OPTIMAL USE OF ANIMAL SLURRIES FOR INPUT REDUCTION AND PROTECTION OF THE ENVIRONMENT IN SUSTAINABLE AGRICULTURAL SYSTEMS

END OF PROJECT REPORT

ARMIS 4168

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SUMMARY

The objectives of manure management in sustainable agricultural systems are to optimise nutrient recovery by the crop and to reduce nutrient losses to the environment. However, farmers still have many practical problems in adopting and applying the research developed for improving manure management strategies. This project identified and addressed three of these problems. These concerned the provision of decision support in relation to environmental risk assessment and application decision strategies; determining the nutrient value of slurry and the development of manure application technology.

The mechanisms and processes by which nutrients are lost following application of organic and mineral fertiliser causing pollution of surface and ground-water are complex. In order to provide an assessment of the environmental risk in terms of nutrient losses from a field, a physically-based computer modelling approach linking several component models was developed and applied in this work. Model simulations were shown to reproduce well the available measured pollution data, provided that a large number of model parameters are also measured or estimated. The output from this systems modelling approach was a series of tables which identify the relative nutrient losses through surface runoff and drainage and the total field loss, for several soil and crop types, climatic conditions, and a large number of nutrient management options. Due to the significant information requirement for this approach, it is advisable that simpler methodologies whereby pollution risks can be ascertained should be incorporated in future efforts.

Decision support software was developed to aid farmers plan the application of slurry and inorganic nutrients. Application strategies can be chosen to minimise the environmental losses for a given nutrient requirement. The software developed is a tool able to perform the following support operations - plan the manure spreading operation based on crop nutrient requirements and the availability of spreading equipment; record slurry spreading events and dynamically adjust the spreading plan during the year; transfer data to and from the spreading control system on the tanker to programme and record

the spreading events; and graphically display the results to the farmer. The software was tested and the simulation exercises demonstrated that its use can both achieve reductions in pollution potential and assist in improving manure management practices on the farm. However, the framework for decision support in relation to slurry applications requires further development for field application.

The project has resulted in the adoption of slurry analysis techniques developed in the Netherlands that improve both the accuracy and the speed of the analysis. The development of a Dutch model to predict the volume and nutrient concentration of manure from fattening pigs for application in other countries requires further work if it is to be successfully adopted in other European countries. The use of an input/output balance model did not provide a reliable means of estimating slurry nutrient value. Both model approaches highlighted difficulties associated with the accurate collection of the farm input data required. Equally, the difficulties associated with taking representative slurry samples from manure storage systems was emphasised.

An In-line nutrient sensing system, to determine the nutrient value of slurry was developed for use on the slurry tanker. The approach offered the advantage of determining, in real time, the nutrient value of the slurry on a per tanker basis and avoids problems associated with sampling. The accuracy of the In-line nutrient sensing system depended very much on its calibration. Therefore, country/area/site specific calibrations may be required. Its ability to estimate the nutrient value of the slurry varied depending on which of the three nutrients (ammonical nitrogen, phosphorus or potassium) were being predicted. The development of the In-line sensor represents significant progress in terms of providing the farmer with tactical information on the slurry nutrient value. Its importance is heightened in the context of links established between the output of the sensor and the application control system on the tanker.

The prototype slurry tanker which was developed provided a platform for practically testing a control system developed (hardware + software), the In-line nutrient sensor and the performance of the complete system in applying slurry nutrients evenly both laterally and longitudinally. The necessity for using a pre-fill chopping/filtering system when using low trajectory type distributors (bandspreader) was demonstrated. The ability of a positive displacement pump fitted with automatic speed control to match changes in forward speed and give an even application rate in the field was demonstrated. The control software developed has the benefit of two-way information exchange via a floppy disc with the farm or adviser's office.

The application of this research at farm level will happen over time. Already, aspects such as the improved procedures for the analysis of slurry have been applied at the Johnstown Castle Laboratories. An improved system for sub sampling the slurry has resulted in more repeatable slurry analysis. Research is continuing to develop simpler methods of providing farmers with indicators of the suitability of land for slurry spreading so that nutrient losses in runoff can be minimised. Many of the innovative features of the prototype slurry tanker will become standards on the newer machines in the next five years. The use of positive displacement pumps combined with pre-fill chopper/filtering systems on Irish low emission spreading systems is now an option available. The project links with machinery manufacturers (Abbey Farm Machinery) was an important factor in the technology transfer for immediate application by the industry.

INTRODUCTION

The objectives of manure management are to optimise nutrient recovery by the crop and to reduce nutrient losses to the environment. Manure research over the last three decades has concentrated on providing the necessary systems and information for farmers to achieve these objectives. However, they still have many practical problems in adopting and applying the research developed for improving manure management strategies. The project work concentrated on slurry or liquid manure rather than solid manure as it is the main form generated on intensive European farms.

This project identified and addressed three of these problems. These were (i) decision support in relation to environmental risk assessment and application decision strategies; (ii) efficiently providing information on the nutrient value of slurry and (iii) the development of prototype application system (Figure 1).

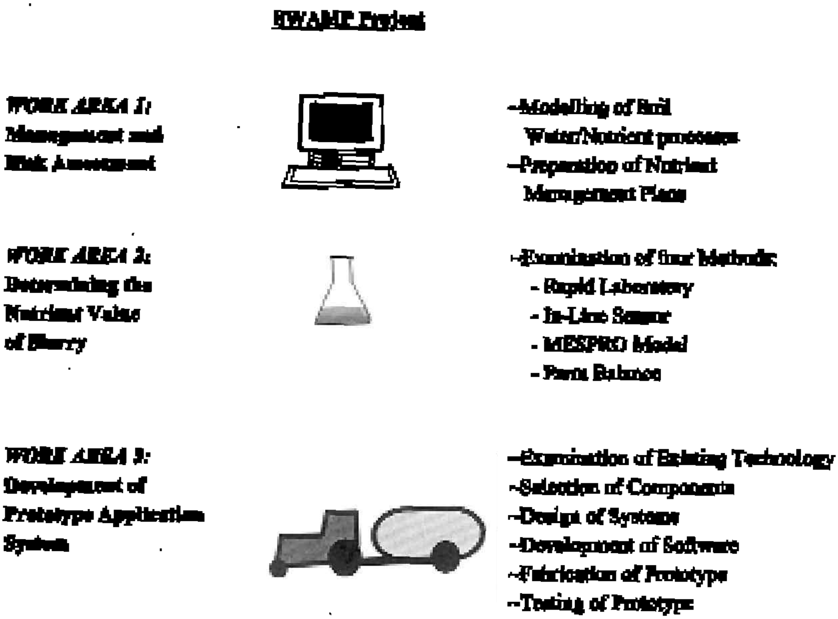

Figure 1. Schematic diagram of project work.

Management and Risk Assessment: The sustainable land application of animal manure requires the farmer to make decisions on the date, rate and method of application. These decisions are both strategic and tactical with agronomic and environmental dimensions. The process is complicated because individual decisions are not independent. Therefore, there was a need to define and develop a framework for a support system that will assist the farmer in the decision making process.

> A project objective was to develop and exploit models to quantify the environment risk associAted with the land spreading of slurry and to develop software to improve decision support in relation to the timing and selection of slurry management so as to reduce pollution potential.

Determining the Nutrient Value of Slurry: Considerable between farm variability in slurry nutrient content exists. This arises from a number of variables including differences in animal types, feeding regimes and storage conditions. The nutrient value of slurry is a prerequisite for determining the agronomically and environmentally appropriate application rate. The information is required at the time of spreading. However, there are difficulties for the farmer in quickly and reliably assessing the nutrient value of slurry. These are primarily associated with the often unpredictable (i.e. weather and soil dependent) occurrence of suitable spreading windows and the requirement to agitate the slurry prior to sampling for nutrient analysis. Rapid on-farm methods of providing an estimate of the nutrient value of slurry have been developed and evaluated. However, they apply to particular nutrient constituents and require, in some cases, a degree of operator skill to ensure reasonable estimates are obtained.

> A project objective was to provide practical methods for the farmer to rapidly determine the slurry nutrient value.

Development of Prototype Application System: Currently, the vacuum tanker and splash method of application is the most commonly used method for the land spreading of slurry in Europe. It is a relatively low cost system and is operationally efficient from the farmer's perspective.

However, the splash plate system has environmental and agronomic deficiencies. The slurry is often applied unevenly and little attention is given to achieving target application rates.

A project objective was to design, construct and evaluate a field scale prototype slurry spreader that would apply slurry at specified nutrient rates; apply slurry evenly both laterally and longitudinally and be operationally efficient and practical.

The project work, funded by the EU, was undertaken by seven contracting groups from Ireland, England, Germany, The Netherlands, Italy, Greece and Scotland. The work was divided into the three Task areas noted above. Within each Task there was a further subdivision of the work into Actions. Responsibility for the work within the Actions reflected the expertise of the participating groups.

METHODS

Management and Risk Assessment:.

