CSG 15

DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS

Research and Development

Final Project Report

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Project title	Modelling manure NPK flows in organic farming systems to minimise nitrate leaching, ammonia volatilization and nitrous oxide emissions
DEFRA project code	**OF0197**
Contractor organisation and location	ADAS, Gleadthorpe Research Centre, Meden vale, Mansfield, Notts NG20 9PF
Total DEFRA project costs	£ 64,297
Project start date	01/09/00
Project end date	31/03/02

Executive summary (maximum 2 sides A4)

Manure is an important source of organic matter and nutrients in organic farming systems, principally nitrogen (N), phosphorus (P) and potassium (K). Careful management is required during storage, handling and land-spreading to (a) ensure the most efficient use of the nutrients in the farming system and (b) to limit emissions of nitrate (NO_3), ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and P to the wider environment. With a likely increase in the organically farmed area, information is needed on best practices for manure management in organic systems to minimise the environmental impacts of these systems.

A simple nitrogen spreadsheet model was constructed for project OF0161 ('Environmental impacts of manure use on organic farms') to calculate the integrated effects of management practices during housing and storage. This was based on existing emission factors from the scientific literature. The aim was to develop this approach further by improving this into a more robust model by (a) incorporating most recent emission factors and (b) linking to existing models for assessing field losses. The aim was that software would calculate NPK fluxes associated with each aspect of the livestock system, and provide options to explore the impact of management change at key stages in the manure management process. The end point was to be a working prototype model/decision support system, which we could be demonstrated to a group of organic farmers and used for discussion of the NPK flows in their systems.

Most of the effort in this short-term project was spent on three aspects:
1. Developing databases and the underlying model calculations.
2. Developing the software for the prototype system.
3. Limited validation of the output.

The two main challenges in the project were (a) allowing a quick and easy representation of the manure management system, which is often complex and (b) being able to represent complex interactions, simply but robustly. The Manure Model (MANMOD) DSS was developed to allow an iconographic-based model

representation of individual farm manure management systems to be readily constructed from a library of system components using a 'drag and drop' operation. This allows the user to construct a diagram of connecting components or 'nodes' (e.g. manure source, housing system, storage system) which direct and limit the flow pathway of nutrients through the farming system. Each component or node represents a key stage of the system.

Once the system has been constructed, pressing the calculation button calculates the following variates for each component of the system: output (i.e. the amounts of N, P and K that will be transferred from that component of the system to the next); balance (i.e. the amount residing in that component of the system); losses (gaseous and 'leachate').

Workshops were held at the start and end of the project. The aim of the first workshop was to discuss with a small group of farmers and advisors their thoughts on the value of a manure management DSS, and their specific requirements for such a system. The second workshop was held after the prototype had been developed, and it was used as an opportunity to demonstrate, primarily to organic advisors the structure of the DSS. The following observations were made as a result of this exercise:

- The approach is a relatively quick and simple way of constructing manure management systems. However, it is still quite complex, given the complexity of many management systems.
- It may be that it is a better tool for advisers so that they can use it for several clients and become more familiar with the tool, compared with a farmer who might use it as a one-off during planning.
- Even at its simplest, some detailed information is required – and in units that the farmer may not be familiar with. For example, washdown volume for the hardstanding, amount of straw (kg/animal/month), etc. However, this is not really a reason for not pursuing this information if it will provide an improvement in management. One point for future consideration would be to include imperial measurements as an option (not included in this prototype).
- One value is the option to scenario test. However, this is reliant on the model being sufficiently refined to be able to fairly represent the changes in response to the system. Further data are required to improve some of these aspects, as already described.

Partial validation of the DSS was undertaken by (a) calculating nutrient flows through typical manure management systems, (b) comparing calculated cattle manure composition with standard data and (c) scenario testing, where individual management factors were altered to study the effects on the system.

The output from the model on test runs looked sensible and appeared to represent interactions between management processes in a logical manner.

