SWAMP[1] - Optimising the use of slurry

SWAMP - Optimiser l'utilisation du lisier.

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Abstract

Collection and storage of farm manures as slurry has become normal practice on intensive livestock farms. This system for manure storage has many advantages including automation of slurry collection, reduced labour requirements and minimal use of bedding materials. Ideally, the slurry should be applied on suitable lands, at application rates which match the nutrient requirements of the crops being grown. This approach will minimise the risk of pollution. Often existing methods of application do not achieve these aims. The slurry is applied at the incorrect rate because the farmer does not know the nutrient content. Even if the nutrient content is known, the type of equipment used may not apply the material evenly. Also different soil types and weather conditions at application will influence the potential for nutrient leakage and associated pollution risks. This recently completed EU funded project - Sustainable Waste Application Management Project (AIR3 CT94-1276) addresses some of the problems associated with utilising slurry and comprises three major research areas :

- *Management and Risk assessment.*
- *Determining the Nutrient Value of Slurry.*
- *The development of Prototype Application System.*

Résumé

[1] Sustainable Waste Application Management Project.

La collecte et le stockage des effluents d'élevage tels que le lisier sont la pratique courante dans les élevages intensifs. Ce système de stockage des effluents présente de nombreux avantages y compris l'automatisation de la collecte du lisier, une réduction de la main d'oeuvre requise et une utilisation minimale de litières. En principe, pour réduire les risques de pollution, l'épandage du lisier devrait se faire sur des terres qui en ont besoin, selon des doses d'application qui correspondent aux besoins en éléments fertilisants des cultures. Bien souvent, les méthodes d'application existantes ne permettent pas d'atteindre ces objectifs. Les quantités appliquées sont incorrectes parce que l'agriculteur ne connaît pas la teneur en éléments fertilisants du lisier. Même lorsqu'il la connaît, le type de matériel utilisé ne permet pas toujours un épandage régulier. Par ailleurs, le type de sol et les conditions météorologiques au moment de l'application influencent le potentiel de ruissellement des éléments fertilisants et les risques de pollution associés. Ce récent projet européen intitulé SWAMP (projet de gestion de l'application durable des déchets) (AIR3 CT94-1276) a été réalisé avec l'assistance financière de l'Union Européenne (UE). Il visait à résoudre certains problèmes associés à l'utilisation du lisier et se subdivise en trois grands domaines d'étude :

- Gestion et évaluation du risque.
- Détermination de la valeur fertilisante du lisier.
- Développement d'un prototype de système d'application.

1. Introduction

For millennia mankind has recognised the importance of recycling organic manures as a nutrient source for crop production (Tunney et al., 1997). However, as production systems have developed there has been a trend towards more specialisation of agricultural activity with an associated reduction in the dependence on organic manure as a nutrient source. The demand for economic systems of food production, the availability of relatively cheap sources of inorganic fertiliser and the development of efficient transport systems for agricultural inputs and products have aided the increased specialisation of production systems (Fluck and Baird, 1980). The collection and storage of farm manures as slurry has become normal practice in many regions. This management system has many associated advantages including the automatic collection of slurry, reduced labour requirements and minimal use of bedding materials. Ideally, the slurry should be applied on suitable lands at application rates which match the nutrient requirement of the crops being grown. This approach will minimise the risk of pollution resulting from the leakage of plant nutrients either to watercourses or the atmosphere (Burton, 1997). For grass based production systems suitable application lands are typically available adjacent to the farm yard. For animal production based entirely on bought in concentrate feed it is more difficult to source suitable spreading sites.

Existing methods of application, e.g. vacuum tankers with splash plates, do not facilitate the effluent utilisation of nutrients in farm slurries (Pain, 1989; Carlson, 1994). The slurry is often applied at the incorrect application rate because the farmer does not know the nutrient content of the material (O'Bric et al., 1992).

