Agronomy Research **17**(2), 322–332, 2019
https://doi.org/10.15159/AR.19.081

Model for ammonia emissions' assessment and comparison of various dairy cattle farming systems and technologies

A. Aboltins[1], L. Melece[2,*] and J. Priekulis[1]

[1]Latvia University of Life Sciences and Technologies, Institute of Agricultural Machinery, Cakstes blvd.5, LV-3001 Jelgava, Latvia
[2]Institute of Agricultural Resources and Economics, Department of Economics, Struktoru str. 14, LV-1039 Riga, Latvia
[*]Correspondence: ligita.melece@arei.lv

Abstract. A dairy cattle farming is an important source of ammonia emissions, particularly in Latvia. Models using a wide range in level of detail have been developed to represent or predict these emissions. Besides, models are useful for improving the understanding of various farm processes and their interacting effects on ammonia emissions. The model for ammonia emissions' assessing or representing, predicting and comparing for manure management chain of dairy cattle was created. The model provides a tool for evaluating mitigation and management strategies, abatement measures and techniques to reduce of ammonia emissions and improve the sustainability of dairy production systems both on the dairy farm and at the national level. It could be used as a supplement tool for officials and experts. The model estimates those ammonia abatement measures and techniques that have the highest emission reduction potential and opportunities for implementation on Latvia's dairy farms. The simulation model assesses the ammonia emissions into each stage of the farming: animal housing, manure management - manure handling and storage, and manure application. An important stage in reducing ammonia emissions is manure storage. It should be noted that the main task of the model was to compare the impact of the ammonia emission reduction options. When entering the number of animals, the average nitrogen quantity per animal, the percentage distribution of manure quantities, the first three levels of the program can be used to estimate the amount of nitrogen to be incorporated into the soil and, as the difference; and the amount of ammonia emissions.

Key words: model, ammonia emissions, mitigation, dairy cattle.

INTRODUCTION

Agriculture is the main source of ammonia emissions, contributing more than 90% of overall emissions. Moreover, emissions mainly occur during the housing of animals, storage and application of animal manures. In most countries, dairy cattle is the largest source of ammonia (NH_3) emissions (EEA, 2016). In 2016 the management of dairy cattle manure was responsible for 54.2% of total ammonia emissions emitted by the manure management of all livestock species and categories in Latvia (Eionet, 2018). Moreover, manure management of dairy cattle generates 23% of total ammonia emissions in Latvia.

The Directive 2016/2284/EU was adopted by EU respecting the revised Gothenburg Protocol of the UN Convention on Long-range Transboundary Air Pollution (EC, 2016). This Directive sets obligations for each EU Member State to reduce ammonia emissions from 2020 to 2029 and from 2030 onwards. Besides, the Directive requires each member state to adopt, implement and regularly update a national program for the reduction of air pollution, particularly ammonia emissions. The adoption of techniques to reduce ammonia emissions needs to be taken into account when estimating national emissions (EEA, 2017). Information will also be needed on the proportions of livestock housed in reduced-emission buildings, the proportion of manures stored under cover and the proportion of manures applied by reduced-emission techniques.

On an EU level it is stressed that thirteen Member States, including Latvia, should make the greatest effort to reduce ammonia emissions, because reported projected emissions are above their agreed commitments (EEA, 2018).

Therefore, for more successful evaluation, assessment and comparing, as well as prioritization of most appropriate ammonia abatement measures for Latvia's dairy cattle farming, the new tool should be developed. The overall purpose for developing models is to provide information for supporting decisions and policies (Jones et al., 2017). A widely used approach for modelling various agricultural systems can be classified as dynamic system simulation models. In contrast to the statistical approach, these models have functions that describe the changes in systems states in response to external drivers (e.g., weather and management practices), and how those changes are affected by other components in the system (Wallach & Thorburn, 2014). This approach is used for all types of models, including crop, livestock, and farming system models, with model outputs being the values of model state variables over time (e.g., typically daily outputs for crop and pasture models). These dynamic models can be used to simulate multiple responses for the specific time and variables as needed (Bjerg et al., 2013; Wallach & Thorburn, 2014), and thus can compare effects of alternative decisions or policies on trade-offs among those various responses.