A twin, interrelated, approach based on two modules was adopted for the development of the management and risk assessment task (Figure 2). These were the Environmental Risk Assessment (ERA) and the Application Decision Support (ADS) modules.

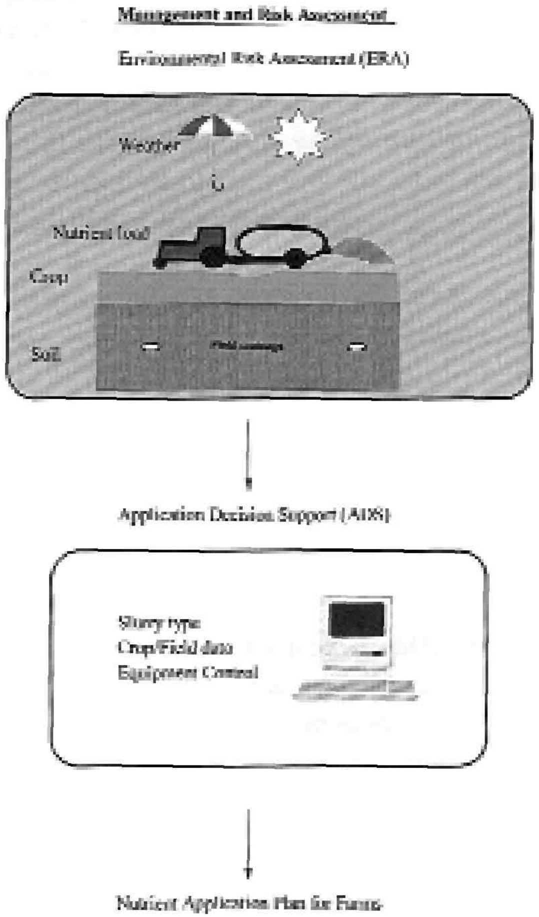

Figure 2. Schematic structure of management and risk assessment work areas.

Environmental Risk Assessment (ERA): Existing weather driven models were evaluated in terms of their ability to simulate the mechanisms and processes which result in nutrient losses causing pollution and further developed to calculate an environmental risk assessment. The Swedish water model SOIL was selected. This multi-layer model, appeared to have the most comprehensive treatment of processes under wet soil conditions and soil heat processes. SOIL could be set up to readily carry out simulations over a long run of years and most importantly of all included representation of macropore flow. The model was adapted to represent circumstances when surface runoff was associated with high water tables. The transport and transformation of nutrients through surface runoff was considered in a new dynamic model of slurry infiltration. This was required to estimate the probability of runoff following slurry application at high risk sites. A simple method of estimating probabilities of runoff due to high intensity rainfall during the critical periods after slurry spreading was employed for an Italian site which was prone to infiltration excess runoff.

The sites selected for the model output validation exercises had a wide range of drainage characteristics i.e. ranging from very poorly drained to efficiently drained systems. Soil input data required by the selected model for two Irish sites (grassland) and five Scottish sites (two grassland and three tillage) were assembled. Runoff monitoring systems were installed at the two Irish sites. Drain flow quantities and nitrate concentrations were measured on four of the Scottish sites. Surface runoff measurement equipment was installed on one of these sites towards the end of project as little or no runoff was observed on three of the sites. Water table depth was measured using a dip well at two sites.

Weather databases for two Scottish, two Irish and one Italian site, required by SOIL (rainfall, mean temperature, vapour pressure wind speed and net radiation) were assembled.

The surface runoff model was calibrated using where possible measured soil hydraulic parameters or otherwise literature values. The combined SOIL and drainage model were validated using time series data. A sensitivity analysis of the relevant drainage parameters was undertaken which identified the key model parameters and the potential problems of badly drained fields.

The soil solute nitrogen (N) dynamic model used was SOILN since the choice had been made to use SOIL as the water model. It has a mechanistic weather driven sub-model representing crop growth. Work on SOILN was required to modify it for grass and grass clover swards as it is designed to represent a cereal crop. The same approach as adopted for SOIL was also followed for SOILN i.e. further development and then calibration of the model using one set of data, then testing or validating using an independent data set.

These models along with ten years climate data were used to make a statistical assessment of the weekly potential for runoff to occur for three soil types, three crops, three climatic conditions and two spreading methods giving a total of 2808 options. The models were further used to assess the annual drainflow losses and total N losses for three soils types, three crop types, three climatic conditions, three slurry application rates, three fertiliser N application rates, two slurry spreading methods, ten slurry spreading dates and two fertiliser spreading dates giving 9720 scenarios. The application decision support software (ADS) has incorporated the results of the ERA output so that nutrient management plans can be prepared for whole farm systems where slurry is applied to fields.

Application Decision Support (ADS): The ADS software was developed to assist a farmer or nutrient planner/adviser in the development of a farm manure management strategy. The ADS structure has three main elements, farm nutrient balance, strategic field-by-field scheduling of manure spreading and tactical field spreading decisions.

The first requirement of the ADS software was to establish the farm nutrient balance. The following steps were adopted to achieve this. A simple direct approach was adopted to calculate the volume and characteristics of the manure produced on the farm. The volumes of water entering the storage facility are considered. ADS considers the storage system (in terms of N loss due to volatilisation) and any treatment (e.g. separation) and their implications for the manure's nutrient concentration at spreading time. The import or export of manure must be considered in establishing the nutrient balance of the farm. Default values for the nutrient concentration of manure are used in ADS. However, where the results of manure analysis are available they should be entered. Crop nutrient requirement are determined by soil fertility levels and the target yields.

The strategic ADS output required is the field-by-field recommendation on the quantities of organic (manure) and inorganic fertiliser to be applied for each crop. The strategic aspects of the farm nutrient balance must consider the spreading windows for the manure, the type of spreading systems available and any legal restrictions on spreading. This required the development of data tables with the spreading windows defined for each crop and spreading system. The timing of the spreading windows had to consider the risk assessment tables output from the ERA module. Naturally, the input data required to establish the nutrient balance is country specific to take account of differences in animal production systems, crop production and climate.

The strategic field-by-field manure management advice must be capable of taking account of tactical adjustments for the day-to-day changes in weather and management. The tactical field-by-field scheduling requires the following information: work capacity of spreading equipment and availability of spreading days. The day-to-day allocation should be prioritised, i.e. priority is given to the field with least available days to ensure completion within the available time frame. The output should ensure that the manure spreading is achieved within the constraints established. If not, the inputs should be capable of change and the process repeated until the requirements and resources are matched. It should also possible to check on the compatibility of the tactical plan with the manure storage capacities required.

A simulation was performed to evaluate the ADS software. The basis was a comparison of the actual farm management practice with those developed using the ADS software. Practical farm data was collected for 10 Italian and 3 Irish farms. The recorded farm management practices were inputted to ADS to evaluate current practices and these were compared to the ADS recommendations.

A GIS system was selected for the interface with the farmer as the most practical way to present numerically and graphically the ADS output. The software was evaluated from the geographical perspective. A set of maps was prepared for the farms used for the ADS databases and evaluation. The maps were digitized and prepared in PCARCINFO format. These were incorporated into the ADS software package in order to establish an interactive link between the maps and the farm data.

Determining the Nutrient Value of Slurry

Two measurement approaches, Rapid Laboratory (Rapid Lab) and In-situ/In-line nutrient sensor, and two modelling approaches, MESPRO and an input/output balance model, were researched.

Rapid Lab: The potential of the IMAG-DLO Rapid Lab approach for slurry analysis was evaluated in Irish and German laboratories. Staff from participating laboratories were trained in the approach by IMAG-DLO. The Dutch laboratory prepared six manure samples for a ring test at the two laboratories and the results were returned for analysis. The German and Irish laboratories collected forty manure samples in their respective countries and analysed them by both the Rapid Lab method and the method conventionally used. The results were sent to IMAG-DLO for analysis.

In-situ/In-line nutrient sensor: Data relating nutrient contents of slurry to physical properties were reviewed and assessed. Based on this a specification was compiled for a prototype In-situ nutrient sensing system comprising a number of separate sensors for determining physical/chemical properties of slurries. The physical sensors included an In-line twin tube vibrating density meter, an ultrasonic total solid meter, a flow meter, and a differential pressure transducer. The chemical sensors included devices to measure redox potential, pH, temperature, electrical conductivity and ammonium ion concentration. Existing commercial sensors were acquired to measure the specified physical and chemical properties, and assembled into a functional unit. The sensors were connected via a data logger to a portable PC. Appropriate software was developed to enable data to be displayed in real time and to control data collection from the keyboard. The In-situ nutrient sensing system was tested in the UK using forty-one slurry samples. The quantitative relationships developed from the analysis of the resulting data were converted into computer algorithms and programmed into the portable PC incorporated in the In-situ nutrient sensing system. Subsequently, the In-situ sensing system was tested in Ireland, Germany and Italy on approximately forty slurries in each country. The data from the In-situ nutrient sensing system international trials were analysed to determine the statistical significance of the relationships. Based on these results the necessary sensors for inclusion in the prototype In-line nutrient sensing system were identified, and the appropriate data conversion algorithms were defined.

