

ValorE: a Decision Support System to Enhance Livestock Manure Management and to Reduce Nitrogen Pollution

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ABSTRACT

Intensive agriculture and livestock breeding represent critical factors in the environment, particularly in the Lombardy region where nitrate vulnerable zones represent 62% of Utilised Agricultural Area (UAA). The problem of reduction of nitrogen losses as leaching of nitrates into groundwater and ammonia emissions into atmosphere can be only addressed through a critical and scientific analysis of animal manure entire production chain. As consequence, the ValorE Decision Support System (DSS-Valorisation of Effluents) has been developed to run simulation both at farm and territorial scale. ValorE allows to define, simulation scenarios on the basis of different manure management options and evaluate these by synthetic indices which take into account environmental, economic, technical, multifunctional and normative aspects. The application of the DSS in a sample of selected farms highlighted its potentiality as a tool to support stockholders' decisions and how an intervention planned at district level could be a useful solution to improve livestock manure management.

Keywords: Decision Support System, Integrated assessment, Livestock manure management, Nitrogen pollution.

1. INTRODUCTION

Livestock production determines serious environmental problems such as greenhouse gas (GHG) emissions, agricultural land use as grazing and feed production and emissions of reactive nitrogen (N) in atmosphere and water. These problems are getting much importance due to the stringent environmental targets required by the agricultural policies and regulations for preventing pollution of land, air and water.

The plain area of the Lombardy region (northern Italy) is characterised by an intensively managed agriculture with high livestock density and elevated use of production factors. Lombardy region accounts for a big part of the Italian livestock: in particular more than 27% of cattle and 45% of pigs (ISTAT, 2012). Though the animal manure is a source of valuable plant nutrients and renewable energy it is a potential problem for the environment and human health. Concerns related to nitrogen pollution as leaching of nitrates into groundwater and ammonia emissions into atmosphere are well-known.

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Nowadays is needed a whole farm perspective to deal with the environmental concerns due to livestock activities. The approach has to consider the strong links among feeding, housing, treatment processes, storage conditions and field application practices along the manure management chain because it affects the soil, air and water quality, the crops growth and consequently the farm income. The selection of livestock manure management options is becoming a strategically important task that farmers and public policy makers have to face.

The awareness of the environmental problem and the requirement of the whole-farm approach have encouraged the development a Decision Support System (DSS) able to provide to stakeholders, such as policy makers, farmers and their consultants, an assessment tool to evaluate different livestock manure management systems (Alfieri, 2012).

2. MATERIALS AND METHODS

2.1 Characteristics of the DSS

The DSS ValorE, consists of three main components: data management subsystem, model management subsystem and a user-interface. Different external databases provide the relevant information to the DSS while a software package developed in the .NET environment and implemented using object oriented and component paradigm (Donatelli *et al.*, 2012) through the C # language, includes several linked models to simulate livestock manure management at farm scale, from the animal feeding to the land spreading. A simple representation of the DSS structure is reported in Figure 1. Two different types of user-friendly interfaces allow to manage the simulation at farm and territorial scale.