Even when the nutrient content is known, the spreading device may not apply the slurry evenly. Different soil types and weather conditions at application will influence the potential for subsequent nutrient leakage and associated pollution risks. A recently completed, EU funded project - Sustainable Waste Application Management Project - *SWAMP* (AIR3-CT94-1276) addressed some of the problems associated with utilising slurry and comprised three major research areas:

(a) Management and Risk Assessment of Slurry Application Operations
(b) Determining the Nutrient Value of Slurry
(c) The Development of a Prototype Application System

2. Management and Risk Assessment

The objective of good slurry management is to make maximum use of the nutrients in the material while minimising the risks associated with land application. Many factors must be considered in the decision process for applying slurry including the quantity of material to be spread, soil type, field drainage system, weather conditions, crop type, time of year etc. The *SWAMP* project developed a decision support system using computer modelling to aid the decision-making process. A twin approach was adopted involving two modules - *Environmental Risk Assessment* (ERA) and *Application Decision Support* (ADS). The ERA module provides an assessment of the nutrient losses (and thus pollution risk) associated with a particular slurry application event while the ADS module aims to provide the decision support for the farmer in making the correct day to day management decisions when applying slurry.

2.1. Environmental Risk Assessment - ERA

Nutrient loss mechanisms from a field include surface run-off of whole slurry, macropore flow through the soil of particulate pollutants, leaching of dissolved nutrients to field drains and deep groundwater, ammonia volatilisation and emissions of nitrogen oxides. Nutrient dynamics as considered by the *SWAMP* project are concerned with the loss of phosphorus and nitrogen in surface run-off and the further loss of N in the form of NO_3 through leaching via field drains or ditches.

The approach adopted to provide the assessment of nutrient loss is to use weather driven simulation models of soil water and nutrient dynamics. These models require site specific historical weather patterns and soil hydrological characteristics and are used to simulate agricultural practices over 10 years of weather data. A statistical analysis of the predictions is then carried out which produces a risk percentage for each week that surface run-off will occur on a field during the critical period after slurry application. A similar procedure produces modelled yearly estimates of N leaching for each field for various agricultural practices.

A number of simulation models were considered for use in the project. SOIL and the SOILN models (Jansson, 1996; Eckersten et al., 1996) were selected as being the most appropriate (McGechan et al., 1997). The SOIL model is a multi-layer model and it can indicate the soil water content and horizontal movement of water to field drain backfill at different depths, as well as deep percolation, with a range of drainage system options. Work was carried out to calibrate and validate the SOIL model for selected sites in Scotland and Ireland. The validation studies with the model showed reasonable agreement between simulations and measurements for drainflow volumes, soil water content, water table height and surface run-off volumes (Lewis and McGechan, 1998).

A similar approach was used to calibrate and validate the SOILN model for nitrogen dynamics (Wu et al., 1998, Wu and McGechan, 1998). The ERA approach produces information about polluting risks from run-off and about N losses when a soil type, crop, climate and a fertilisation strategy has been defined.

2.2. Application Decision Support

ADS was devised to assist the farmer in developing a successful farm manure management strategy and the module has three main elements :

- nutrient balance to the farm
- strategic field by field scheduling of slurry application (planning)
- tactical field spreading decisions (day to day operation)

The nutrient balance is based on details of livestock types and number, housing, nutrient losses (e.g. treatment or storage), import or export of manure from the farm and crop nutrient requirements. Strategic scheduling takes into account the spreading system available and its related nutrient losses, the amount of organic fertiliser available in relation to crop requirements, the spreading days available depending on location and restrictions on any spreading operation due to legislation. The final output of this section is a field-by-field recommendation on the volumes of slurry to be applied on each field and for each spreading event. It also provides information on the top-up requirements for mineral fertiliser if necessary. The final section aids the farmer in the making of day to day decisions on slurry application taking into account weather conditions and practical farm operational constraints, e.g. work capacity of machines.