The models have been developed and applied world-wide to quantify emissions and to test mitigation strategies (Del Prado et al., 2013). A large number of approaches and computational techniques exist to support decision-making under deep uncertainty (Haasnoot et al., 2013). It is not possible that developing a model all factors affecting the agricultural system can be taken into consideration (Antle et al., 2017). Accordingly, models are based on a logical structure in which some factors determined by the model developer or model user.

The purpose of the study was to develop the simulation model assesses the ammonia emissions into each stage of the dairy cattle farming, particularly manure management. The model should provide a tool for evaluating mitigation and management strategies, abatement measures and techniques to reduce of ammonia emissions.

MATERIALS AND METHODS

Principle of program construction

The model is designed for comparative studies/ calculations of ammonia emission as result of implementation of various abatement measures. The specialized software is designed for convenient review of ammonia emissions in the form of a tree structure.

Ammonia emission review programs are built on the .NET Framework, which is supported by default on all Microsoft operating systems. The software screen is shown in the Fig. 1.

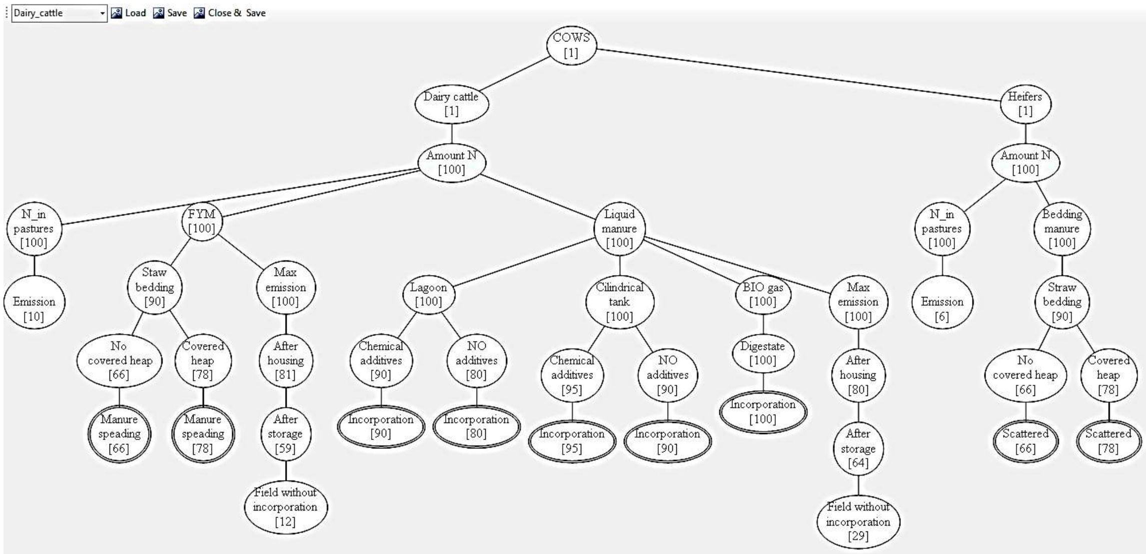

Figure 1. Software screen, where numbers in brackets indicate the output of nitrogen (N) units per animal via excreta.

