Developing a decision support system for manure management

Développement d'un système d'aide à la décision
pour la gestion des déjections animales.

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Abstract

In 1991 the University of Guelph formed a group to bring together representatives of all the stakeholders concerned about manure management. The deliberations of the group, together with views of farmers and advisors obtained at focus workshops across Ontario, resulted in a report summarizing the state of the art in manure management. The report identified key areas for research and development. Many of the proposals for research were included in the Federal-Provincial Green Plan initiative. The recommendation of most concern to the industry was the integration of available information into a form that could guide farmers in improving manure management.

The University formed a team to develop a computer-based decision support system (DSS), the first version of which was completed in 1997. The DSS deals with manure management from the feed input, manure release and handling in the barn, storage, field application, transformation in the soil, to incorporation of nutrients in crops.. The information on nutrient loss is used to estimate off-farm economic impact of the manure system. The DSS also features a weighted rating system to compare different systems.

Résumé

En 1991, l'Université de Guelph a réuni un groupe de travail comprenant l'ensemble des acteurs concernés par la gestion des déjections animales. Les travaux de ce groupe ainsi que les contributions d'agriculteurs et de professionnels ont abouti à la préparation d'un rapport contenant l'état de l'art sur la gestion des déjections. Plusieurs propositions de recherches furent par la suite dans le contrat de plan « Vert » Etat Fédéral - Province. L'une des principales recommandations était le besoin d'intégrer l'information disponible sous une forme utile pour guider les éleveurs dans leur choix de gestion des déjections. L'Université a alors rassemblé une équipe pluridisciplinaire pour développer un système d'aide à la

décision, dont la première version fut présentée en 1997. Ce système aborde la gestion des déjections depuis l'alimentation, la production de déjections et la gestion dans le bâtiment, au cours du stockage ainsi que l'épandage, la transformation dans le sol et l'incorporation par les plantes. Les informations sur les pertes d'éléments sont utilisées pour calculer le coût et l'impact économique du système.

1. Introduction

There has been increasing concern about the impact of animal manure on the wider environment[1], and this has resulted in constraints to the growth or absolute size of animal production in different regions. In 1991 the University of Guelph formed a group that brought together representatives of all the stakeholders concerned about manure management. Their deliberations, together with views of farmers and advisors obtained at focus workshops across Ontario, resulted in a report summarizing the state of the art in manure management [2]. The workshops highlighted the need to integrate information related to the feed and supply of water to confined animals, the design of barns and the associated storage facilities for manure, opportunities for processing manure, transportation of manure, the land application and utilization of manure in crop production, and the protection of the environment from odour and excess nutrients (including carbon). Within each of these topics, the economic aspects, educational needs, and the development of an understanding of the processes involved, were identified as important goals that would allow the farming community to meet its challenges. The University of Guelph group established for Ontario a priority for research and extension related to manure. A total of twelve priority areas was identified. The first two were: I) develop extension packages to assist farmers in making more effective use of nutrients in manure; ii) establish a research program involving engineers, animal scientists, agronomists, soil scientists and economists to develop a comprehensive framework by which alternative manure management systems can be compared. The University, through its partnership for agricultural research and development with the provincial agricultural ministry (Ontario Ministry of Agriculture, Food and Rural Affairs-OMAFRA), formed a team to develop a computer-based decision support system (DSS) that would encompass both priority areas. Most of the other priority areas for research were included in the Canada-Ontario Green Plan initiative (see *http://res.agr.ca/lond/gp/gphompag.html*). This paper describes the integration of research, development and extension in the process of constructing the DSS, and highlights the structure of the program that was completed in 1997.

2. Procedures

The team of scientists was selected according to the research recommendation. In addition, researchers and extension workers from other public sector organizations and from private consultancies were invited to attend team meetings. An email discussion platform was set up as a list-serve address. Subsequently a web site has been established (see *http://www.oac.uoguelph.ca/ManSys/*). Two members of the team agreed to act as project co-ordinators.