A full specification of the In-line nutrient sensing system was prepared and a prototype device was constructed and tested prior to installation on the prototype spreader. After installation on the prototype tanker, the In-line nutrient sensing system was evaluated using a further thirteen slurries.

MESPRO: A dynamic version of the Dutch MESPRO model to calculate slurry volume and composition for fattening pigs was used in the study. A schematic representation is shown in Figure 3. German and Italian participants each selected a number of pig farms based on an agreed set of selection criteria. Data on the number of animals, feed inputs, water consumption and usage, slurry production, wet floor area, temperature of stored slurry and of the house were collected. Slurry production was measured and samples taken for analysis. MESPRO was modified to accommodate the regional differences in the pig production systems identified. The modified MESPRO output for these units was compared with the measured values.

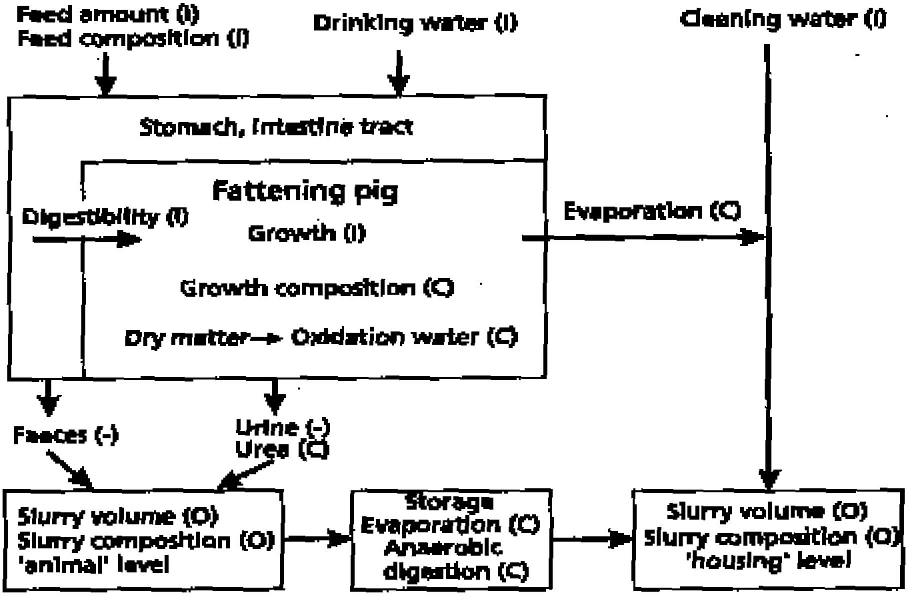

Figure 3. Schematic representation of MESPRO model for estimating the volume and composition of slurry from fattening pigs. (I = input data; C = calculation; O = output data).

Balance model: An input/output nutrient balance model as a means of providing an estimate of slurry nutrient value was researched. The balance estimate was determined by subtracting the nutrient output in animal product from the nutrient input. The value of the balance model as a predictive method for estimating the nutrient value of the slurry was evaluated by correlating the balance model estimate of the nutrient concentration in slurry with the measured slurry nutrient concentrations in trials involving fifteen German pig farms, eight Irish pig units, eleven German dairy farms and eleven Irish dairy and cattle farms. The data collected on the farms included, feed and animal inputs, animal production data and measured slurry production and concentration. Published values for the nutrient concentration of animal product (milk or meat) were used.

Developing a Prototype Application System

Research was undertaken on the development of a prototype application system (Figure 4). This involved an assessment and selection of blockage prevention systems; machine design and fabrication; development of application control software and finally the testing the operational efficiency of the prototype.

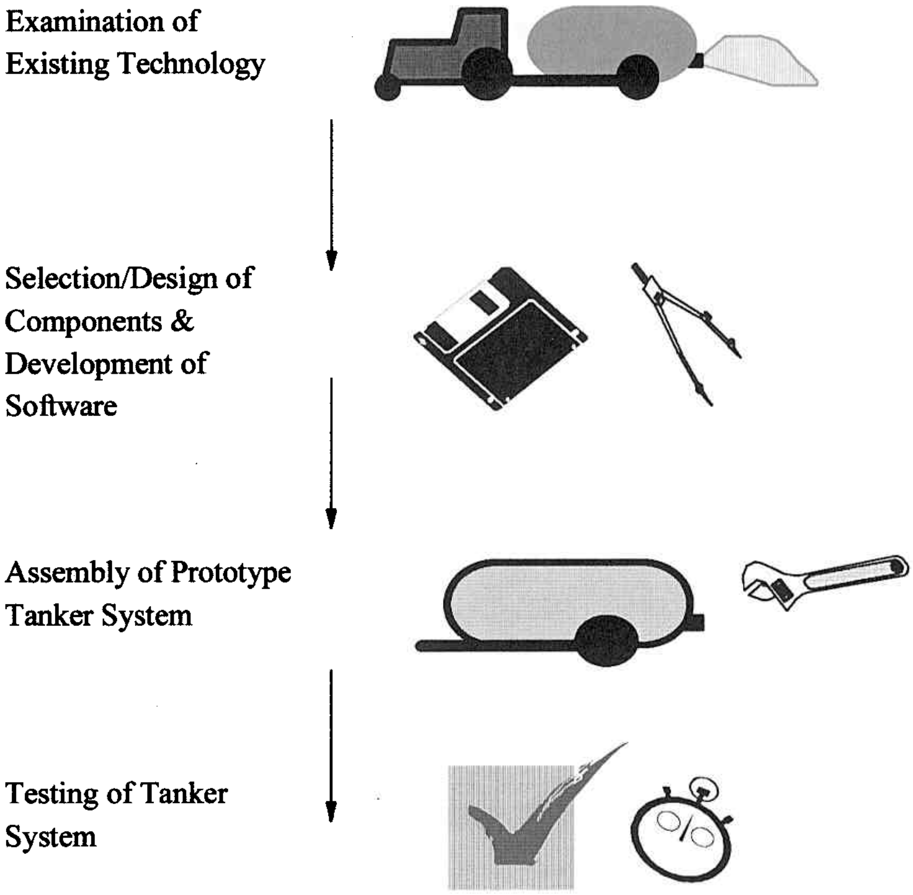

Figure 4. Schematic diagram of work on prototype development.

Blockage prevention: There were two phases of this work which was conducted in The Netherlands. The first involved a survey of 33 slurry contractors who have at least five years practical experience with slurry spreading systems. Two of these contractors kept records on blockages experienced during the study.

Three types of chopping/filtering systems were then selected for testing. These involved measurement of the capacity loss experienced while filling a tank load; examining the chopping/filtering efficiency when stones, pieces of different sized wood, plastic and straw were added to slurry; and their efficiency when a mixture of liquid and solid manure was used.

Design and fabrication of machine system: The prototype was based on a 7.2 m3 cylindrical tank mounted on a mono-beam chassis unit. An hydraulically driven positive displacement pump was selected. The distribution system selected was a bandspreader fitted with a mascerator. In addition, a pre-fill mascerator was selected for fitting on the inlet side of the pump.

A PTO powered independent hydraulic system was selected for the unit. The slurry pump is driven by an hydraulic motor and controlled with an electrohydraulic proportional valve. Forward speed is measured by proprietary tractor mounted radar sensor and the control system is designed to maintain consistent application rate independently of forward speed.

Control system software was developed to manage the required control functions on the tanker. Central to this system was a tractor mounted PC which provided the platform for the machine control functions in conjunction with the programmable logic controller (PLC).

A number of monitoring devices were required to facilitate control operations. These included in addition to forward speed measurements, a slurry level sensor; slurry flow sensors, slurry valve position sensors, rotation sensors on the pump, mascerator. A schematic diagram of the control system structure is shown in Figure 5.

Prototype testing: The operational efficiency of the prototype was evaluated in a series of static and dynamic tests. Pump performance and application rate was assessed by operating the pump at set speeds over recorded time intervals while transferring either water or cattle slurry to a bowser tank mounted on load cells. The evenness of slurry application, both laterally and longitudinally, achieved by the prototype while applying slurry in the field was assessed at specific pump speeds ranging from 200 to 600 rpm. The method used was to fix napkins on aluminium frames and collect the slurry as the machine transversed the frames. For lateral distribution assessment, the output from each outlet was measured. For longitudinal distribution the outlets 8 and 15 were selected at random and the output from these outlets was assessed. After spreading the napkins were collected individually and weighed. The response performance of the pump system was assessed by recording the effect of changing forward speed on pump speed. The start up response of the pump was also assessed by recording speeds during start up events for two target forward speeds. The pump speed and forward speed were simultaneously measured and compared.