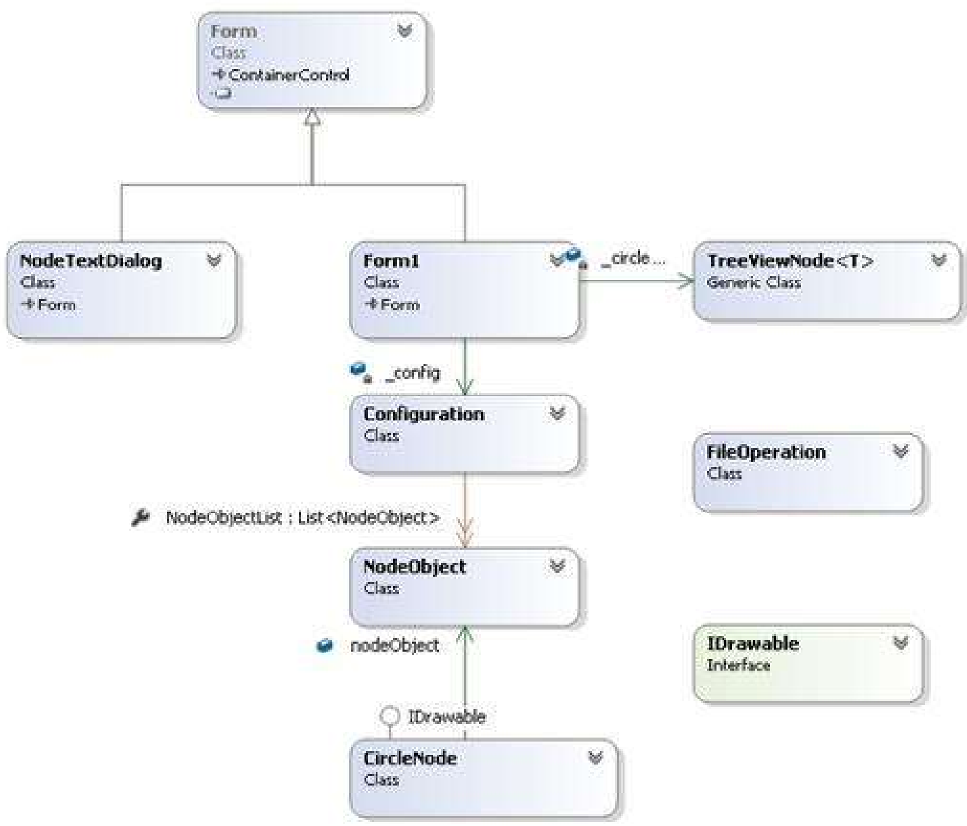

Figure 2. Program Class Diagram.

The program has two dialogue windows that are inherited from the ‘Form’ class (Fig. 2):

– ‘*NodeTekstDialog*’ is implemented to enter the tree branch parameters of the model.

–‘*Form1*’ is a representation of a tree structure.

The ‘*TreeViewNode*’ class, which is the ‘*IDrawable*’ interface, is used to create the tree structure of the main window ‘*Form1*’. This class reconstructs a tree structure that is curiously constructed. With these classes, the tree structure is recursively shaped.

For the maintenance of the parameters of the tree branches, a ‘*Configuration*’ class has been created, in which a list of parameters of each tree branch with the properties of the class ‘*NodeObject*’ is realized. These characteristics are presented in Fig. 3.

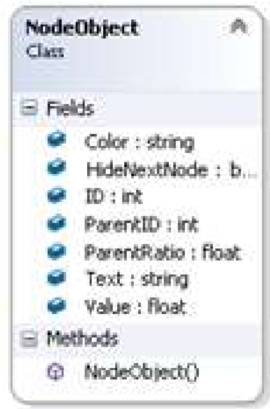

Figure 3. Properties of ‘*NodeObject*’.

The program consists of files such as ‘*Aep.exe*’ - an executable file and files with a launcher ‘* *.pig*’. The file ‘* *.pig*’ stores all parameters related to the developed calculation model. When the ‘*Aep.exe*’ software has been started, the algorithm searches for all files that have the extension ‘* *.pig*’ and retrieves all attributes of the file in the selection window of calculation model (Fig. 4). Selecting a particular model will activate the ‘*Load*’ button. By pressing the ‘*Load*’ button, the program will create a tree after the selected model. In this selection window, the model branch actions could be selected: ‘*Add Child*’ - add a new sub-branch under the selected branch; ‘*Edit Child*’ - edit the parameters of the selected branch; ‘*Copy*’ - copy the selected branches of the selected branch; ‘*Paste*’ - to create sub-branches of ‘*Copy*’ branch on selected branch; ‘*Delete Node*’ – to delete selected branch. If there are sub-branches of the selected branch, they will also be deleted; ‘*Refresh - Restore*’ - the model view; ‘*Save’* - to save the model.

The retention of these properties in the file is accomplished with the class ‘*FileOperation*’, which implements *XML* serialization and deserialization. The model structure is stored in a file with the extension ‘*pig*’. The file model is stored in *XML* file language structure. The name can be changed in the ‘*<text> </ text>*‘ label. This text will appear in the select models window.

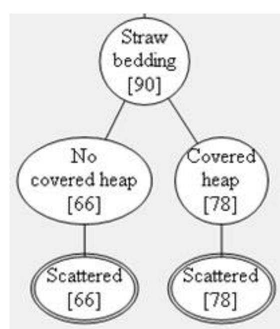

Figure 4. Branch display of tree structure.