3. Determining the nutrient value of slurry

Slurry in farm stores typically has a variable nutrient content (O'Bric et al., 1992) which makes it difficult to efficiently use in a planned fertilisation programme for crop production. The variable nutrient content of slurry is a result of the variation in animal type, diet composition, dilution with water etc. Further variation from the mean nutrient content within individual stores results from the stratification of the material over time, e.g. surface crust formation in cattle slurry and settlement of solids in pig slurry.

Four methods of measuring or estimating the nutrient content of slurries were considered as part of the project and details are outlined in Table 1. The estimation methods are considered useful for long-term planning of application strategies, e.g. while the measuring methods are more applicable for use with actual application operations.

Measuring Methods	Estimation Methods
Rapid Laboratory	MESPRO Model
In-Line Sensor	Balance Approach

Table 1.
Methods examined for determining nutrient value

3.1. Rapid Laboratory Analysis

Laboratory analysis of slurry samples requires the collection of a sample which is representative of the total amount of manure. Agitation before sampling is essential. The ability to rapidly produce a result for the farmer is necessary for practical purposes. The Rapid Laboratory Analysis approach aimed to develop and test a standard protocol for measuring the nutrient content of slurry which could be adopted in all laboratories. IMAG coordinated the work on this development. An advantage of the new method is that only one digestion step is needed to obtain a solution in which total nitrogen, total phosphorus and total potassium can be measured with methods available in most laboratories. A successful ring test was carried out in participating countries to validate the accuracy of the method (Derikx and Beurskens, 1997). Figure 1 gives a schematic presentation of the procedure used.

Sample in the laboratory (0.5-1.0 kg)
↓ Mixing
(dry matter content $\leq$ 150 g/kg)

Subsample (5 g wet weight)
↓ Addition of chemicals
($H_2SO_4/H_2O_2/Cu^{2+}$)

Digestion (3 hours, 330^{o}C)
↓

Dilution (250 ml)

↓ Sedimentation/(Filtration)

Final analysis

- 50 ml nitrogen
- 0.1 ml phosphorus
- 1 ml potassium

Figure 1.
Schematic pathway of the combined determination of N, P and K of manure samples

3.2. In-Line Sensor

The development of an on tanker in-line nutrient sensing system would remove the potential error resulting from the sampling operation from stores when taking slurry samples for analysis as the nutrient content of each tanker load of material could be measured. Another major advantage of the technique is that the results are immediately available for use.

Previous research has shown that correlations exist between the nutrient content of slurries and total solids or bulk density (Piccinni and Bortone, 1991; Tunney and Bertrand, 1989). These approaches have utilised simple physical measurements (e.g. hydrometers) to yield predictions of phosphorus and total nitrogen. In general, these methods are inconvenient for frequent use. The work programme undertaken in the *SWAMP* project and directed by Silsoe Research Institute involved the development of an in-line sensor for slurry using a number commercially available physical and chemical sensors. Initially, a small scale, *in situ* device was constructed and tested on slurries in the UK, Italy, Germany and Ireland. Following analysis of the data a field scale unit was constructed and fitted to a prototype tanker. The unit was tested with a range of cattle and pig slurries in the UK and Ireland. A single card computer was programmed to convert the individual physical and chemical measurements to values of nutrients available in the slurry, which were displayed in the tractor cab. The sensing system was tested with 18 different slurry samples. In each case the slurry was recirculated through the sensing system until stable readings of ammoniacal nitrogen (AN), phosphorus (P) and potassium (K) were recorded. A sample of each slurry was taken for laboratory analysis of AN, P and K. The predicted values from the in-line sensing system were compared with laboratory results.

The sensing system gave a good prediction of the ammoniacal nitrogen for all slurries tested, with a coefficient of determination (r^2) of 0.92. The standard error was 0.38 kg/m^3 in a range of 0.63 to 5.29 kg/m^3 (i.e. < $\pm$ 10%). The results for phosphorus were disappointing (r^2 = 0.44), based on the full set of slurries tested.