To check if the outputs were sensible, a simple dairy system was run in MANMOD, first using the assumption that it was a slurry system, and then a straw based system. By drilling down through the output screen for the manure store it was possible to determine the calculated nutrient contents of slurry (kg/m^3) and FYM (kg/t). This was a challenging test, given the transformations that MANMOD has to model. Despite this, the comparison with standard values in RB209 was reasonable.

Nutrient content (kg/m^3 or kg/t):

Manure	Source	N	P_2O_5	K_2O
FYM	Manmod	4.8	2.1	4.9
	RB209	6.0	3.5	7.2
	Organic	5.2	2.9	6.3
Slurry	Manmod	4.1	2.3	5.2
	RB209 (10% DM)	4.0	2.0	5.0
	Organic (8% DM)	2.5	1.2	2.5

However, given the variability associated with manure composition, it may be fortuitous. The comparison was better for 'conventional' slurry. This was not surprising given that a slurry system is more straightforward, and does not have the complicating factors of interactions with straw during housing and manure storage. The

FYM calculation seemed to consistently underestimate nutrient content for N, P and K. One possible reason could be the mass loss calculation, and this needs further investigation. Standard values for manure from an organic holding were also included in the comparison. These manures tend to have a smaller nutrient concentration. For FYM, because MANMOD calculated smaller nutrient concentrations than those reported in RB209, and because concentrations are smaller for the organically produced manures, there appeared better agreement between MANMOD and organically produced manures. However, the better agreement between calculated nutrient contents and those from organic holdings was pure coincidence, given that nutrient excretion rates in the model are based on ‘conventional’ livestock. This is further supported by the fact that the organically produced slurry had nutrient concentrations of about a half of those calculated by MANMOD.

This last point is important. Whereas the loss processes are the same for organic and conventional systems, the starting point for MANMOD is the nutrient excretion rates by the livestock. Because of lack of data for organic livestock, these rates are based on conventionally reared stock. Therefore, they are not entirely appropriate for organic producers.

To further test if MANMOD was sufficiently sophisticated to be able to determine differences between changes in management, adjustments to individual elements were made to observe the changes in N fluxes. None of the practices had effects on P and K fluxes. Converting to a slurry system increased ammonia losses during the housing and storage (open slurry store) phase. Increasing the amount of straw only had a small effect on the N losses before land-spreading. The calculation method assumes only a relatively small amount of N immobilisation during the housing and storage phases. A 10-fold increase in straw addition decreased ammonia losses in the model by 4% when the manure was stockpiled. Further experimental data are required to confirm the assumptions in our calculation. The largest effect came from composting the manure, compared with stockpiled (undisturbed) manure. This was because of the active composting (stirring/heating) encouraging ammonia loss. This is clearly critical to the N balance of the system. The basis of the calculation was described above and was supported by the previous OF0161 literature review. However, this is so critical that the relationship should be further confirmed. The slurry store management had a significant effect on ammonia losses during this phase. Compared with an open store, a ‘covered store’ decreased losses to 80% and a ‘crusted’ slurry halved N losses.

The aim of the project was to produce a prototype system. We have done this but, because of the complexity of the systems that we are trying to represent, we recognise that much more detailed validation of the model is required before it can be disseminated. One of the problems was that there were few data that could be used for validation, but there are now several Defra-funded studies that could be used in the next phase of the work.

Scientific report (maximum 20 sides A4)

INTRODUCTION

Manures are an important source of organic matter and nutrients, principally nitrogen (N), phosphorus (P) and potassium (K), in organic farming systems. But with manure use comes the need for careful management during storage, handling and land-spreading. The driving forces for this need are (a) ensuring the most efficient use of the nutrients in the farming system and (b) pressure (supported through current and impending legislation) to limit emissions of nitrate (NO_3), ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and P to the wider environment. With a likely increase in the organically farmed area, information is needed on best practices for manure management in organic systems to minimise the environmental impacts of these systems.