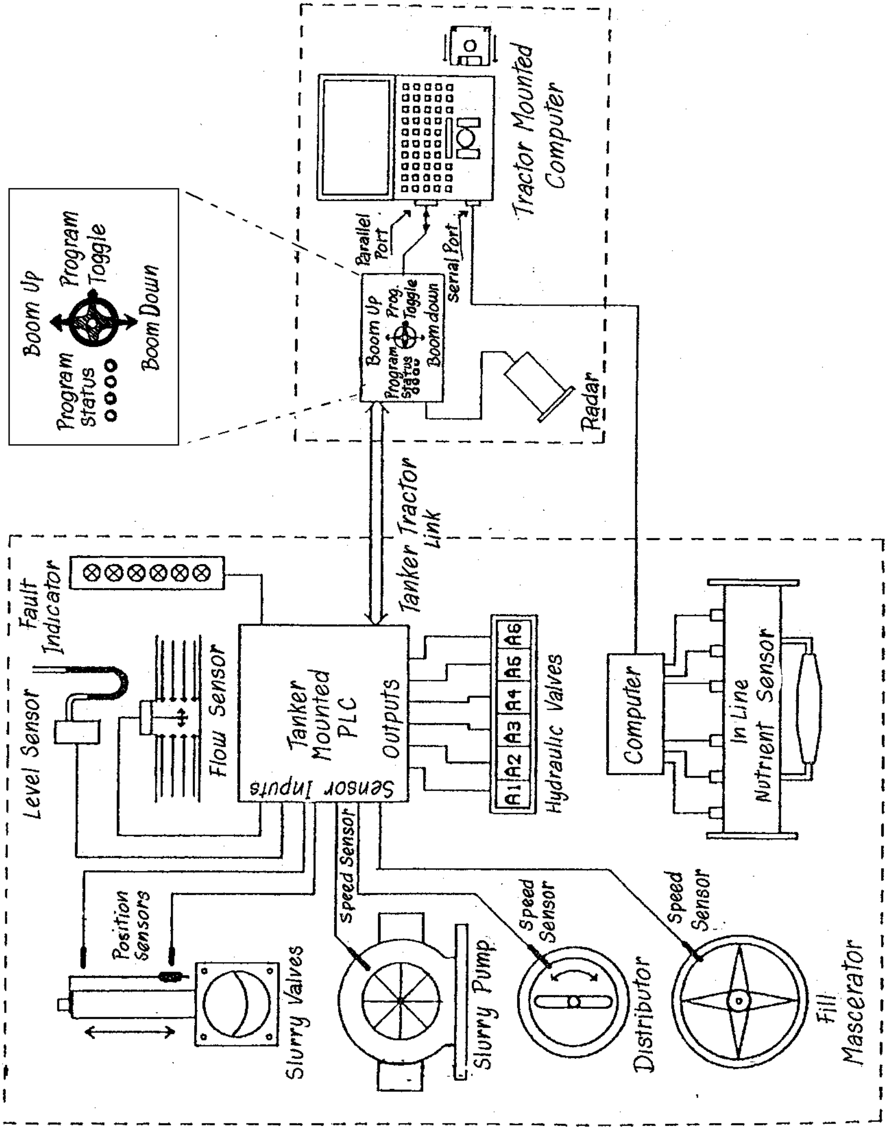

Figure 5. Schematic diagram of control system structure.

RESULTS

Management and Risk Assessment

Environmental Risk Assessment - Runoff: Simulations were conducted using data for six soil profiles and three weather data sets (East and West coast Scotland and Southern Ireland[1]). These were validated against field measurements of runoff from the two Irish sites.

The results indicated that decisions about the suitability of fields for slurry spreading were more important than the timing of spreading in terms reducing the probability of runoff. It is suggested that fields can be categorised as follows regarding surface runoff:

- Totally unsuitable for slurry spreading, runoff pollution risk unacceptably high in both summer and winter, or unsuitable because of proximity to open watercourses, water sources, houses etc., liable to flood, or newly drained, moled, subsoiled or cracked (Category 1).
- Totally unsuitable for slurry spreading in winter but acceptable risk in summer. A clear weather window (the summer, e.g. April - September) can be defined at the strategic planning stage. During this weather window, spreading days need to be selected according to the criterion to keep pollution risk from runoff at an acceptable level (Category 2).
- Suitable for spreading in summer and winter, but spreading days need to be selected according to the criterion in winter to keep pollution risk from runoff at an acceptable level. This applies to soils/sites with a fairly narrow range of profile conductivity, about 5 - 10 mm/day (Category 3).
- Suitable in summer and winter, only very occasional (and randomly/unpredictably occurring) runoff, pollution at acceptable level if slurry spread any day, but pollution risk reduced very slightly if spreading days selected according to criterion (Category 4).

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[1] The climate of the East of Scotland is generally dryer and cooler (by 0.7˚C annually) than that of the West of Scotland, with a greater marked variation in monthly rainfall patterns for the Western climate resulting in a higher annual rainfall total, and with a slightly longer daily sunshine. Comparing the Irish climate data set with the West of Scotland, shows that annual rainfall is slightly less for the Irish data set, but with the Irish temperatures being approxamimately 1.2˚C higher over the year.

- Surface runoff never occurs, so slurry can be spread at any time without causing runoff pollution (Category 5).

For fields suitable for spreading in summer but not winter (Category 2), the timing decision concerns both selection of the weather window, in this case April - September, and selection of days with suitable conditions within this window. The most complex timing decision concerns fields in Category 3. In this case, careful selection of spreading days in winter is important to avoid runoff pollution. It was interesting to find that the inclusion of a weather forecast condition in the spreading day selection criterion is of very small benefit in terms of reducing risk. The same decision about selecting spreading days can be applied to fields in Category 4, but the benefit in reducing pollution is very small. There are no relevant timing decisions regarding fields in Categories 1 or 5.

Environmental Risk Assessment - Leaching: Simulations were carried out using 12 years of climate data with identical applications in each year. The 360 management scenarios consisted of three possible slurry applications with 10 spreading dates (involving single and split applications) for both surface spreading and injection, and three possible fertiliser applications with two spreading dates. The effects of the N management scenarios on nitrate drainage flows, total gaseous N losses and crop yields for grass, winter and spring cereals was investigated. Furthermore, seven soils with varying degrees of drainage efficiency and three climatic conditions were studied. The objective was to produce N budget tables for ADS which deals with best management practices for N fertiliser and slurry applications.

The results indicated that an effective environmental risk assessment of N losses from a field can be made using physically-based models. They also suggested that the most important decision about slurry spreading concerns the selection of spreading date and the selection of fields which are likely to produce only moderate leaching effects.

Strategic decisions can be based upon the results of these simulations, provided that in practice a farm manager can recognise and match the actual soil type and drainage condition of the fields on which spreading is to occur with the simulated field types. In future, further field types will be added to the simulation data-set, increasing the available choice.

A problem of transportability of calibrated models between countries was identified, since surface runoff takes two forms, saturation (high water table) runoff being of greater importance in Northern Europe, whereas infiltration (Horton) runoff is the typical form which is relevant in Southern Europe (runoff following intense rainfall events). The detailed analysis of runoff pollution risks using the SOIL model was carried out for saturation runoff in Northern Europe, but a simple method based on analysis of storm events at an Italian site was also devised for estimating pollution risks from infiltration runoff in Southern Europe.

The physically-based simulation model SOILN combined with a volatilisation model, was calibrated and validated for several soil types and crops. Using this calibrated version, nitrate leaching from the seven field sites previously mentioned, for grass, spring and winter cereal crops, and for three climatic areas, was determined. Since results are given for all combinations of soils, crops and climates, the transportability of the model results required discussion. This issue was addressed by a sensitivity analysis which identified that leaching is most sensitive to the hydrologic pathways, and less so to the crop N uptake and soil C/N cycling parameters for a well fertilised field. On this basis, the calibrated model is considered to be transportable in terms of application to different crops and climates, provided that the hydrological characteristics of a field are correctly represented.

Application Decision Support (ADS): The ADS software was developed. It provides decision support to the user in terms of

- calculation of quantities of manure available and its nutrient concentration,
- nutrient advice on the manure quantities to be applied for the crop(s) in each field at each spreading event.
- balances the quantities of available manure and total manure to be spread,
- summarises the inorganic fertiliser needs for each field,

- allocate farm resources and prioritise fields for manure spreading and if required, reschedule spreading events after each spreading,
- evaluates farm manure storage capacity.

The ADS software has data entry and viewing facilities guided by a series of menus. When the user selects a particular farm they are presented with nine options including farm profile; manure sources; dilution of manure; treatment/storage; interchange of manure; manure - nutrient amounts; field data; spreading equipment and spreading options. Each time the user selects, by highlighting the required option, the window changes to the respective topic. The options are in a logical sequence but they are accessible to the user all the time.

The result of the ADS consultation, based on the input data provided, are presented in five summaries.

The first contains the field by field nutrient advice or recommendation for each crop, based on a specific spreading method and window. An indication of the percentage of the available liquid and solid manures applied to each field is provided. The calculated data on the manure nutrients applied to each field is given. These can be modified by the user and the programme will automatically update the system.

