - p_i\rvert$
Relative mean absolute error	$RMAE = \frac{MAE}{\overline{o}}$
Bias	$Bias = \frac{1}{n}\sum_{i=1}^{n}o_i - \frac{1}{n}\sum_{i=1}^{n}p_i = \overline{o} - \overline{p}$

where o_i and p_i are the individual predictions of Volt'Air and the meta-model, respectively, n is the number of simulations and o and p bar are the mean of the predictions of Volt'Air and the meta-model, respectively.

From the evaluation shown in Table 4, overall performance of the MLRT and LR meta-models is similar, and better than that of the MLRL meta-model. However, this assumes that all of the metrics should have a similar weight, which is not necessarily the case. This is particularly true of the model bias, since all models have a prediction bias of less than 1% TAN, which is almost negligible.

Removing this metric from the analysis indicates that the MLRT model performs best and so this formulation was selected as the most appropriate.

Table 4: Summary of the evaluation for each meta-model formulation and for each fertiliser type. Shaded cells highlight the best performing model for each metric.

Slurry			
Metric	**MLRL**	**MLRT**	**LR**
RMSE	15.74	***11.90***	11.93
RRMSE	0.29	***0.22***	***0.22***
MAE	11.41	***8.71***	8.98
RMAE	0.21	***0.16***	0.17
Bias	0.50	-0.88	***0.00***
R^2	0.69	***0.77***	***0.77***
FYM			
RMSE	9.01	7.37	***7.19***
RRMSE	0.13	0.11	***0.10***
MAE	7.15	5.44	***5.16***
RMAE	0.10	0.08	***0.07***
Bias	0.59	-0.09	***0.00***
R^2	0.48	0.59	***0.61***
UAN			
RMSE	10.83	***4.66***	6.32
RRMSE	1.11	***0.48***	0.65
MAE	3.46	***2.29***	4.34
RMAE	0.36	***0.24***	0.45
Bias	-0.67	0.33	***0.00***
R^2	0.74	***0.88***	0.77

The coefficient values for this formulation for the three fertiliser types are shown in Table 5.

Table 5: Coefficient values used in the NH_3 emission meta-models

Coefficient	Slurry	FYM	UAN
Constant	6.03	4.91	-7.21
Mean Air Temperature (°C)	0.356	0.117	0.268
Mean Water Vapour Pressure (kPa)	-2.19	-1.11	-1.73
Mean Solar radiation (W m^{-2})	-0.00735	-0.00515	-0.00331
Mean wind speed (m s^{-1})	0.103	0.100	0.234
Total rainfall (mm)	-0.00497	-0.00239	-0.00527
Latitude (°N)	-0.112	-0.0609	-0.0686
Clapp and Hornberger texture class	-0.0642	--	--
Soil pH ($H_2$0)	--	-0.0444	1.03
Sand (0-100%)	-0.00810	--	--
Clay (0-100%)	--	-0.00585	-0.0102
Soil organic C content (0-100%)	0.255	--	0.108

When used for generating emissions for chemical transport models, information on the temporal variability is also useful. For example, the emissions for a fertiliser application in a cold climate may take place over several weeks whereas the emission from a similar application in a warm climate may be complete within a few days. These temporal differences need to be reflected in the regional-scale emission patterns. In order to include this information in the meta-modelling approach, another set of meta-models was parameterised for the time needed to volatilise 95% of the total 30 day emissions, using the same meta-model structure (Table 6) but including the %TAN volatilised from the first set of models as a parameter and setting the theoretical maximum value to 30 days.

Table 6: Coefficient values used in the meta-models for the number of days to 95% of total emissions

Coefficient	Slurry	FYM	UAN
Constant	5.28	32.2	2.49
30 day meta-model emission (% TAN)	-0.0232	-0.237	0.00797
Mean Air Temperature (°C)	--	0.755	-0.159
Mean Water Vapour Pressure (kPa)	-2.45	-11.1	--
Mean Solar radiation (W m^{-2})	0.00324	-0.0162	0.00922
Mean wind speed (m s^{-1})	0.359	0.661	0.0865
Total rainfall (mm)	-0.00700	-0.00980	-0.00404
Latitude (°N)	--	-0.214	0.0321
Soil pH (H_20)	-0.277	-0.590	-0.363
Sand (0-100%)	0.0170	0.0133	--
Bulk density (g cm^{-3})	-2.34	--	-1.47