The model consists of branches of a tree structure depicted in the form of a bubble. The bubble consists of an oval ring. Inside the ring are the name of the branch and the value of that branch in brackets (Fig. 4).

The values in brackets are indicated the amount of the total N quantity lost in emissions at each of the manure management stages without the use of ammonia emission reducing measures.

To make the model easier to review, the sub-branches of branch have the ability to hide in the program. Hiding the branches can be done by sliding the cursor over the selected branch bubble and by double-clicking the left mouse button. After the button double-clicks the sub-branches of the selected branch will not be displayed and the branch bubble will be displayed with a double line (Fig. 4).

RESULTS AND DISCUSSION

The program design principle with applications was described below. The created model aimsto determine the effectiveness of ammonia abatement measures, in which ammonia emission factors (EFs) are used for calculations. Emission factor (EF) methods have long been utilized for quantifying NH_3 emissions from individual category of livestock (e.g., dairy cow) or specific manure handling processes (Deng et al., 2015). Emissions from livestock, i.e., dairy cattle, farming occur during different stages in the manure management chain. The practical options to reduce ammonia emissions from manure management can be implemented during the individual stages of manure management, i.e., during grazing, from animal housing, manure storage and manure application (Amann et al., 2017).

The model traces the chain of N changes from animal manure occurring to application/ incorporation. Ammonia emissions are quantified using a nitrogen (N) flow approach, in which the NH_3 emission is calculated from the N flows and NH_3 emission factors (EFs) (Velthof et al., 2012).

The primary module of the simulation system evaluates ammonia emissions at each stage of the manure management chain and manure application: animal housing (barns, sheds or pastures/ grazing), manure treatment and storage and application or disposal of manure (Fig. 5). Despite that an application of inorganic N-fertilizers is also a significant source of ammonia emissions, it is not included in model, because does not apply directly to dairy farming.

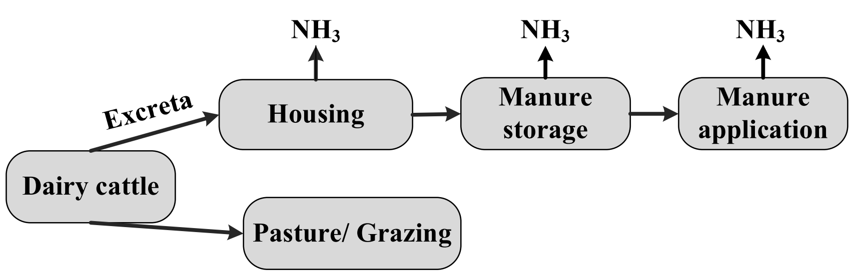

Figure 5. Schematic representation of ammonia emissions model.

Depending on the number and category of animals, stalls, ventilation and manure collection methods, ammonia emissions can be determined at the housing stage. An important stage in reducing ammonia emissions is the storage of both types of manure – liquid manure or slurry (hereinafter referred as – liquid/ slurry) and solid manure. It consists of environmental conditions (temperature, humidity and wind direction and speed), storage type and storage technologies. The manure application time, depth of incorporation and application technology also reduces or increases ammonia emissions (EEA, 2016).

The ammonia abatement options that have the highest emission reduction potential and that have possibility to implement in Latvia's dairy farming were selected for model calculations (Table 1). The choice of measures to reduce ammonia emissions was based on the results of the research carried out by Melece et al. (2017). Differences in agricultural practices, such as housing and manure management, and differences in climate have significant impacts on emissions.

Table 1. Ammonia abatement or mitigation measures and reduction potential for dairy cattle farming

Abatement measure		NH_3 reduction	
		%	coefficient
Housing facilities			
Adsorption by bedding, e.g., straw		50%	0.50
Farmyard or solid manure storage			
Plastic sheeting (floating cover)		50%	0.50
Liquid manure or slurry storage			
'Tight' lid, roof or tent structure		70%	0.70
Replacement of lagoon, etc., with covered tank or tall open tanks		50%	0.50
Application of solid manure			
Incorporation of surface applied manure:	Immediately	90%	0.90
	In 4 hours	50%	0.50
	In 24 hours	30%	0.30
Application of slurry			
Injection 10-30 cm		90%	0.90
Injection 4-6 cm		75%	0.75
Acidification of liquid manure		50%	0.50
Trailing shoe		50%	0.50
Direct incorporation following surface application:	Immediately	75%	0.75
	In 4 hours	50%	0.50
	In 24 hours	30%	0.30

Source: Melece et al., 2017.