The second result screen highlights any manure surpluses or deficits following manure allocation to the field. The programme can automatically adjust the manure allocations to achieve a better balance between the quantities available and allocated.

The third screen presents the user with advice on the spreading dates, rates and methods of application on a field by field basis. It also provides the data on the quantities of "top up" fertiliser to be applied and the total (manure and fertiliser nutrients).

The fourth screen provides tactical spreading information for the farmer i.e. when reviewing whether or not to spread manure in the coming week. It includes data on the allocation of farm resources (spreading equipment) to spreading events. The allocation of farm resources is prioritised on the basis of urgency, *i.e.* priority is given to the field with the fewest days left for completing the spreading within the specified spreading windows.

The user is also presented with data on the probability of runoff risk following spreading during that particular week. Warning messages are given if there is not enough time to complete spreading within the programmed time.

The final results screen provides a summary of the information that is to be exported (on disk) to the tanker application control system.

A GIS module was developed to display spatial data as maps. The map windows are divided in two areas: the data area - displaying the spatial data and the legend area - displaying information about the semantics of the displayed data.

The effectiveness of the ADS to reduce nitrate leaching risk was evaluated. Actual farm practice was compared with that recommended by ADS software for ten Italian and three Irish example farms (Tables 1 and 2).

The N leaching losses and total N losses on the Italian farms can be reduced by 10 and 13%, respectively, if the farmers adopted the ADS recommendations over current practice. The potential for reducing N losses on the Irish farms appears limited. The probably reflects crop type, soils and weather differences. However, total N losses can be reduced through improved manure management.

Table 1 Comparison of leaching and total N losses based on current farm practice and ADS recommendations for 10 Italian farms.

Farm	Farm area (ha)	Current farm practice		ADS Recommendation	
		N leached (kg)	Total N losses (kg)	N leached (kg)	Total N losses (kg)
Sudati	51	4451	5152	3194	3706
Asti	20	668	778	655	730
Andena	28	2208	2559	2146	2360
Bonandrini	38	2526	2928	2455	2700
Bossi emilia	114	8868	10263	7718	8781
Peviani e Rizzi	48	1449	1660	1426	1637
Danelli Antonio	48	3526	4091	3215	3778
Boselli	44	3590	4171	3308	3822
Barbaglio	72	5160	6004	4890	5461
Baronchelli	29	1243	1431	1210	1375

Table 2 Comparison of leaching and total N losses based on current farm practice and ADS recommendations for 3 Irish farms.

Farm	Farm area (ha)	Current farm practice		ADS Recommendation	
		N leached (kg)	Total N losses (kg)	N leached (kg)	Total N losses (kg)
O'Leary	38	177	762	174	681
Corcoran	59	253	1254	245	1000
Murphy	54	247	1118	242	960

Determining the Nutrient Value of Slurry

Rapid Lab: The manure (2 cattle, 2 pig and 2 poultry) used in the ring test was prepared by IMAG-DLO and tested for homogeneity prior to dispatch to the Teagasc and German laboratories. Both participating laboratories received a sample of each batch of manure. These were analysed for total N, P and K using the Rapid Lab method. The results were returned to IMAG for analysis which indicated that the techniques was successfully adopted by both laboratories.

The next stage of this process involved a comparison between the Rapid Lab method and the conventional analysis procedures at the German and Irish laboratories using local cattle, pig and broiler manure samples. 1 The difference between the mean values of both methods for Teagasc is shown in Tables 3 by d, where s.e. represents the standard error belonging to the difference d. A t-test was used to determine the significance, if any, between both methods. Lack of significance in the test used indicates both methods giving were producing the same result.

Table 3 The systematic error between Rapid Lab analysis and conventional or own analysis of N, P, and K in pig, cattle and poultry manure at Teagasc, Ireland.

	Pigs			Cattle		
	d	s.e. g/kg	t (109)	d	s.e g/kg	t (104)
N	-0.327	0.107	3.05*	-0.068	0.080	0.86
P	-0.126	0.045	2.80*	-0.030	0.022	1.35
K	-0.165	0.053	3.13*	-0.071	0.065	1.10

*Indicates exceeding critical value of t (P=0.05)

In-situ/In-line Sensor: The principal requirement was for a system to sense/measure variations in composition and changes in concentration caused by dilution in order to achieve greater accuracy in the land application of plant nutrients in slurries. Techniques which have been tried in the past include measurements of density and electrical conductivity (EC) and of total solids (TS) by oven-drying of samples. The potential of using EC as a means of estimating N and K content was established. The relationship between specific gravity and P merited consideration. However, by combining data from several sources, a clearer picture emerges.

An In-situ sensor, developed by Silsoe Research Institute was tested in four of the participating countries. The sensing system required sets of algorithms to convert the raw sensor data to values of N, P and K for each slurry groups. These were developed using data from tests conducted with English slurries. The equipment performed reliably.

Nitrogen: When ammonical nitrogen (AN) is expressed graphically against EC for all of the data obtained in all four countries a useful correlation was found between the two, which compares extremely well to the regression line fitted to the previous data.

Phosphorus: Total solids concentration measured by laboratory methods was found to be a good predictor of P concentration in both cattle and pig slurry when the data from all four countries were plotted and compares reasonably well with the regression lines fitted to the previous data. However, for the reasons of convenience, measuring TS by oven drying is not feasible under farm conditions. Therefore, correlations between P and density were examined. Phosphorus correlated moderately well with density in pig slurries although P in the cattle slurries did not correlate with density.

Potassium: Previous work has indicated that K correlates with the EC. When the data for K and EC are plotted for all four countries, a moderate correlation for both cattle and pig slurries was found and these regression lines compare well with those from previous data.

Calibration results: Results of multiple regression analysis of previously published data indicated that this technique could improve the accuracy of nutrient estimation. Therefore, this technique was applied to the results of the international trials of the In-situ sensor.

The data collected during the work with the In-situ nutrient sensing system was classified into 15 different groups for data analysis. However, the data analysis indicated that 8 of the 15 slurry groups were most useful. The other seven groups, including animals of all types in each country (four groups), all slurries collected (one group) and all pig or all cattle slurries (two groups) were not used because the associated regression analyses offered no improvement over the 8 groups selected. This format allowed multiple linear regressions to be used including three measured properties. However, the analysis of the data from the In-situ nutrient sensing system suggested that only two properties were required, and then only in certain circumstances. The In-line nutrient sensor was built and installed on the prototype slurry tanker for testing.

Nitrogen predictions: The In-line nutrient sensing system gave a good prediction of the AN, with a resulting coefficient of determination (r^2) of 0.92. The standard error being 0.38 kg/m3 in a range of 0.63 to 5.29 kg/m^3, in other words to an accuracy of better than ± 10%.

Phosphorus predictions: When all of the data were compared, the results were disappointing, with an r^2 of 0.44. However, if the data are split into 4 subgroups, that is cattle and pig in each of the countries, a clearer picture emerges. For the pig slurries a much improved fit is observed for both the UK and Irish data, with resulting r^2 values of 0.99 and 0.82, respectively. There were insufficient UK cattle data and all of the Irish predicted values had the same value of 0.27 kg/m^3. This occurred because previous calibration based on results from the In-situ nutrient sensing system had revealed a weak correlation between density and P in Irish cattle slurries. However, none of the other measured properties were able to provide better predictions of P content.

Potassium predictions: The predictions from the In-line sensing system were encouraging with a resulting r^2 of 0.70. The standard error being 0.62 kg/m^3 in a range of 0.81 to 6.49 kg/m^3, in other words to an accuracy of better than ± 12%. However, on examination of the data it can be seen that the two UK cattle data skewed the data. If these are removed, the resulting r^2 values improves to 0.88 and the standard error to 0.41 kg/m3, in other words to an accuracy of better than ± 10%.

MESPRO: The MESPRO model estimates of slurry production and quality parameters, based on the model input data taken on 11 German and 16 Italian pig farms, were compared against the measured parameters on the same farms. The German data indicated that the MESPRO over estimated total slurry production for 7 of the 11 experimental units compared with the measured production. However, the reverse was the case with the Italian data from the 16 units.

The mean random deviation and mean systematic deviation between the calculated and measured values of output parameters from the German and Italian units were calculated.

The random deviation and systematic deviation between MESPRO estimates and measured values of slurry production were 35 and 24%, respectively on the German farms. The respective values for the Italian data were 61 and -50%, respectively.

Random deviations for the German data between MESPRO estimates and measured values of excreted dry matter and dry matter related nutrients (P, magnesium and calcium) and their concentrations in the slurry range from 33 to 59%. Total excreted dry matter and nutrients show significant systematic deviations, whereas systematic deviations of nutrient concentrations were not significant. All systematic deviations, except for K concentration, were positive which means that MESPRO over estimated these parameters. The observation of relative small deviations between calculated and measured K excretion implied that K input and K output was reasonably in balance. This provides an indication of the accuracy of the collected data.