Evaluation of the meta-models

The predictions of NH_3 emissions by the meta-model correlate well with the predictions of the Volt'Air model, except for FYM due to the small range of the majority of the predictions and an overestimation of emissions for the low emission scenarios (Figure 7). Due to data and processing time limitations, it was not possible to test the model with an independent data set to assess model performance. However, cross validation of the meta-models (by leave one out cross validation) shows that the meta-model coefficients are robust. The cross validation also gives an indication of model performance, as shown by the evaluation metrics in Table 4. This assessment shows that the meta-model for UAN deviates most (in relative terms) from the Volt'Air predictions (RRMSE: 0.48 and RMAE: 0.24), although this is mostly because the emission predictions are small. On average, the models for Slurry, FYM and UAN deviate from the Volt'Air predictions by 16%, 8% and 24%, respectively and the prediction bias is small (less than 1% TAN).

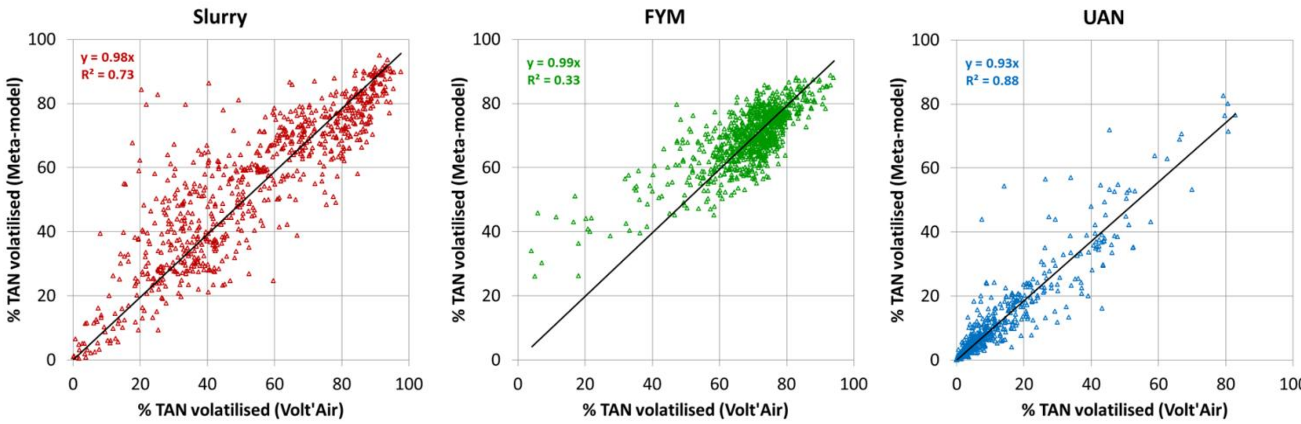

Figure 7: Meta-model predictions of proportion of TAN volatilised plotted against the Volt'Air predictions, for the three meta-models. The solid line, equation and correlation coefficients shown in each graph are for the linear regression forced through the origin.

For Slurry, FYM and UAN, the mean emission predictions of the meta-models (55%, 70%, 9%, respectively) compare surprisingly well with the emission factors from the EMEP/EEA air pollutant emission inventory guidebook (55%, 79% and 10%, respectively), showing that the meta-models (and by extension, Volt'Air) predicts emissions of the correct order of magnitude.

The strong air temperature dependence of the predicted emission rates is quite different to that of other modelling approaches. For example, the ALFAM model (Søgaard et al., 2002), whose temperature dependence is also incorporated into the model of Gyldenkærne et al. (2005), estimates an increase in emissions of 2-3% for each 1°C temperature increase. However, the Volt'Air predictions show increases of up to 18% for each 1°C temperature increase for Slurry and up to 24% for UAN. In order to test the temperature response of the Volt'Air model, it will be necessary to validate the model using datasets over a large climate gradient.

The performance of the meta-models for predicting the duration of the emissions (time to 95% of complete emission) was poorer than that of meta-models for predicting the proportion of TAN volatilised (Figure 8) with relative mean average errors (RMAE) of 36%, 52% and 17% for Slurry, FYM and UAN respectively. However, the emission duration is less critical than the total emission when generating emissions for chemical transport models and so these errors are considered to be acceptable.