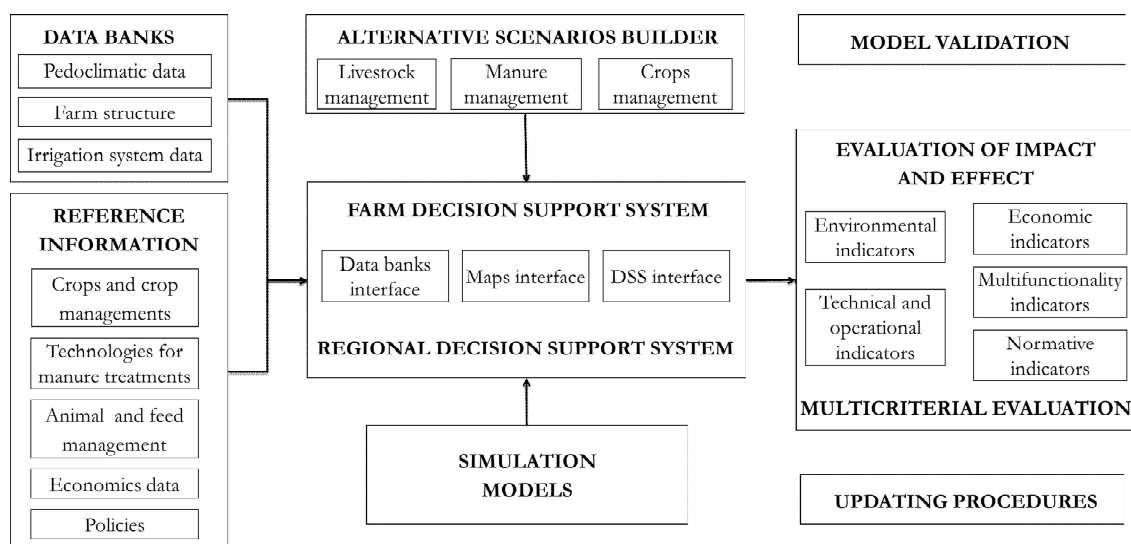


Figure 1. Schema showing the general structure of DSS ValorE.

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2.1.1 Databases and References Information

All the information to run the system are stored on available and wide databases, which are provided by Lombardy Government. Such regional data concern (i) farm structure, (ii) meteorology, and (iii) pedological characterisation. Another database contains several tables of default data referred to technical and agronomic management derived from existing literature and farmers interviews.

2.1.2 Structure of the Software

The intended purpose of the DSS is to simulate each stage of livestock excreta cycle from excretion by the herd to the crop N uptake as well as the N cycle and losses occurring via leaching, and gaseous emission (volatilization and denitrification) at farm scale.

The structure of DSS consists of different modular components relating a specific stage of the manure production process for a variety of livestock types (mainly dairy cows and pigs). Each component allows for selection of strategies to simulate a specific process and each module results represent the input data of the subsequent one (Figure 2).

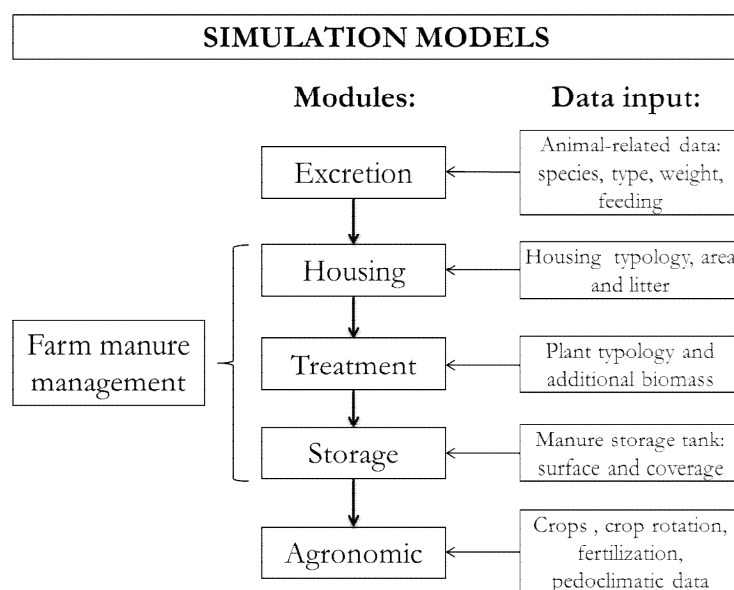


Figure 2. Modular component of the DSS relating to each specific stage of the manure production processes. Each module implements its specific simulation model.

Excretion module

To evaluate the impact of the different livestock rations on urine and faeces excreted by cattle and swine the dynamic of N and P content is simulated as a function of feed intake. The models allows to estimates separately for urine and faeces the amount of N and P excreted; in particular the output are: (i) the excreted products as fresh matter (kg FM d^{-1}), (ii) urine and its N content (kg d^{-1}), (iii) the amount of faeces, calculated as difference between the total excreted products and urine (kg d^{-1}), (iv) the N faeces

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content and v) the milk N content (kg d^{-1}). The sub-model for dairy cattle and pig are developed according to literature, whereas the excretion of other animal species such as, poultry, sheep, goats and horses, is estimated as a fixed percentage of live weight, as recommended by existing regional legislation.

Farm manure management modules

Slurry is subjected to chemical and physical modification with relative gaseous losses to the atmosphere. For the storage and treatment processes the module simulates: (i) the final volume of slurry, (ii) the final chemical and physical composition (N, P_2O_5 and K_2O), (iii) the solid and liquid fraction, (iv) gaseous losses to the atmosphere (NH_4^+ , N_2 , N_2O , CH_4 and CO_2), and (v) the eventual production of biogas and cogenerated electric energy in the anaerobic digestion treatment. ValorE includes several treatments: solid-liquid separation, anaerobic digestion with biogas and energy production, ammonia stripping, nitrification and denitrification, aerobic stabilisation and composting.