Under project OF0161, a desk study was undertaken to (a) identify the important N flows in three types of organic farming systems (extensive upland, intensive lowland mixed and stockless vegetable systems) in relation to manure use and (b) determine the effects of changed management practice on these flows. A study of the published literature has highlighted the key stages for manure nutrient management prior to land spreading [1]:

Dietary inputs - amounts of N excreted and the partitioning between urine and faeces is important in determining the fate of N through the farming system. Diet affects this partition, but there is no evidence of differences between organic and non-organic rations. Clearly, a crude N balance (N in feed - N in milk) provides a good guide to risk. Because N removal in milk is a small component, the more intensive systems are likely to generate more N as excreta.

Housing - it is estimated, in the UK, that NH_3 losses from housing constitute *c.* 35% of the total NH_3 emissions from cattle production systems (compared with 14% from manure storage) [2] and about 20% of total N_2O emissions [3]. The limited available information suggests that losses by NH_3 emission during housing are larger from slurry based systems than from cattle housed on straw. The converse is true of N_2O losses.

Solid manure storage - composting offers advantages (namely sterilisation) but also can exacerbate loss of nitrogen as NH_3, due to the heat generated and regular aeration by turning of the heap during the early stages. Losses of up to almost 80% of the total N have been reported [4]. There is a strong link with C:N ratio (and, therefore, straw amount), and an analysis of the numerous experiments suggested that the C:N ratio should be >30 at the start of composting to retain N (i.e. to reduce losses to <10%). Loose covering has little effect on retaining nitrogen [5]. NPK are also lost in leachate during manure storage (but only represent a true loss if the leachate is not collected for recycling).

Slurry storage - losses are predominantly as NH_3 and are typically 0.05% (winter) - 0.1% (summer) of the total N content per day [1]. A crust will approximately halve losses. Stirring breaks any crust and also brings more ammonium to the slurry surface, thereby increasing volatilisation. Aeration will have similar effects, but may also increase N_2O emissions if it produces intermittent aerobic and anaerobic conditions. Covering stores will substantially decrease losses and options range from straw to concrete structures. Effectiveness increases with cost!

A simple N model was constructed for project OF0161 [1] to calculate the integrated effects of management practices during housing and storage. The calculations suggest that an all-slurry system (though not permitted under organic regulations) would retain more N than a straw-based system [6]: losses from slurry are greater during housing, but less during storage (assuming the slurry lagoon is covered or has a crust and is not regularly stirred - regular agitation removes this differential between slurry and FYM). However, increasing the proportion of slurry in a system shifts the risk of N loss to the field (as ammonia and nitrate in particular): N losses from FYM during this stage are less, especially if composting has decreased the ammonium N content of the manure.

The question that is inevitably asked is 'do conventionally managed systems provide more of an environmental risk than organic systems?' For N, there is no straightforward answer. Many of the loss processes from manure will be the same between systems but they will be modified by management and by the intensity of the enterprise. It is this latter point - i.e. the nutrient balance - that will have most impact on any comparison; farms with a large nutrient excess will be more prone to large losses. Thus, generally, organic farms are likely to provide less emissions than conventional farming systems involving livestock. The move to more solid based systems may result in smaller losses of N during housing, but practical measures to reduce losses during storage and after land application need to be investigated.

It is this interaction between different N loss pathways that needs to be better represented in, for example, a simple model or decision support system. This would allow the effects of management decisions on N loss interactions to be demonstrated, thus enabling best practice to be developed in terms of the environment and N retention within the farming system.

For example, using the spreadsheet calculation described above, an organic lowland mixed farming system (representing a reasonably intensive system) had a calculated N surplus and calculated ammonia emission per animal less than published data for equivalent conventional farms [7]. Ammonia losses were the major loss pathway from the manure N but, overall, nitrate leaching was the major N loss because of leaching from the ley-arable phase.

This project aimed to develop further a decision support system that would describe and quantify the effects of management practices on N (and P and K) flows in manure management systems, with special reference to organic production systems.