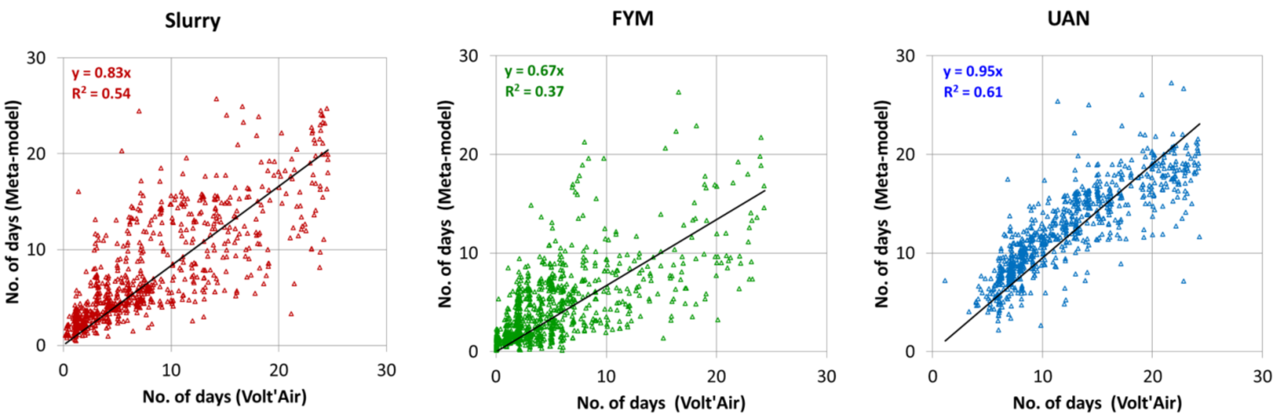

Figure 8: Meta-model predictions of number of days to 95% emission plotted against the Volt'Air predictions for the three meta-models. The solid line, equation and correlation coefficients shown in each graph are for the linear regression forced through the origin.

Applicability of the meta-models

The meta-models presented here have been developed from Volt'Air simulations for three specific fertiliser types with typical but specific parameterisations (application rates, slurry properties etc.). However, in order to be applied generally, e.g. for national inventories or for emission data for chemical transport models, the predictions need to be extended to other fertiliser types and situations. The meta-models can be used for other fertiliser types by modifying the emission predictions using the Tier 2 emission factors from the EMEP/EEA air pollutant emission inventory guidebook. As an example, for mineral fertilisers, the UAN meta-model predictions can be multiplied by the ratio of emission factors for Urea and UAN (0.243:0.125) to predict emissions for Urea (Table 7). However, in some cases this may result in an emission of more than 100% of TAN and so the emission rate will have to be limited to 100% in such cases.

Table 7: Tier 2 emission factors for NH_3 emissions from mineral fertilisers (taken from EMEP/EEA, 2013).

	Tier 2 EF_i, kg NH3 kg N^{-1}	
Fertiliser type	Low soil pH	High soil pH
Ammonium nitrate (AN)	0.037	0.037
Anhydrous ammonia	0.011	0.011
Ammonium phosphate (MAP and DAP)	0.113	0.293
Ammonium sulphate (AS)	0.013	0.270
Calcium ammonium nitrate (CAN)	0.022	0.022
Calcium nitrate (CN)	0.009	0.009
Ammonium solutions (AN)	0.037	0.037
Ammonium solutions (Urea AN)	0.125	0.125
Urea ammonium sulphate (UAS)	0.195	0.195
Urea	0.243	0.243
Other NK and NPK	0.037	0.037

A similar approach can be used in the case of organic fertilisers, using the emission factors shown in Table 8. However, to produce spatially and temporally varying emission predictions, activity data on the spatial and temporal distribution of the application of different fertilisers types is required, which is currently lacking generally for the EU, although may be available for some countries. At the EU level, estimates have been made of the spatial distribution of organic and mineral fertilizer inputs based on a mass balance and crop requirements approach (Leip et al., 2008), although no disaggregation was done for the different fertiliser types. This disaggregation could be done using regional and national activity data for livestock types, farming systems, mineral fertiliser sales etc. but it is not a simple procedure and is beyond the scope of the present task. Equally, the meta-models could be extended to include factors such as slurry/FYM properties, application rate and method, crop canopies, incorporation, irrigation etc. but the usefulness of this analysis would also be limited by lack of data at national or European scales. The best that can be done at the moment is to use the three meta-models as reference situations, modifying the predictions using the EMEP/EEA Tier 2 emission factors. For chemical transport modelling the emission predictions (e.g. grid square average emissions) can be normalised to the present value from the official emission inventories (if necessary) and then the meta-models can be used to predict how these emission rates will change under a changing climate.