The first action point for the team was to undertake a literature review pertinent to the needs of the envisaged DSS. This provided an assessment of the significance that gaps in information would have for the reliability and precision of the DSS. The material was drawn from North America, Europe, Asia and Australasia. This review was published as a book [3] comprising nine chapters, although due to the overwhelming volumes of literature available and the need to work to a tight time schedule, and considerable selectivity was inevitable. Individuals provided an overview of alternative DSS's for manure management. It was concluded that despite the large number of existing software packages there was still a need for a comprehensive DSS dealing with manure handling and nutrient management.[4] One important factor was that improvements in computer hardware and software have made complex operations, until recently only possible on mainframes, feasible on home-computers.

Impacts of animal diet on the nutrient content of manure were reviewed. One aspect that needed further research was the estimation of the quality of dairy manure based on feed input.[5]. Various models were examined that predict the excretion of N and P by different age classes of pigs. From these models the nutrient content of manure on an individual farm could be calculated. It was concluded that more research was necessary to assess the consequences of phase feeding and amino acid supplements for manure quality.[6] After excretion, changes take place in manure composition in the barn and during longer-term storage prior to field application. Significant gaps were identified in knowledge of the aerobic and anaerobic processes taking place in solid manure piles, and knowledge of the influence of depth below the surface of solid piles or liquid storages on composition.[7] The pH of manure is important for ammonia (NH_3) loss, but predicting the value at the surface of liquid manure was a major limitation in estimating NH_3 volatilization. The capability to predict N_2O loss from manure was also recognised as a significant gap in knowledge.[7] The gaseous emissions from swine and dairy cattle farms are affected by the design of livestock barns, manure storage, and the field application of manure. The proportion of the total emission originating in the barn was identified as requiring research, so too was the amount of the emission that was redeposited locally.[8] The interrelationship between the production and emission of CO_2, CH_4, N_2O and NO was seen as an important area that required more work.

In his review of recent research on crop response to manure nutrients, especially nitrogen (N), phosphorus (P) and potassium (K), Beauchamp[9] identified that the following aspects of manure N availability required further research:

- ➢ improve methods to predict manure N availability with particular reference to the organic N fraction from monogastric and ruminant livestock;
- ➢ mprove understanding of the roles of ammoniacal N and beddings in relation

to net immobilization and net mineralization of N in soil following manure application to land;

- clarify crop responses to N in fall-applied manure compared with spring-applied manure;
- develop a soil N test that reflects the availability of the organic N following manure application;
- clarify the impact of animal diet on availability of manure P relative to fertilizer P, particularly with respect to differences between monogastric and ruminant livestock

It was concluded that research on manure phosphorus was generally of lesser priority than that on manure N. Nevertheless the availability of manure P deserved attention.

An assessment of the factors associated with the transport of N, P and micro-organisms into surface and groundwater indicated that prediction of the contribution from preferential flow to the transport of NO_3^- and bacteria was necessary. It also indicated that the ability to predict transport of bacteria to ground water was limited.[10]

Although on-farm economics of manure management has been studied extensively, information was needed to allow a cost-benefit analysis for alternative management systems.[11] Alternative methodologies were identified as needed for evaluating the economic value of environmental damages caused by contamination stemming from manure.[12]

The team also decided to adapt existing programs wherever possible rather than always create entirely new code. Research was then focussed on establishing appropriate provincial databases for input parameters and rate constants of processes.

A call for research proposals to cover identified issues related to manure management was issued in 1996. This included work on the release of nitrogenous gases from manure in storage and after application to arable fields, the development of improved method to predict availability of N in manure, and the evaluation of contamination of water resources from agriculture, including animal production units. Specific contracts were placed to develop models to cover the transport of gases from livestock barns and manure storages, provide information on the transport of micro-organisms from manure to ground water after land application, and develop a cost-benefit database for different components of manure handling systems.

Information from the projects on manure funded under the Canada-Ontario Green Plan initiative was also made available for development of the DSS.

To encourage industry participation in the development of the DSS and obtain basic information on the manure handling systems in use in Ontario, the Dairy Farmers of Ontario and Ontario Pork, which together represent about 14,000 of the producers in the province, were asked to support a survey of their members. Producers were asked about the physical plant used for manure management, and about their use of computers. Of the dairy farmers who responded to the survey, 34% said they would consider using a computerized DSS to aid their manure management. The comparable number for hog farmers was 42%. This provided adequate assurance that development of a computerized system would be an appropriate goal.