The systematic deviations in the Italian data for nutrient concentrations are all positive. The negative systematic deviations between calculated and measured values of slurry production and excreted nutrients suggest a strong underestimation by MESPRO for these parameters. The positive systematic deviations for dry matter and nutrient concentrations in the slurry and no substantial differences in the level of deviations between dry matter related nutrients on the one hand and dissolved nutrients on the other indicate representative slurry sampling. This leads to the conclusion that the data collected on slurry production was inaccurate.

Balance model: The results of the German and Irish trials are summarised in Tables 4 and 5

Table 4 The balance estimate/measured nutrient concentration in slurry for the German dairy and pig trials (%).

	No. of trials	Balance estimate/ measured nutrient concentration N	P	K
Fattening pig	15	136	120	111
Dairy	11	121	116	107

Table 5 The balance estimate/measured nutrient concentration in slurry for the Irish dairy and pig trials (%).

	No. of trials	Balance estimate/ measured nutrient concentration N	P	K
Fattening pig	3	147	61	77
Lactating sows	5	87	84	61
Dairy cows	8	127	108	128
Beef	2	175	125	116

The German results show a general over estimate of the nutrients by the balance approach compared with the measured nutrient concentration for both fattening pigs and dairy cows. The Irish data is more variable with both under and over estimates by the balance estimate.

Developing a Prototype Application System

Blockage Prevention: Blockages of the small bore pipelines on low emission distribution systems (bandspreaders, shallow injectors) are caused by external contaminants. Results of interviews with Dutch slurry spreading contractors indicated that blockages can be almost eliminated using chopping/filtering systems. Generally, these are fitted on the inlet side of the slurry pump so that the actual chopping and filtering is done during filling and protection is provided for the pump when using positive displacement type pumps. Tanker filling time was increased when using a chopping/filtering system in combination with a vacuum pump. The losses varied from 10 to 20%. The capacity loss was much lower when using a positive displacement pump (2 to 5%). The size of pump capacity did not significantly influence pump losses. The type of chopping/filtering system did not influence these losses either for the vacuum and the positive displacement pump.

The performance of the three chopping/filtering systems only differed slightly in the tests. Straw, feed stuffs and hay were handled by the chopping/filtering systems without causing blockages. One of the systems tested was selected and fitted to the prototype tanker system. Its compact design was a factor in its choice.

Design and Fabrication of Machine System: All mechanical, hydraulic and control components were fitted to the prototype tanker system in accordance with designs agreed (Plate 1). In operation the control system gives the operator three basic options available on the in-cab interface unit, (a) fill, (b) mix/analyse and (c) spread. These options are activated from the tractor mounted laptop computer. The relevant parameters, pump speed, tanker contents, forward speed and spreading rate are continuously monitored and displayed on the computer screen. Fault conditions are flagged on the computer screen and the spreading system is shut down if a serious fault occurs. A series of flashing indicators on the tanker identify the specific fault.

The control system software was designed to function either as a standalone unit, or in conjunction with an office based PC providing ADS information via floppy disc. The operator interface is divided into nine sections as follows:

MOTT 1.	Main Menu
MOTT 2.	Import Data
MOTT 3.	Display ADS/ERA Information
MOTT 4.	Fill Tanker
MOTT 5.	Mix/Analyse
MOTT 6.	Transport
MOTT 7.	Pre-Spreading Information
MOTT 8.	Spreading
MOTT 9.	Save Data

The options and functions available at each stage of the software are summarised in Appendix.

Prototype Testing: A series of static pump tests were conducted. The pump output characteristic was linear. The variation in pump output recorded when pumping either water or slurry of (78 g/kg DM) was less than 8% at pump speeds across the normal range of operation.

The mean results of the lateral distribution of the band spreader are shown as percentage of the mean flow per outlet for the pump speeds of 200, 300, 400, 500 and 550 rpm, respectively (an example is shown in Figure 7) The corresponding coefficients of variation (CVs) were 16.8%, 13.7%, 12.1%, 9.7% and 11.6% respectively.

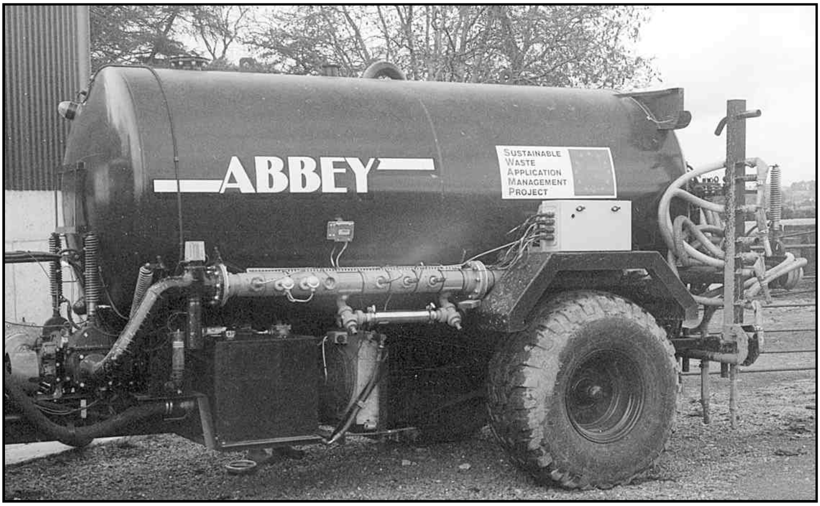

Plate 1. The assembled prototype tanker.

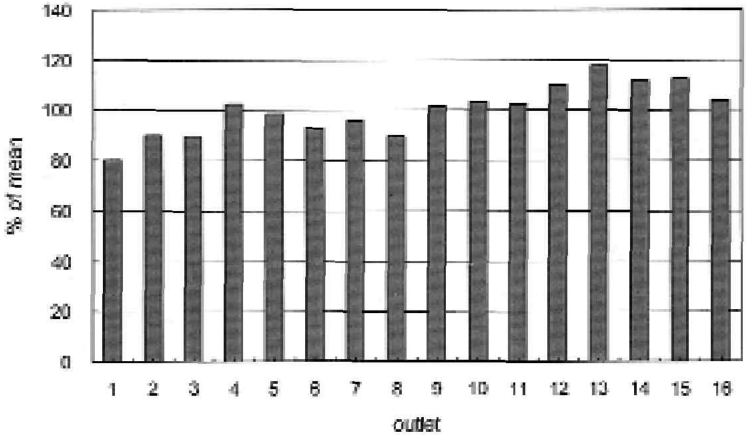

Figure 7. Lateral distribution of bandspreader as percentage of the mean flow per outlet for the pump speed of 550 rpm.

The results of the longitudinal distribution of the band spreader are shown as percentage of the mean flow of the outlet number 8 and 15 for pump speeds 300 and 500 rpm. The CVs were < 11% in the 300 rpm tests and < 7% in the 500 rpm tests.

The ability of the control system to maintain pre-selected target rates of application in the field was assessed by measuring total manure collected during evenness testing and by measuring the relationship between pump speed and forward speed. For set target application rates and two step changes in forward speed (increasing and decreasing) the pump speed closely maintained its relationship with forward speed until forward speed goes above 11 km/hr. However, this is above the physical capabilities of the pump to deliver the required volume of slurry. The results showed that the pump reaches required output within 6 seconds of start up. This is an insignificant interval when compared with the estimated volume of the delivery system of 0.1 m^3 (i.e. pipework, volume from pump outlet flange to discharge point) and confirms that effective control of application rate can be accomplished with the design.

DISCUSSION

The objective of the work described was to research, develop and validate technologies and management strategies which will provide farmers with the means of prudently utilising the nutrients in animal slurries for crop production and minimising the pollution potential associated with land spreading. There were three major elements to the work undertaken: Management and Risk Assessment; Determining the Nutrient Value of Slurry and the Development of Prototype Application System

Management and Risk Assessment

The objective of the management and risk assessment work was to develop and exploit models to quantify the environmental risk associated with the land spreading of liquid animal manure and to develop software to improve decision support in relation to the timing and selection of management options for slurry application so as to reduce pollution potential.

Environmental Risk Assessment (ERA):The mechanisms and processes by which nutrients are lost following application of organic and mineral fertiliser, causing pollution of surface and ground-water are complex.

In order to provide an assessment of the environmental risk in terms of nutrient losses from a field, a physically-based modelling approach linking several component models was developed and applied in this work. Model simulations were shown to reproduce well the available measured pollution data, provided that a large number of model parameters are also measured or estimated. However, due to the significant information requirement for this approach, it is advisable that simpler methodologies whereby pollution risks can be ascertained should be incorporated in future efforts. The use of simpler types of model in this work was not pursued as they are considered at present, to give an inadequate representation of the factors on which these particular pollution processes depend. The methodology used here can be considered as a template for future research, with the results held as a standard for comparison. Ultimately, the aim of this systems modelling approach was to produce a series of tables, which identify the relative nutrient loses through surface runoff and drainage and the total field loss, for several soil and crop types, climatic conditions, and a large number of nutrient management options.