However, separate inspection of the results for UK and Irish pig slurries showed a better prediction (r^2 = 0.99 and 0.82, respectively). The standard errors were 0.02 kg/m^3 in a range of 0.24 to 1.73 kg/m^3 (i.e. < $\pm$ 10%) and 0.75 kg/m^3 in a range of 0.09 to 1.77 kg/m^3 (i.e. < $\pm$ 45%), respectively. The predictions for potassium were also encouraging (r^2 = 0.70). The standard error was 0.62 kg/m^3 in a range of 0.81 to 6.49 kg/m^3 (i.e. < $\pm$ 12%) (Scotford et al., 1997).

3.3. MESPRO

MESPRO is a mathematical model for estimating the amount and composition of stored slurry produced by fattening pigs (Aarnink and van Ouwerkerk, 1990; Aarnink et al., 1992). The model was developed for the common situations on Dutch pig farms characterised by storage of slurry under slatted floors in the pig house. The aim of the work in *SWAMP* was to assess the potential use of the model for pig houses in Germany and Italy and thus to see if such an approach would be practical in other areas of Europe. In order for the approach to be successful the MESPRO model was modified. The model output is highly influenced by the input parameters feed intake, water to feed ratio, digestibility of crude protein, digestibility of N-free extract and ambient temperature. Accurate information of these parameters is essential for practical applicability of the model. In some cases it was clear that inaccuracy in the measurement of some parameters had a large effect on the calculated slurry volume and nutrient content. To increase the applicability of MESPRO in such situations it is necessary to use default values for the less essential parameters and limit the number of variables to the essential parameters.

3.4. Balance Approach

A nutrient input/output balance for pig and cattle farms was developed and evaluated. The approach could be used to predict slurry nutrient values in situations where all the parameters required in the complex MESPRO model were not available. The hypothesis proposed for the balance approach to estimate the nutrient value of slurry was:

Nutrients in manure (kg) = nutrients in feed (kg) - nutrient removal in animal product (kg)

$$N_{calc} = N_{input} - N_{removal}$$

The approach was tested by correlating the calculated value (N_{calc}) with the measured value of nutrient content by laboratory analysis.

The results achieved indicated that the balance approach had potential to provide an estimate of the nutrients contained in the manure without having to physically sample and test the material. In general, the approach tended to overestimate the nutrients in the slurry. This is not surprising as N_{calc} is by definition the upper limit for the nutrient concentration in the slurry. In the case of nitrogen there is no provision for known losses (e.g. volatilisation) that occur between excretion and measurement. Consequently, N_{calc} would be expected to be greater than N measured.

4. Development of a prototype application system

A prototype application system was designed and fabricated (Lenehan et al., 1997). The work involved the testing and selection of mechanical components, the fabrication and assembly of the tanker system and the development of a PC based control system. The tanker system uses a hydraulically driven positive displacement pump (Vogelsang) to allow control of application rate. Control is achieved using an electrohydraulic proportional valve (Danfoss) receiving a signal from the control system. A bandspreader is fitted to ensure even lateral application rate is achieved. A prefill mascerator (Vogelsang) is fitted on the inlet port of the tanker to reduce the risk of blockages when applying slurry with the bandspreading device. The in-line nutrient sensing system is mounted on the side of the tanker and is constructed from a 2.84 m length of 0.1 m diameter ABS pipe (Class C). The individual physical and chemical sensors are connected using suitable adapters. An in-cab PC is used as the principle hardware device with appropriate software developed to carry out required operations. A schematic diagram of the Control System Structure (CCS) is shown in Figure 2. The required CSS software is divided into four sections:

(i) <u>CSS 1 - Control software for nutrient measurement</u>
This software is able to accept information on nutrient content either from the in-line nutrient sensor or direct input to the in-cab PC via keyboard/floppy disk.

(ii) <u>CSS 2 - Calculation software to determine required volumetric application rate</u>
This software uses the data from CSS 1 and the ADS/ERA software operating in the farm or advisory office to calculate the required volumetric application rate.