3. Development of the software

The construction of the DSS was based on an earlier program (MCLONE - **M**anure, **C**ost, **L**abour, **O**dour, **N**utrients and **E**nvironmental) developed for swine operations.[13] Fleming's program was written in Turbo Prolog and had a DOS window system of presentation. This software had been upgraded to use inputs from a mouse control.[14] The new program, MCLONE3, was developed by Ma[15] to bring the DOS program into a modern computer language. KnowledgePro++ (Knowledge Garden, Inc., Lake Worth, FL) was chosen to use a Windows™ based expert system presentation.

MCLONE3 uses an object-oriented format within KnowledgePro. Through a set of screens users may provide their own inputs, save the input data files and run the program again. There is a separation of program and data. More sensitive data such as costs are put in separate files so that the program does not have to be recompiled when updating. With KnowledgePro the hypertext feature is built in and used for explanations of the 'why' and 'how'. That is, hypertext provides the user with a response as to why the question is being asked. Similarly hypertext is used to explain how the program will arrive at an answer. A certainty factor calculation has been added although the user does not have the ability to change these values. That is, the certainty of the answers is judged within the program based on expert knowledge about the topic. The certainty value is reported to the user along with the results in each section.

4. Key features of the DSS

Manure production is normally based on previously available data on output for the number, size and type of dairy and swine animals[16] (Table 1). Another method of determining swine manure production has been added, called the detailed method for estimation, in which feed intake is used to determine nutrient and mass output.[6] In this approach, feed that goes to waste is assumed to end in the manure. N in feed is assumed to be in crude protein, and will have a digestibility that depends on the age of the animals. Undigested protein contributes to the faeces N load. Digested protein contributes to an increase in the lean yield of the animals or is excreted in urine. Provision is made to take account of changes in the nutrient content of manure due to feed additives, such as phytase and amino acids. The relative proportion following the urine pathway depends on the age and size of the animal. For liquid storages, summer and winter precipitation and evaporation for the various regions of Ontario are taken into account to estimate manure volume.

To account for the additional water entering the manure in the barn, different inputs to the program are required depending on the animal type. For dairy cows the user inputs the total amount of waste water produced per day. For swine farms, the user inputs additional water added expressed as a percentage of manure produced for feeders, starters and breeders. Input for precipitation can be provided by the user, and for net precipitation, summer evaporation is made equal to precipitation. Winter evaporation (November-April) is based on an estimate of 60% of the precipitation being lost by evaporation from an open manure pit. The final volume of manure is then given by the sum of the volume excreted, the volume of wash water, and the net precipitation.

	Manure mass kg/day	N kg/day	P kg/day	K kg / day
Dairy cows	86	0.45	0.094	0.29
Dairy calves	62	0.27	0.066	0.28
Swine	84	0.52	0.180	0.29

Table 1.
Manure production of dairy and swine (per 1000 kg of body mass)

Field application takes account of the maximum hydraulic loading possible without liquid manure running-off the soil surface. The recommended application rate allows either nitrogen (N) or phosphorus (P) limitations depending on the soil test results or other environmental factors. Users can also set their preferred rate. Crop uptake[18] and ammonia volatilization remove N from the soil, while the sources are manure-N, any applied fertilizer-N, and residual N from previous manure. Credit is given for manure applied, or leguminous crops grown, in the previous two years.

N loss during each stage of handling is monitored by the DSS and finally reported at the end of the program. The loss values were updated from the latest research findings. They include such modifiers as losses based on type of barn, e.g., open dairy housing; losses from storage taking account of loading method, loading rate and wind speed; losses during field application, where the rate of N loss reflects inefficiencies in the method of spreading, e.g., irrigation, and from denitrification when manure is injected. After surface spreading the amounts of ammonia volatilization varies depending on the length of time before manure is incorporated.

Comparing the N retained on the farm with the total amount excreted by the animals provides one means by which the environmental impact of a manure management system is assessed. Advice on protecting water courses from P contamination following manure application is also included in the DSS. A phosphorus index for Ontario (P Index) was developed based on a program developed in Delaware.[17] Essentially the index combines inherent properties of the soil and the field with management factors (Table 2). This index provided a further limitation to manure spreading on fields susceptible to erosion. Phosphorus not taken up by crops builds up in the soil and is flagged at 60 mg kg^{-1}. Above that limit, application of manure is restricted to that removed in the harvested crop. Potential environmental impact due to P derived from manure is then determined from the soil P test, the amount of P applied relative to crop requirements, the risk of storages overflowing due to inadequate volume for the number of animals housed or due to the limited windows of opportunity for manure to be spread. The potential pollution rating is given as a function of the sum of the P index value, the risk associated with the application of manure greater than crop requirements, the risk due to storage shortage, and the number of days over which the shortage might occur.