As mentioned above, Volt'Air has not been validated for fertiliser applications to organic soils and so it is not known whether the low emission predictions for organic soils are realistic. However, given that organic soils were present at only 41 of the 522 locations used for the simulations and that only 10 of these sites correspond to agricultural land (from the CORINE land cover database), the contribution of organic soils to NH_3 emissions will be very small and can be neglected.

With regards to the emission duration, the meta-models developed for the time to 95% of emissions are only useful if spatial information is available on the timing of fertiliser applications. In the absence of regional statistical data on the timing of fertiliser applications, a simple crop growth model can be applied such that used by Gyldenkærne et al. (2005), which estimates the most likely application period using temperature sums for each crop type and then applies a Gaussian distribution to simulate the variability in application dates due to management factors etc.

Table 8: Tier 2 emission factors (EFs) for NH_3 emissions from organic fertilisers (adapted from EMEP/EEA, 2013).

	Spreading EF (%TAN)	
Livestock	Slurry	Solid
Dairy cows	0.55	0.79
Other cattle (young cattle, beef cattle and suckling cows)	0.55	0.79
Fattening pigs (8–110 kg)	0.4	0.81
Sows (and piglets to 8 kg)	0.29	0.81
Sheep (and goats)	--	0.9
Horses (and mules, asses)	--	0.9
Laying hens (laying hens and parents),	0.69	0.69
Broilers (broilers and parents)	--	0.66
Other poultry (turkeys)	--	0.54
Other poultry (ducks)	--	0.54
Other poultry (geese)	--	0.45
Buffalo	--	0.55

5. Milestones achieved:

None. No milestones are linked to this Deliverable

6. Deviations and reasons:

The deliverable has been completed 4 months later than the planned date. The main reason for this delay was a reassessment of the objectives of this work in relation to the other WPs, following a discussion on ammonia emission models at the second project meeting held in Edinburgh in October 2012. The conclusion of this discussion was that we should focus on developing an emission model that can be incorporated easily into a chemical transport model (such as the EMEP model) instead of focusing on improving existing process-based approaches for climate-induced changes in environmental conditions. This change of focus delayed the progress of the task by more than 12 months, most of which has been made up in order to not delay the Deliverable excessively. This four month delay has not had any repercussions on the progress of connected WPs (e.g. WPs 6 and 7), since these WPs are not currently in a position to make use of the modelling approaches presented here.

7. Publications:

None to date although these results are planned to be presented at the open science conference to be held in Budapest in September 2014.

8. Meetings:

The following meeting have been held during the duration of the task

Date	Location	Attendance	Objectives
Oct 2011	Project kick-off meeting (Brescia, Italy)	WP3 partners	To discuss the state of the art of emission modelling and plan WP activities
Sept 2012	COST-ÉCLAIRE Workshop (Paris, France)	INRA, UPM	To select the model of volatilisation and improvements to perform for ÉCLAIRE WP3 applications

Date	Location	Attendance	Objectives
Oct 2012	Annual project meeting (Edinburgh, UK)	Ammonia emission modelling community of ÉCLAIRE (WPs 3, 6, 7 etc.)	To discuss the common goals with regards to NH_3 emission modelling and set the priorities for ÉCLAIRE
Sep 2013	Videoconference	INRA, UPM	Discuss work to be prepared and presented at the annual project meeting
Oct 2013	Annual project meeting (Zagreb, Croatia)	Ammonia emission modelling community of ÉCLAIRE (WPs 3, 6, 7 etc.)	To discuss the progress so far and check that the work is heading in the right direction to achieve common goals
Mar 2014	Videoconference	INRA, UPM	To finalise the details of the Volt'Air simulations
Jun 2014	Videoconference	INRA, UPM	To discuss the results of the Volt'Air simulations and agree on the data analyses required

9. List of Documents/Annexes:

None

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