For this purpose, it was formally considered that at the beginning of manure management or first stage (i.e., housing, grazing) output of each animal via excreta is 100 units of nitrogen (N). The reduction coefficient of implementing measure (Table 1) and emission factors (EFs) of ammonia emissions (Table 2), were used for estimating the changes of the N quantity at the each stage manure management, as well as through the manure management chain, for every ammonia abatement option or measure (i.e., technique). Remaining nitrogen (N) was estimated by Eq. (1):

$$N_r = [1 - (EF \times R_c)] \cdot 100 \qquad (1)$$

where N_r – remaining nitrogen units; EF – emission factor; R_c – emissions reduction coefficient.

The model calculations were performed using the Tier 2 emission factors (EFs) or values (Table 2) (EEA, 2017).

The default Tier 2 emission factors (EFs) from manure management of dairy cattle (Table 2) are from EMEP/EEA air pollutant emission inventory Guidebook 2016 (EEA, 2016) part 3B Manure management, which are updated in 2017 (EEA, 2017). Tier 2 uses a mass-flow approach based on the concept of a flow of TAN through the manure management system (EEA, 2017). It should be noted that the calculations of a mass-flow approach must be carried out on the basis of kg of N.

Table 2. Emission factors (EFs) used for calculation of the ammonia emissions from manure management of dairy cattle

Livestock	Manure type	EF housing	EF storage	EF spreading	EF grazing
Dairy cattle	Slurry/ liquid	0.20	0.20	0.55	0.10
	Solid	0.19	0.27	0.79	

Source: EEA, 2017.

Despite ammonia emission factors (EFs) in the livestock and manure management has been planned to review in 2019 by UNECE (2018), there is no restrictions in our model to replace the current EFs values with new ones.

Because the model is dynamic not static, it allows to make various changes and additions, for example, to delete some of NH_3 abatement measures (i.e., techniques) or to add new ones, as well as to change reduction coefficient. All ammonia abatement options or measures (i.e., techniques) in dairy cattle farming, which are presented in the Table 1, were evaluated using the created model.

Due to the limited length of the paper some examples of the model are presented below.

The calculation results, using the equation (1), for example, for the straw bedding in dairy cattle stalls, which reduces ammonia emissions (expressed as N units) by 50% or coefficient is 0.50 (Table 1), and emission factor – EF = 0.19 (Table 2), show that after housing 90 N units remain in manure and then reach the manure storage (Fig. 6):

$$N_{r\,straw} = \lfloor 1 - (0.19 \cdot 0.5) \rfloor \cdot 100 = 91 \quad (2)$$

where $N_{r\,straw}$ – remaining N units, using straw bedding.

Without use of straw bedding in the dairy cattle stalls, after housing less N – 81 units remain in manure and then reach the manure storage (Fig. 6):

$$N_r = (1 - 0.19) \cdot 100 = 81 \quad (3)$$

where N_r – remaining N units.

Ammonia emissions' reduction expressed as N units in the first stage (housing) and partially second stage (storage) of dairy cattle manure management before the application is shown in Fig. 6.