(iii) <u>CSS 3 - Control software for spreading operation</u>
This software uses data from CSS 2, a forward speed sensor and a slurry pump speed sensor to produce a control signal for an electrohydraulic proportional valve to maintain correct slurry pump speed. In addition, CSS 3 functions in parallel with the tanker monitoring system which continuously checks tanker contents and system faults detected by tanker mounted PLC (Programmable Logic Controller). CSS 3 provides information on actual application performance for subsequent processing by the final section of CSS software.

(iv) <u>CSS 4 - Software for data generation for output files</u>
This software processes the data on actual application performance in the field and prepare files which can be transferred by floppy disc to the office PC operating the ADS/ ERA software for record updating.

The computer screen is used in the cab to present continuous information as analogue displays to the operator on slurry pump speed, application rate, forward speed, tanker contents and fault condition indication.

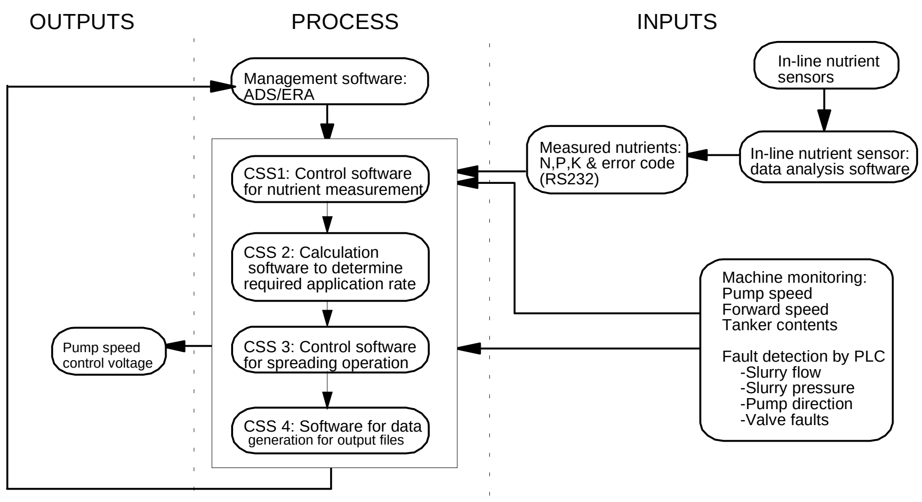

Figure 2
Control System Structure

A field testing program was carried out in Ireland. The results of the testing program showed that with the bandspreader an even distribution could be achieved independent of slurry pump speed. The coefficient of variation (CV) on lateral achieved varied from 9 to 14%. The CV obtained for longitudinal distribution was less than 10%. The results are in good agreement with earlier research carried out by Huijsmans and Hendrikz (1992).

5. Conclusions

The *SWAMP* project provides the framework for an integrated slurry management system. It attempts to draw together a number of approaches. The concepts of Environmental Risk Assessment (ERA) and Application Decision Support (ADS) were introduced and developed. A number of methods for the rapid provision of information on nutrient content of slurries in a practical way which can be used by the farmer were examined and tested. A full scale prototype and associated control technologies has been designed and fabricated to achieve the goals of accurate application of precise quantities of slurry nutrients while minimising pollution risks.

6. References

Aarnink, A.J.A. and van Ouwerkerk, E.N.J. (1990). Model voor het berekenen van het volume en de samen stelling van vleezvarkansmest (MESPRO) IMAG-DLO, Wageningen, Rapport 229, 58 pp.

Aarnink, A.J.A., van Ouwerkerk, E.N.J. and Verstegen, M.A.W. (1992). A mathematical model for estimating the amount and composition of slurry from fattening pigs. Livestock Production Science, 31 (1992), 133-147.

Burton, C.H., Beck J., Bloxham P.F., Derikx P.J.L., Martinez J., (eds) (1997). « Manure management - treatment strategies for sustainable agriculture ». Silsoe Research Institute, Wrest Park, Silsoe Bedford, UK. 181 p.