Agronomic module

The agronomic module is based on the crop simulation model, ARMOSA (Acutis *et al.*, 2007). Nevertheless, the efficacy of process-based models at large scale is questionable due to the long computational times required. Therefore, a meta-model that can provide comparable results as the original model at a lower computational cost is used.

The ARMOSA model simulates crop growth, water and nitrogen dynamics in arable land. The crop simulation module is based on SUCROS – WOFOST model (Supit *et al.*, 1994); the water dynamics can be simulated using the cascading approach, or the Richards' equation, solved as in the SWAP model (Van Dam *et al.*, 1997) and nitrogen dynamics is simulated according to the SOILN approach (Johnsson *et al.*, 1987).

The meta-model was performed starting from the results of 70.000 simulation under different scenarios of cropping systems in Lombardy. In particular, the agricultural management was defined in function of the farm types and the pedoclimatic conditions of the region. The meta-model development involved the sensitivity analysis (Saltelli *et al.*, 2005) of the input variables on the ARMOSA output in order to finally reduce the input data. Results of N losses and crop yields under different cropping systems, management and pedo-climatic conditions are provided by the meta-model.

2.1.3 Farm and Territorial Simulations

The farm represents the simulation unit whereas the aggregation of farms lets for a regional assessment under a specific scenario. In order to carry out the territorial analysis, a WebGis application was developed to elaborate a tabular and map based summary, at different aggregation scales (e.g. farm, hydrologic basin, municipality, county, region, NVZs, etc). The farm simulator is aimed at farmers and allows the analyses of management and of technological alternatives available for the pre and post-excretion management to better valorise the livestock manure. The territorial simulator is aimed at policy makers and is available on a WebGis interface which handles spatially distributed input and output data. It works on a regional scale and allows the evaluation of the impact of alternative management options and regulatory measures from the agronomic, environmental and economic point of views. All the maps exported from the software are in Italian language since it was not performed an English version.

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2.2. Tasks of the DSS

To carry out comparative analysis the software offers a possibility to know the current perspective in terms of manure management system at farm or territorial scale by interrogating the databases available. Then it is possible to enhance the N management generating different alternative scenarios both at farm and territorial scale, thanks to an extensive choice of management options. Changes can be focused on manure and cropping system management. Current and alternative scenarios defined as sustainable can be evaluated and compared by using indicators. Moreover a specific tool of the DSS makes possible to investigate the effect of policy measures.

2.2.1 Query Tasks

The software offers the possibility to be used as instrument for easy interrogation of the regional databases. Both predefined and custom queries can be generated and the results are available in exportable reports (Excel or PDF format). The query system is based on a WebGis interface, to help the users to obtain aggregated information for specific geographic areas (i.e. region, provinces, municipality, farms etc.). Thus, it makes possible to obtain a general perspective of the farming systems characteristics including the potential and critical environmental issues related to the manure management. The domain available includes: animals herd, animal housing, manure storage, manure treatments, cropping systems, economical and mechanisation aspects, policies aspects (e.g. normative compliance of slurry storages) and pedo-climatic characteristics.

2.2.2 Alternative Scenarios Generator

The alternative scenarios generator allows to select options referred to manure collection systems, storage facilities and manure land application methods and includes possible changes at cropping system level. This generator permits the evaluation of different managerial hypothesis for improve the N efficiency of a single farm or for a sample of farms. Several inputs, such as i) number of LSU, protein content in animal ration and the daily weight increase rate (kg d^{-1}), ii) livestock housing, iii) slurry treatment, iv) manure storage feature v) type and timing of manure application on the basis of calculated fertilisation plan, vi) cropping system and vii) fertiliser management scheme, can be modified.

2.2.3 Indicators

The evaluation of actual and alternative scenarios and their comparison is computed with the software through the calculation of a wide range of indicators. They are a synthetic representation, both expressed as quantitative and qualitative scales, of the implications on technical, agronomic, environmental, energetic, and economic aspects due to the adoption of a particular management.