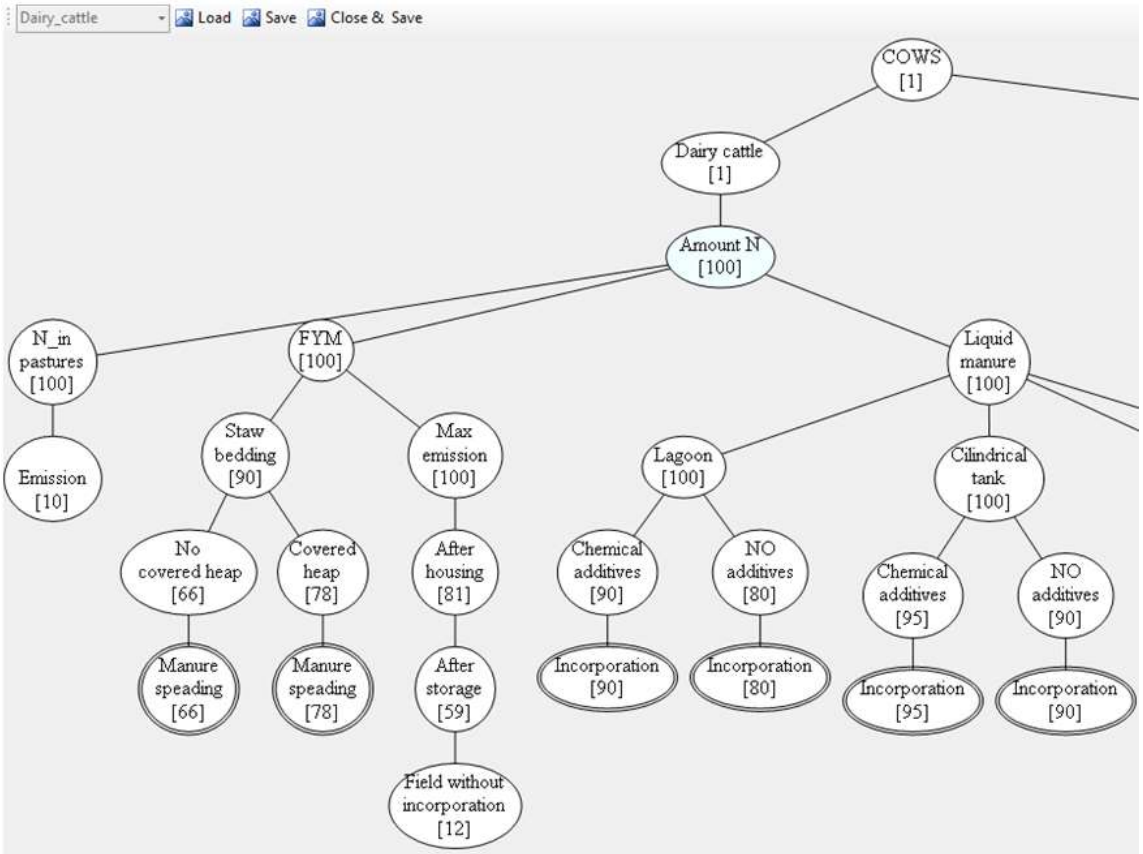

Figure 6. Values of remaining nitrogen units via the dairy cattle housing, storage, treatment and application.

An example showing the N remaining values for solid manure storage (covered heaps or non-covered heaps) in the tied-stall dairy cattle housing type, using straw bedding, as well as for various manure application and incorporation options is given in Fig. 7 (part of the model screen).

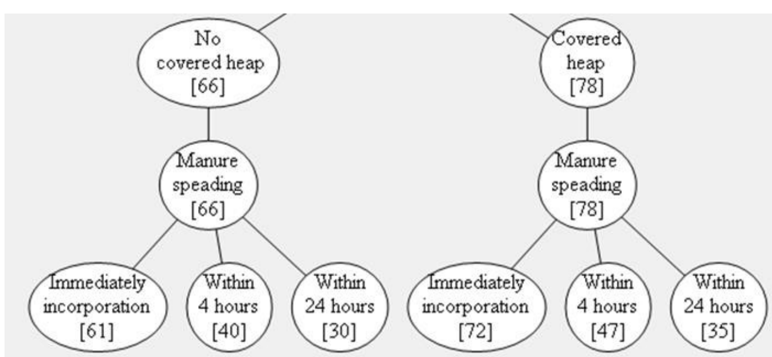

Figure 7. Part of model screen: storage and application/ incorporation of solid manure of dairy cattle with straw bedding.

Whereas, N remaining values via the dairy cattle liquid/ slurry storage in lagoon, manure treatment and application/ incorporation techniques are presented as part of the model screen (Fig. 8).