Carlson, G. (1994). Nutrient utilisation of slurry by using different application strategies and techniques. Animal Waste Management Proceedings of 7th Technical Consultation of the ESCORENA Network on Animal Waste Management, J.E. Hall, ed.; Bad Zwischenahn, Germany, 17-20 May 1994, pp. 171-181.

Derikx, P.J.L. and Beurskens, A.G.C. (1997). Analysis of manure composition by means of rapid lab method, a ring test IMAG-nota, p 9718, Wageningen, 22 pp.

Eckersten, H., Jansson, P-E and Johnsson, H. (1996). The SOIL N model User's Manual. Department of Soil Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Fluck, R.C. and Baird, C.D. (1980). Agricultural Energetics, AVI Publishing Company, INC, Westport, Connecticut.

Huijsmans, and Hendriks, J.G.L. (1992). Slurry distribution of spreader and injectors. In Proceedings of International Conference on Agricultural Engineering, Swedish Institute of Agricultural Engineering, Uppsala, Sweden, p 622-623.

Jansson, P-E (1996). Simulation model for soil water and heat conditions. Report 165, Department of Soil Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden, 82 pp.

Lenehan, J.J., Keppel, D., Carton, O.T., Cumby, T., Scotford, Huijsmans, J. and Perros, J. (1997). Development of *SWAMP* prototype slurry spreader. In Proceedings of 23rd Irish Grassland and Animal Production Association Research Meeting, University College Dublin, April 1997.

Lewis, D.R. and McGechan, M.B. (1998). Watercourse pollution due to surface run-off following slurry spreading PART 1, Calibration of the soil water simulation model SOIL for fields prone to surface runoff. Journal of Agricultural Engineering Research 72, (3), 275-291.

McGechan, M.B., Graham, R., Vinten, A.J.A., Douglas, J.T., and Hooda, P.S. (1997). Parameter selection and testing the soil water model SOIL. Journal of Hydrology, 195, 312-344.

O'Bric, C., Carton, O.T., O'Toole, P., Cuddihy, A. and Lenehan, J.J. (1992). Nutrient values of cattle and pig slurries on Irish farms and the implications for slurry application rates. Irish Journal of Agricultural and Food Research, Volume 31, No. 1 pp. 89-90.

Pain, B. (1989). Atmospheric pollution from slurry. In: Proceedings of slurry and sludge management meeting. IGAP Hurley, Chalcombe Publications UK.

Piccinini, S. and Bortone, G. (1991). The fertiliser value of agricultural manure: simple rapid methods of assessment. Journal of Agricultural Engineering Research, 1991, 49: 197-208.

Scotford, I.M., Cumby, T.R., Richards, P.A., Keppel, D., Lenehan, J.J. (1998). Development of an in-line nutrient sensing system for livestock slurries (submitted). Abstract for publication in proceedings of AgEng 98 Conference, Oslo, Norway.

Tunney, H. and Bertrand, M. (1989). Rapid field tests for estimating dry matter and fertiliser value of animal slurries. In: Proceedings of CIGR, 11th International Congress on Agricultural Engineering, September 1989, Dublin. Balkema, Rotterdam, ISBN 90 6191 9762.

Tunney, H., Breeuwsma, A., Withers, P.J.A. and Ehlert, P.A.I. (1997). Phosphorus fertiliser strategies: Present and Future. In: Proceedings of International Workshop, Teagasc, Johnstown Castle, Ireland, Phosphorus Loss from Soil to Water, CAB International, UK ISBN 085199 1564.

Wu, L., McGechan, M.B., Lewis, D.R., Hooda, P.S. and Vinten, A.J.A. (1998). Parameter selection and testing the soil nitrogen dynamics model SOILN. Soil Use and Management (in press).

Wu, L. and McGechan, M.B. (1998). Simulation of biomass, carbon and nitrogen accumulation in grass to link with a soil nitrogen dynamics model. Grass and Forage Science (in press).