Work with the models concerning surface runoff pollution gave a very decisive result that had not been anticipated at the start of the project - that tactical decisions about selecting days suitable for spreading slurry are only of benefit for a limited range of sites. These could be defined in terms of having an intermediate level of profile conductivity (with values in the range 5 - 10 mm/day), a parameter indicating both hydraulic conductivities of the soil layers and effectiveness of the field drainage system. Sites which do not come into this category are either unsuitable for spreading slurry at all in winter (low profile conductivity), or can receive slurry in any weather conditions at any time of year without risk of pollution (high profile conductivity).

This result emphasises the importance of developing methods of assessing runoff susceptibility of sites in terms of their profile conductivity for strategic decisions about which fields on farms to use for slurry spreading. Conversely, the method of assessing the daily air filled pore space of a field for tactical decisions about timing of spreading is of lesser importance, as this is only of benefit at a limited range of sites with intermediate profile conductivities.

The physically-based simulation model SOILN combined with a volatilisation model, was calibrated and validated for several soil types and crops. Using this calibrated version, nitrate leaching from the seven field sites previously mentioned, for grass, spring and winter cereal crops, and for three climatic areas, was determined. A sensitivity analysis identified that leaching is most sensitive to the hydrologic pathways, and less so to the crop N uptake and soil C/N cycling parameters for a well fertilised field. On this basis, the calibrated model is considered to be transportable in terms of application to different crops and climates, provided that the hydrological characteristics of a field are correctly represented.

Application Decision Support (ADS): The ADS software was developed to assist a farmer or nutrient planner/adviser in the development of a farm manure management strategy. The ADS structure has three main elements, farm nutrient balance, strategic field-by-field scheduling of manure spreading and tactical field spreading decisions. The three follow logically, can be run individually with different frequency and will update the other(s) if appropriate.

A limited number of simulations were performed to demonstrate the ADS software. The basis was a comparison of the actual management practice with those developed using the ADS software. The results indicated the potential of ADS to provide decision support in terms of reducing nitrate leaching losses. Equally, ADS demonstrated its ability to provide the farmer with tactical decision support in relation to the suitability of management options.

A GIS system was selected for the interface with the farmer as the most practical way to present numerically and graphically the ADS output. The software was evaluated from the geographical perspective. This approach of data presentation was considered to be useful.

The ADS software developed illustrates the potential of decision support systems to assist farmers and advisers. The framework proposed and developed is useful. However, considerable work is required to refine the approach for local use on farms.

Determining the Nutrient Value of Slurry

The work involved four different approaches to providing information for the farmer on the nutrient value of the manure. Two measurement approaches, Rapid Lab and In-line nutrient sensor, were considered. Two estimation or modelling approaches, MESPRO and an input/output balance, were evaluated.

Rapid Lab: The objective was to introduce the Rapid Lab method of manure analysis to laboratories in Germany (LUFA) and Ireland (Teagasc). The method improves the speed and accuracy of the lab analysis by using a single digestion process and the use of a sampling mixer to ensure the homogeneity of the sample received for analysis. To achieve this work was undertaken in two areas: (i) a ring test and (ii) a comparison of the Rapid Lab method with the conventional manure analysis methods used in participating labs.

The individual ring test results for the manure sample nutrient concentrations indicate that there was no laboratory with significantly lower or higher results than the established mean. Outliers, based on the Cochran's test (ISO-5725) were excluded from the analysis and the standard deviations and coefficients of variation were reduced. The coefficients of variation for broiler manure were in most cases higher than those for pig or cattle manure. This may reflect sub-sampling problems with the solid compared with liquid manure.

A comparison of the results from this ring tests with previously reported ring tests indicate the Rapid Lab method is a reliable method of manure analysis for dry matter, N, P and K.

Comparison between own lab method and Rapid Lab method: The mean results for Rapid Lab and conventional method for the LUFA and Teagasc laboratories were compared. The conventional method at LUFA generally gave lower values than the Rapid Lab. The analysis of the results found a systematic error in the P results for all manure samples between the two methods. No consistent systematic error was found for N and K results. The differences in the P results may have arisen either from the use of a particular perhyrol containing P or the high sensitivity of the colorimetrical method used in Rapid Lab or the high nutrient concentrations in the manure samples used in the test or indeed a combination of these factors.

The conventional Teagasc laboratory method gave significantly lower results for pig slurry compared with the Rapid Lab. There was a similar difference for cattle slurry but it was not significant. This may be explained by the better mixing and sub-sampling achieved with the Rapid Lab approach or may indicate an incomplete digestion step.

This results indicate the successful transfer of the Rapid Lab method to the participating laboratories. They now have the capability of providing a more efficient service. Therefore, Rapid Lab technology can be transferred to other European laboratories using the same approach i.e.ring tests and training. It should be noted that the technique does not address the other delays, travel time for slurry from farm to laboratory, and delays in the returning the results to the farmer.

The validity of any laboratory analysis on a manure sample depends on both the accuracy of the sampling and of the analysis. The accuracy of sampling will generally be lower than that of the analysis considering the nature of the material. This creates a challenge for the farmer to ensure that the slurry is fully agitated prior to sampling. The natural settling process which occurs in slurry will not only result in different nutrient values for slurry removed earlier in the emptying process than later, but also in different nutrient ratios. Slurry contains solid particles with a high specific density, which therefore tend to settle. This process proceeds faster in a slurry with a high water content, e.g. pig slurry. Nutrients like P tend to be linked to these particles, where as K and ammonium are more evenly distributed throughout the water fraction. Bound N is mostly linked to organic particles, which tend to form floating layers on the slurry. Achieving the required level of agitation for sampling may be difficult where manure is stored under the animals because of the problems of hydrogen sulphide emissions during mixing.

In-line nutrient sensor: A prototype In-situ nutrient sensing system was developed and evaluated on 160 different slurries; 40 in each of the four participating countries. Using the information gained during these trials an In-line nutrient sensing system was developed to work on a slurry tanker. The approach offered the advantage of determining, in real time, the nutrient value of the slurry on a per tanker basis.

The accuracy of the In-line nutrient sensing system was found to depend very much on its calibration. When identifying the algorithms to use there was always a compromise between the accuracy of the nutrient sensing system and the variety of slurries to which it could be applied. The ideal situation would comprise just three algorithms to predict N, P and K for all of the slurries tested. However the data analysis demonstrated that greater accuracy could be achieved using different sets of algorithms for each specific slurry group. In this case, collated data were split into eight slurry groups. i.e. cattle and pig slurry in each of the four countries. However, through more detailed classification of the data, for example to region or even farm level, it was envisaged that the accuracy of the prediction would improve, but the complexity and applicability of the nutrient sensing system would decrease. Since it was envisaged that the nutrient sensing system would be used mainly by contractors, rather than by individual farmers, the sensible compromise was to calibrate the nutrient sensing system on a species per country basis.

The ability of the In-line nutrient sensing system to estimate the nutrient value of the slurry varied depending on which of the three nutrients (N, P or K) were being predicted. Overall, the measurement of N proved to be the most accurate and reliable, providing useful estimates in all four cases tested (cattle and pig slurry in UK and Ireland).

For P and K, the overall results were not as good. However, when subsets of the data were examined individually, the results improve considerably. P in pig slurry was predicted accurately, although the In-line sensing system needed re-calibration. P measurement in cattle slurry proved unreliable. K was quite good in all cases except for UK cattle slurry.

The results did not correlate perfectly with the nutrient values obtained by conventional laboratory analysis. However, the sensing system technique offered the compensating advantage of being able to estimate nutrients in each tanker before it is applied.

The development of the In-line sensor represents significant progress in terms of providing the farmer with tactical information on the slurry nutrient value. Its importance is heightened in the context of links established between the output of the sensor and the application control system on the tanker.

MESPRO: The MESPRO model estimates of slurry production for both the German and Italian data were 30% higher and systematically higher than the measured production. There are a number of possible reasons for the observed discrepancies. On some German farms the water to feed ratio was between 2 and 6:1 compared with Dutch values of between 2 and 3:1. This higher water consumption combined with the model underestimates of water loss due to evaporation at ambient temperatures may have contributed to the observed differences. Measurement of slurry production on some Italian farms was difficult especially where slurry was discharged using an overflow system. Equally the Italian results suggest the failure to account for the contribution of extraneous water (e.g. rainfall) to the measured slurry production. It should also be noted the Dutch validation studies were done using the earlier static MESPRO model and selected data sets. This may have contributed to a bias in the comparison between the Dutch validation compared with the Italian and German validations.

Deviations in model and measured values for DM and P concentrations were larger than those for N and K on German farms. The systematic positive deviations between the calculated and measured P values contrast with what would have been expected as a result of the over estimate in slurry production. This may reflect non representative slurry sampling. Problems associated with slurry sampling were noted above.

The collection of data on farms in Italy and Germany for MESPRO provide an indication that the required data are not easily collected.