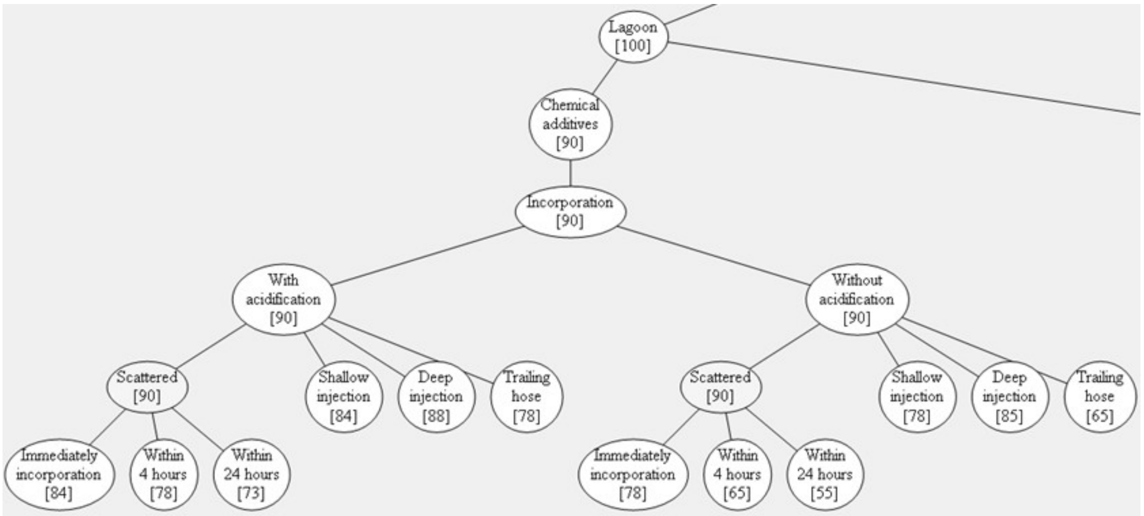

Figure 8. Part of model screen: storage, treatment and application/ incorporation of slurry or liquid manure of dairy cattle.

Acidification of livestock manure can reduce emission of the ammonia (NH_3), as well as greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) (Sommer et al., 2017). A number of the slurry acidifying additives have been considered, i.e., in Latvia, that may reduce the ammonia emissions from liquid manure or slurry, but they are not strongly recommended as abatement measure due to the following considerations: (i) safety issues (i.e., risk to workers, animals and the environment) by adding sulphuric acid to manure at any stage of the farm operation; (ii) adding additives other than acids to slurry, has not proven to be effective in reducing emissions or presents practical problems limiting their use (UNECE, 2015; Loyon et al., 2016).

Notwithstanding the need to develop integrated approach, in which interactions between ammonia and greenhouse gases emissions should be explored, are proposed by scholars and experts (i.e., EC, 2016; Hendriks et al., 2016; Sajeev et al., 2018), the purpose of using the model, term of its development and amount of financing was determined by the funder.

CONCLUSIONS

The developed model provides an opportunity to assess the impact of each individual ammonia abatement or mitigation measure (i.e., technique) both at a given stage of dairy cattle manure management and throughout the all manure management chain.

The model is applicable both on the dairy farm and at the national level to predict and estimate the effectiveness of the specific reduction measure. The model also can be used in developing ammonia abatement strategies by the policy-makers, as well as in the decision-making process on state support to farms for the implementation of investment-intensive, but more effective measures for ammonia emissions reduction.

Ammonia emissions of manure management, and the mitigation potential of individual and combined measures to prevent emissions, are calculated for dairy cattle with an emissions factor approach. However, a more precise determination of ammonia emissions requires a model that accounts for the complex interactions between C and N transformations at each stage of the manure management chain.

Further research is required to provide evidence of the effectiveness and practicability of liquid manure or slurry acidification, as well as to clarify the application stage in manure management chain.

ACKNOWLEDGEMENTS. The paper was partially supported by the Ministry of Agriculture of Republic of Latvia, project No 10.9.1-11/17/886); and project 'INTERFRAME-LV' (No VPP-IZM-2018/1-0005) within the National Research Program 'Challenges and Solutions of the Latvian State and Public in the International Context'.

REFERENCES

Amann, M., Gomez-Sanabria, A., Klimont, Z., Maas, R. & Winiwarter, W. 2017. *Measures to Address Air Pollution from Agricultural Sources*. Laxenburg, Austria, International Institute for Applied Systems Analysis (IIASA). 40 pp.

Antle, J.M., Basso, B., Conant, R.T., Godfray, H.C.J., Jones, J.W., Herrero, M. & Tittonell, P. 2017. Towards a new generation of agricultural system data, models and knowledge products: Design and improvement. *Agricultural systems* **155**, 255–268.