Factor	Assessment	Options for modifying factor
Soil erosion rate	Soil type, slope, ground cover, rainfall	Introduce conservation practices
Soil water management	Run-off, infiltration	Introduce conservation practices
Soil P	Soil test	Adopt nutrient management strategies
P application	Fertilizer rate, manure rate	Ensure sufficient land area for spreading
Method of P application	Equipment adopted	Restrict time that manure is left on the soil surface
Susceptible water body	Distance to water course	-

Table 2.
Factors affecting environmental risks from phosphorus management on farm fields

The problems of odour from barns and manure storage are dealt with using the minimum separation distance acceptable between these structures and non-farm properties.[18] Odour associated with field application is assumed to be proportional to the loss of ammonia by volatilization associated with this operation.

Data requirements for the DSS model's socioeconomic components are subdivided into those for evaluation of on-farm economics and those associated with the cost of environmental damage. On-farm economics requires information on operating costs (for labour; fuels; equipment - custom hire or rentals -; repairs and maintenance for equipment and machinery), ownership costs (depreciation and opportunity cost interest on capital assets such as manure storage facilities, manure collection and field distribution equipment), and benefits from manure (opportunity cost value of plant nutrients applied to the soil and the value of any soil-productivity enhancements due to organic matter accumulation). The manure management system is treated as modular, and costs are incurred for each system component. Of the operating costs, the user supplies actual costs for equipment, custom hire, and rentals, unit costs for labour and fuels, plus quantity of labour used. Fuel use and maintenance costs are based on ASAE standards.[16] Similarly, for ownership costs, annual amortization is calculated from the ASAE standards equation. Benefits derived from manure are based on opportunity cost value of plant nutrients alone, there being no reliable data source for longer-term soil productivity enhancements; plant nutrient (nitrogen, phosphorus and potassium) quantities are according to laboratory analysis of manure samples at point of field application, and unit values are according to current retail costs of N, P and K in synthetic fertilizer form.

For environmental damage cost assessment, a proxy was used. Attention is focused on social acceptability aspects of manure management. The assumption is made that social acceptability is inversely related to odour emissions and indirectly, to gaseous emissions, and that the contamination of water resources can serve as proxy for environmental damage. Risk assessments related to release of odour from barns, manure storages and during land application, to the release of nitrogenous gases, and to the contamination of water resources due to the leaching of nutrients, are developed for each alternative manure-handling systems using a simple scalar of 1 to 10, 10 for lowest risk and 1 for highest.

The information generated in the potential pollution rating package, the odour rating package, the nutrient rating package, the cost rating package, and labour rating package is brought together in a framework of assessment for the efficiency rating of the whole system.[13].The user can set the relative importance of each of the five aspects to his own situation, with the provision of weighting factors (Fig. 1). The sum of the five values of the weighting factor has to equal 100. This assessment framework allows the user to compare different manure handling systems and evaluate how the weighting of priorities can enhance or affect adversely the efficiency of the manure management.

As far as possible, geographically-local data are used for equipment replacement costs, labour costs and capital borrowing costs, so as to reflect regional conditions. Otherwise, published secondary sources are used, where available. In many cases, required data are not available in published form, and need to be generated by the manure management team.

Fig. 1 Schematic for the DSS - MCLONE3.

Note the opportunity to vary the weighting associated with each of the five key areas that are combined in the rating of the system.

The alpha-test version of the DSS is available for evaluation by downloading from the University of Guelph's manure management team web site (see : http://www.oac.uoguelph.ca/Mansys/)

5. Conclusions

A comprehensive decision support system for manure management has been developed following an extensive process of consultation and review[20]. During the process, close links have been established between the multi disciplinary team assembled for the task and the dairy and swine industries through the data acquisition process. The importance of public concern for the environment has resulted in the assessment of the manure handling system considering nutrient use efficiency, odour production, and impacts on water resources as well as the labour resources and costs. The user of the DSS can change the relative weighting given to these aspects in comparing different manure management systems.

6. References

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