Balance model: A simpler balance approach, based on the difference between nutrient inputs and outputs, to estimate the nutrient value of manure, was also evaluated on Irish and German cattle and pig farms. The balance model generally overestimated the actual nutrient concentration in the manure for cattle and pig farms. Ammonia loss during storage provides some explanation for the overestimation of N. The input/output model overestimate of P suggested a systematic error with slurry sampling. The P in slurry is bound to the solid fraction which tends to settle at the bottom of the tank. Agitation of the pig slurry prior to sampling was not possible. Therefore, the slurry sampling techniques may not have accurately sampled the stratified profile of the slurry in the storage tanks. The explanation of the overestimation in K is more difficult as it is evenly distributed in the slurry. A further potential source of error is the measurement of the height of slurry in the tanks. There was considerable between farm variability which may reflect practical difficulties associated with data collection on farms. The results from the input/output balance, based on measurements under "relatively controlled conditions" suggest that similar data collected under practical farm conditions is unlikely to provide a useful tactical estimate of nutrient value for use on the farm.

Development of Prototype Application System

Three mechanisms to reduce blockages in low trajectory application systems were evaluated. On the basis of this evaluation such mechanisms are effective at minimising the problems of blockages in the field. This is supported by the experience of operators. However, this must be complemented by farmers ensuring that a minimum of extraneous materials enters the slurry store. Equally, proper agitation of the slurry, prior to application, is an important factor in this respect.

Testing of the filter and the distribution of the prototype spreader was also carried out on the completely assembled prototype spreader. The results show that with the band spreader an even distribution can be achieved independent of the pump speed. The CV for the lateral distribution varied from 9 to 14% at pump speeds used in practice. The CV of the longitudinal distribution was lower than 11%. The slurry distribution achieved with the band spreader is an improvement on broadcast surface spreading (splashplate). Other factors that reduce the the ability of the splashplate to apply slurry evenly are that the user is not aware of the effective optimum working width. Small changes in spreading width result in a more uneven distribution. Splashplate spreading width was shown to be influenced by the pump speed.

The prototype slurry spreading system which was developed provided the platform for practically testing the control system (hardware + software), the In-line nutrient sensor and the performance of the complete system in applying slurry nutrients evenly both laterally and longitudinally. The control software developed was proven in tests to function effectively. The two-way information exchange with ADS software, via a floppy disc, was proven to work.

CONCLUSIONS

- The physically-based modelling approach linking several component models was developed and applied in the work The model output satisfactorily reproduced field measurements of runoff. However, the model has a significant data input requirement in terms of soil parameters which makes it less practical for general use.

- Simpler methods to predict pollution potential should be investigated in the future

- The results suggested that selecting suitable spreading days for slurry spreading is only applicable on a limited range of sites *i.e.* those having intermediate levels of profile conductivity (5-10 mm/day), a parameter indicating both hydraulic conductivities of the soil layers and effectiveness of the field drainage system. Sites which do not come into this category are either unsuitable for spreading slurry at all in winter (low profile conductivity), or can receive slurry in any weather conditions at any time of year without risk of pollution (high profile conductivity).

- A framework for the development of decision support software was successfully developed. Its effectiveness was tested. However, more work is required to develop the software for field application.

- A Dutch manure analysis procedure was successfully transferred and adopted by two of the participant laboratories. This procedure improves the repeatability of the analysis and can assist in a faster turn around in samples received. However, it should be noted that validity of any laboratory analysis depends on both the accuracy of the sampling and of the analysis. The accuracy of sampling is generally lower than that of the analysis considering the nature of the material. The taking of a representative slurry sample from a storage tank is difficult.

- The development of the In-line sensor represents significant progress in terms of providing the farmer with tactical information on the slurry nutrient value. Its importance is heightened in the context of links established between the output of the sensor and the application control system on the tanker.

- The potential of using two modelling approaches as predictors of slurry nutrient concentration was attempted. Difficulties with accurately collecting the farm data require by both models preclude this approach as a simple means of predicting the nutrient value of farm slurries.

- The use of a chopping/filtering system is an effective means of reducing blockages in low emission (band spreader and shallow injection) spreading systems. The results of interviews with Dutch slurry spreading contractors highlighted the need to keep extraneous materials out of the slurry store and for agitation prior to removal as a means of reducing the potential for blockages.

- The prototype slurry tanker developed with its application control system has proven to be effective in achieving an even spread of slurry at the target application rate. Many of its features are set to become standards on Irish spreading equipment over the next five years.

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APPENDIX

The options and functions available at each stage of the MOTT software

	Display	Actions Available to the Operator	Automatic Functions	Calculations required	Inputs/outputs from tanker PLC
MOTT 1, Main Menu	Ten options (operator selectable) are displayed on the main menu screen. These are: set-up page, MOTT 2 import data, MOTT 3 display ADAS/ERA information, MOTT 4 fill tanker, MOTT 5 mix / analyse, MOTT 6 transport, MOTT 7 pre-spreading information, MOTT 8 spreading, MOTT 9 store data and Quit MOTT.		None	No	None
Set Up Page 1	The following are text fields are displayed: farm name, name of field, field area, slurry type, crop type, planned date of spreading, required nutrient application rate, maximum volumetric application rate, maximum nutrient application rate, predicted nutrient concentrations, special instructions.	The operator can enter the information in the text fields. Two other options are available: return to main menu & set up page 2.	None	No	None
Set Up Page 2	The following text fields are displayed: operator name, spreader width, pump calibration factor, maximum forward speed, season start date, nutrient used for mixing/analysing, number of values to be used for rolling averages, percentage standard error used for mixing/analysing	The operator can enter the information in the text fields. Three other options are available: return to main menu, set up page 1 & continue.	None	No	None
MOTT 2, Import Data	Three options (operator selectable) are displayed on the screen. These are: import data , return to main menu and continue.		None	No	None
MOTT 3, Display ADAS/ERA Information	The following information is displayed: farm Name, name of field, field area, slurry type, crop type, planned date of spreading,, required nutrient application, maximum volumetric application rate,	Three options are available : return to main menu, display manual information and continue.	None	No	None

	Display	Actions Available to the Operator	Automatic Functions	Calculations required	Inputs/outputs from tanker PLC
	maximum nutrient application rate, predicted nutrient concentrations, special instructions				
Display Manual Information	The following information is displayed: farm Name, name of field, field area, slurry type, crop type, planned date of spreading, required nutrient application, maximum volumetric application rate, maximum nutrient application rate, predicted nutrient concentrations, special instructions	Three options are available: return to main menu, display ADAS/ERA information and continue.	None	No	None
MOTT 4. Fill Tanker	Analogue display to indicate tank contents	Four options are available: start filling/stop filling, return to main menu, continue and transport.	Stops the tanker filling when full.	No	Fault condition Tanker contents
MOTT 5. Mix/Analyse	Analogue display to indicated the slurries estimated nutrient content, and its standard error in terms of N, P & K.	Four options are available: start mixing analysing/stop mixing analysing, save in-line nutrient sensor data, return to main menu and continue.	Indicates to the operator when the tank is completely mixed.	Yes	Fault condition Tanker contents In-line sensor
MOTT 6. Transport	Two options (operator selectable) are available: return to main menu and continue		None	No	None
MOTT 7 Pre-spreading Information 1	The following information is displayed: confirm drivers name, confirm farm name, confirm field name, confirm time and date, confirm working width of spreader, confirm slurry type, confirm crop type, select slurry nutrient values	The operator must answer the questions that are displayed. Two options are available: return to main menu and confirm information.	None	Yes	None
Pre-spreading Information 2	The following information is displayed: required volumetric application rate,	Three options are available: return to main menu,	None	Yes	None

	Display	Actions Available to the Operator	Automatic Functions	Calculations required	Inputs/outputs from tanker PLC
	maximum permitted volumetric application rate, target forward speed, required nutrient application rates, nutrient content of slurry used, calculated target nutrient application rates.	change pre-spreading information 1 and continue			
MOTT 8 Spreading 1	Three options (operator selectable) are available: initiate spreading, return to main menu and continue		None	No	None
Spreading 2	Analogue display to indicate pump speed, application rate, tanker contents and forward speed.	Two options are available: start spreading/ stop spreading and continue. Note also available is a soft start and stop option.	Stops spreading when the tanker is empty	No	Fault conditions Tanker contents Forward speed Pump speed
MOTT 9 Save Data 1	Four options (operator selectable) are available: view data, store data to disc, discard data and return to main menu. The operator can also enter comments		None	No	None
Save Data 2	The following information is displayed: operator's name, farm & field, actual date and time of spreading, working width of spreader, average forward speed during spreading, distance covered whilst spreading, total area covered, total volume of slurry applied, calculated volumetric application rate, actual volumetric application rate, required nutrient application rate, nutrient concentrations used, calculated target nutrient application rates, actual nutrient application rates, spreading time, filling time, transport time, other time, comments.	The operator cannot edit any of the data except add comments. Only one option is available: continue	None	Yes	None