Bjerg, B., Norton, T., Banhazi, T., Zhang, G., Bartzanas, T., Liberati, P. & Marucci, A. 2013. Modelling of ammonia emissions from naturally ventilated livestock buildings. Part 1: Ammonia release modelling. *Biosystems Engineering* **116**(3), 232–245.

Del Prado, A., Crosson, P., Olesen, J.E. & Rotz, C.A. 2013. Whole-farm models to quantify greenhouse gas emissions and their potential use for linking climate change mitigation and adaptation in temperate grassland ruminant-based farming systems. *Animal* **7**(s2), 373–385.

Deng, J., Li, C. & Wang, Y. 2015. Modelling ammonia emissions from dairy production systems in the United States. *Atmospheric Environment* **114**, 8–18.

EC 2016. Directive (EU) 2016/2284 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. *OJ* L **344**, 1–31.

EEA 2016. EMEP/EEA air pollutant emission inventory guidebook 2016 - 3.B Manure management 2016. *https://www.eea.europa.eu/publications/emep-eea-guidebook-2016.* Accessed 11.12.2018.

EEA 2017. Emission factors. *http://efdb.apps.eea.europa.eu.* Accessed 9.12.2018.

EEA 2018. NEC Directive reporting status 2018. *ttps://www.eea.europa.eu/themes/air/national-emission-ceilings/nec-directive-reporting-status-2018.* Accessed 11.01.2019.

Eionet 2018. Central Data Repository, Latvia, National emission inventories (CLRTAP). *http://cdr.eionet.europa.eu/lv/un/clrtap/inventories*. Accessed 12.01.2019.

Haasnoot, M., Kwakkel, J.H., Walker, W.E. & ter Maat, J. 2013. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global environmental change* **23**(2), 485–498.

Hendriks, C., Kranenburg, R., Kuenen, J.J.P., Van den Bril, B., Verguts, V. & Schaap, M. 2016. Ammonia emission time profiles based on manure transport data improve ammonia modelling across north western Europe. *Atmospheric Environment* **131**, 83–96.

Jones, J.W., Antle, J.M., Basso, B., Boote, K.J., Conant, R.T., Foster, I. & Keating, B.A. 2017. Brief history of agricultural systems modelling. *Agricultural Systems* **155**, 240–254.

Loyon, L., Burton, C.H., Misselbrook, T., Webb, J., Philippe, F.X., Aguilar, M. & Bonmati, A. 2016. Best available technology for European livestock farms: Availability, effectiveness and uptake. *Journal of Environmental Management*, **166**, 1–11.

Melece, L., Priekulis, J., Āboltiņš, A., Jonkus, D., Laurs, A., Krieviņa, A., Pecka, A. & Hāzners, J. 2017. *The selection and assessment of effectiveness of ammonia emissions mitigation and reduction measures in agriculture*, Report of 2nd stage of MoA project No 10.9.1-11/17/886. Riga, AREI. 79 pp. (In Latvian).

Sajeev, M., Purath, E., Winiwarter, W. & Amon, B. 2018. Greenhouse gas and ammonia emissions from different stages of liquid manure management chains: abatement options and emission interactions. *Journal of Environmental Quality* **47**(1), 30–41.

Sommer, S.G., Clough, T.J., Balaine, N., Hafner, S.D. & Cameron, K.C. 2017. Transformation of organic matter and the emissions of methane and ammonia during storage of liquid manure as affected by acidification. *Journal of Environmental Quality* **46**(3), 514–521.

UNECE 2015. Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions. *http://www.unece.org*. Accessed 7.02.2018.

UNECE 2018. Addendum - 2018–2019 workplan for the implementation of the Convention. ECE/EB.AIR/140/Add.1. *https://www.unece.org.* Accessed 9.12.2018.

Velthof, G.L., Van Bruggen, C., Groenestein, C.M., De Haan, B.J., Hoogeveen, M.W. & Huijsmans, J.F.M. 2012. A model for inventory of ammonia emissions from agriculture in the Netherlands. *Atmospheric environment* **46**, 248–255.

Wallach, D. & Thorburn, P.J. 2014. The error in agricultural systems model prediction depends on the variable being predicted. *Environmental Modelling & Software* **62**, 487–494.