2.3. Case study using the DSS

ValorE DSS was used to evaluate the effect of alternative management option on the nitrogen management at the regional scales selecting a sample of farms. The actual farm configuration was labelled as “actual scenario” (ACT) while the hypothetical farm configuration is labelled as “alternative scenario” (ALT). The sample area was

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represented by nine neighbouring municipality localised in the province of Bergamo. It was chosen because is a nitrates vulnerable area with high organic N load. Within the area, through a “query” function, were selected only livestock farms, over 50 ha of agricultural utilisable area (UUA) and that did not respect the limit of 170 kg per year ha^{-1} of nitrogen from organic fertilisers. The sample was composed by 28 farms. The organic N load aggregated at municipality level is very high and ranged from 325 to 605 kg ha^{-1} of UUA.

The alternative scenario hypothesized involved the implementation of the nitro-denitro treatment plant with the removal of N. The livestock manure is first separated in a liquid and solid fraction. The liquid fraction enters in the nitro-denitro plant and successively stored in a tank for the final agronomic use. The remaining part is moved to a belt press and stored in covered facility together with the solid fraction obtained from the first separation. The final product could be applied on fields or sold outside farm. The simulation of the actual farms configuration was done using input data from the regional databases updated at 2011.

3. RESULTS AND DISCUSSION

The first positive effect due to the implementation of nitro-denitro treatment plant was the strong reduction of the organic N available to be distributed on farms fields. As reported in Table 1 the reduction ranged from 39% to 66% demonstrating that nitro-denitro process is a reliable solution to get compliancy with nitrate directive under derogation limits (i.e. 250 kg ha^{-1} of organic N) (Figure 3). Moreover, relevant advantages from an environmental point of view can be obtained. N leaching and ammonia volatilisation were reduced from 38% to 75% and from 24% to 34%, respectively (Table 1).

Table 1. Effects of the implementation of the nitro-denitro treatment plant.

Municipality	N distributed on field (Kg ha ⁻¹)			N leaching (Kg ha ⁻¹)			Ammonia volatilized (Kg LSU ⁻¹)		
	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %	ACT	ALT	INCR(+) DECR(-) %
Antegnate	544	206	-62	219	77	-65	68	50	-26
Barbata	537	182	-66	197	77	-61	96	68	-29
Calcio	488	168	-66	135	52	-61	51	37	-26
Covo	503	201	-60	223	69	-69	44	29	-34
Fontanella	606	249	-59	231	89	-61	81	59	-27
Isso	538	239	-56	159	40	-75	45	34	-26
Pumenengo	326	199	-39	135	84	-38	42	32	-24
Romano di Lomb.	587	254	-57	109	50	-55	47	36	-24
Torre Pallavicina	419	200	-52	131	62	-53	47	35	-25
LSU: livestock standard units; ACT= actual scenario; ALT= alternative scenario									

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Unfortunately the fertilisation value of manure was halved because of the 50% of N was lost as N_2 . This aspect implies the reviewing of the nitrogen fertilisation plans. From an economic point of view the direct costs of construction are relevant: for a dairy farm of 130 ha with 55 lactating cows and an annual volume of liquid manure produced of 12000 m³, the expected investment (estimated by the software) is approximately 380.000 Euro. However, considering the aids provided by the measure 121 of the current Rural Development Programme (2007-2013) applied in the Lombardy region the economic investment could offset by 35-40%.

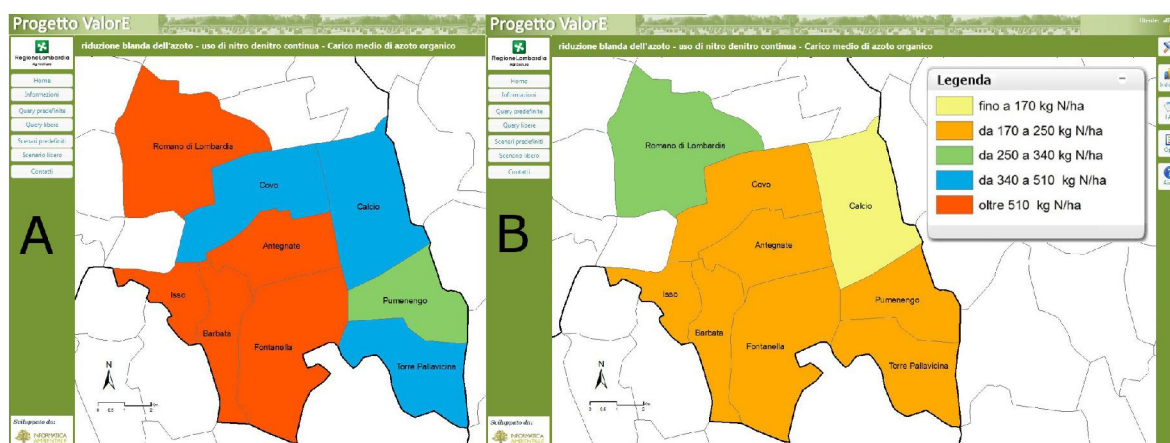


Figure 3. Mean organic N load (kg ha⁻¹) [carico medio di azoto organico] aggregated at municipality scale for the ACT scenario (a) and after the implementation of the nitro-denitro plants (ALT scenario) (b).

4. CONCLUSIONS

The DSS developed is an attempt to create an instrument for the environmental protection in a very intensive agricultural area with one of the livestock density higher in the World. Through the ValorE software the analysis can be carried out for all the farms in the region, and alternative management scenarios as well as hypothesis of policies can be tested. The spatial and integrated approach allows to deal with conflicting objectives, interests and expectation of the stakeholders involved.

The main advantages of the DSS ValorE over other similar systems is that is designed to manage different livestock manure types. The OOP targeting at modularity and reusability allows a more intuitive and strong separation among data, models and interfaces. The architecture of the software and the OOP offers an easy and automatic updating of the application and of the model algorithms as well as the possibility to maximise the ease of maintenance. The farm simulator could help farmers and their consultant such as agronomists and technicians of the Italian farmers organizations to find better solution to valorise the organic manure in environmental, technical, agronomic and economic terms. Whereas, the territorial simulator represents a tool to support policy makers under the decision process, i.e. for example the planning of the Rural Development Programme interventions. The results of management option for a

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sample of farms has shown how the intervention planned at district level could be a useful solution to improve livestock manure management.

5. REFERENCES

- Acutis, M., S. Brenna, M. Pastori, A. Basile, A., R. De Mascellis, A. Bonfante, P. Manna, A. Perego, M. Fumagalli, D. Gusberti, M.C. Velardo, P. Trevisiol, M. Sciacaluga, G. Albani, F. Malucelli, S. Vingiani, N. Orefice. 2007. Modellizzazione della dinamica dell'acqua e dell'azoto nei suoli agricoli lombardi – Progetto ARMOSA - (Modelling water and nitrogen dynamics in Lombardia), *Regione Lombardia quaderno della ricerca*, n. 65.
- Alfieri L., 2012. Development of expert systems for the mitigation of nitrogen pollution at farm and regional scale. Ph. D. Thesis. University of Milano, 99 pp.
- Demmers, T. G. M., L. R. Burgess, J. L. Short, V. R. Philips, J. A. Clark and C. M. Wathes, 1999. Ammonia emissions from two mechanically ventilated UK livestock buildings. *Atmospheric Environment* 33(2): 217-227.
- Donatelli, M., Cerrani, I., Franchini, D., Fumagalli, D., Rizzoli, A.E., 2012. Enhancing Model Reuse via Component-Centered Modeling Frameworks: the Vision and Example Realizations. Proceedings of *International Congress on Environmental Modelling and Software* Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.) pp. 1185-1192.
- ISTAT, 2012 (Istituto Nazionale di Statistica), 2010. Verified on September 25th, 2012 and available on http://agri.istat.it/sag_is_pdwout/jsp/Introduzione.jsp?id=8A|11A|9A.
- Johnsson, H., Bergstrom, L., Jansson, P.-E., 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. *Agriculture Ecosystem and Environment*, 18, 333-356.
- Saltelli, A., Ratto, M., Tarantola, S., Campolongo, F., 2005. Sensitivity analysis for chemical models, *Chemical Reviews*, 105, 2811-2827.
- Supit, I., Hooijer, A.A., Diepen, C.A. van, (Eds), 1994. System description of the WOFOST 6.0 crop simulation model implemented in CGMS. *Publication EUR 15956 EN of the Office for Official Publications of the EU*, Luxembourg.
- Van Dam, J. C., Huygen, J., Wesseling, J. G., Feddes, R. A., Kabat, P., van Walsum, P. E. V., Groenendijk, P., van Diepen, C. A., 1997. Theory of SWAP version 2.0. *Report 71. Technical Document 45*, Wageningen, 167 pp

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