OBJECTIVES

The overall objective of the project was to demonstrate options for improved manure management on organic livestock systems, by the development of computer software to integrate nitrogen flux models with an interactive interface for the definition of the farm environment, including stock management and manure storage systems, and the timing of spreading of manure to agricultural land. Specific scientific/technical objectives were:

1. Establish a Farmer Focus Group (FFG) and define organic livestock and manure management systems representative of existing farm management practices;
2. Compile a database on livestock excreta characteristics and rates of production, for the range of stock type and age classes identified in the systems above (1);
3. Utilise the MANNER (MANure Nitrogen Evaluation Routine) model for the estimation of ammonia emissions and nitrate leaching after field application;
4. Develop a model of nitrous-oxide and ammonia emissions from livestock units and manure storage systems, expressing emissions as a percentage of the total ammonium and uric acid nitrogen (TAN) content of the manure, on a monthly time-step;
5. Compile a database on nitrous-oxide and ammonia emission rates for each type of existing livestock housing, and manure collection and storage system, for use with the model developed above (4);
6. Develop a prototype of the decision support software, and refine the technical specification and scope of the system following user-testing by the FFG;
7. Demonstrate the application of software to representative organic livestock systems, and evaluate the potential for technology transfer.

APPROACHES TO THE PROJECT

Overview

A simple spreadsheet based model was developed as a part of project OF0161 to estimate the effects of management practices on N losses during animal housing and manure storage [1]. This was based on existing emission factors from the scientific literature. The aim was to develop this approach further by improving this into a more robust model by (a) incorporating most recent emission factors and (b) linking to existing models for assessing field losses.

The aim was that software would calculate NPK fluxes associated with each aspect of the livestock system, and provide options to explore the impact of management change at key stages in the manure management process. The end point was to be a working model/decision support system, which we could be demonstrated to a group of organic farmers and used for discussion of the NPK flows in their systems.

Modelling approaches

The two main challenges in the project were:

- Allowing a quick and easy representation of the manure management system – manure systems are complex, from type and numbers of animals, type of housing, etc. There are a large number of management combinations available. Often, software systems fail because of the time and effort required to input sufficient information to enable the software to undertake calculations. This is particularly the case if the approach to data collection is menu-driven. However, much has been learnt about user-friendly input and output screens during the development of the MANNER and SPREADS programs, and we based our approach on the same as that for the SPREADS model: assembling systems by linking icons on-screen. This is described in more detail under 'results'.
- Being able to represent complex interactions, simply but robustly. The approaches are described below.

First, several sources that were used to develop the necessary algorithms, e.g.:

- Literature review and spreadsheet developed in project OF0161.
- Emission factors from the updated nitrous oxide and ammonia emission inventories.
- MARACCAS model [8].
- MANNER for field losses of N from manure.
- Codes of practice/EU Livestock regs for manure output quantities.

Then, we had to identify models of an appropriate level of complexity to accurately calculate nutrient (particularly N) fluxes that are responsive to management change, whilst minimising the need to input environmental data. It was identified that gaseous emissions and nitrate leaching following spreading of manure could be calculated using the MANNER model [9]. The MANNER model calculates potential ammonia-N losses following spreading as a function of the manure's dry matter (DM) content and the content of total ammonium and uric acid N ('total ammoniacal N' - TAN). Actual losses as a proportion of the potential are calculated as a function of the delay to incorporation, using Michaelis-Menten type functions fitted to empirical data [1]. Following losses due to volatilisation, the remaining TAN is assumed to be converted to nitrate-N that is susceptible to loss through over-winter leaching. The proportion of the remaining TAN leached as nitrate is calculated as a function of over-winter soil drainage (hydrological effective rainfall) and the total water content of the soil profile at field capacity (volumetric moisture content) using a simple elution model derived from the SLIM model [10].

The aim was, therefore, to build an empirical model of gaseous emissions from a range of existing stock units and manure storage systems using similar approaches to those above, i.e. to represent the stages of manure management as detailed in Figure 2. It was thought that <u>annual</u> emission rates incorporated within the national ammonia and nitrous oxide emissions inventory [2, 3] and the MARACCAS model [8] could be modified to allow calculation of emissions on a monthly time-step. These models calculate emissions as a percentage of total ammonium and uric acid N content. The change of emission rate time-step may have required development of algorithms that represent the declining rate of release with time, in a similar way to the use of Michaelis-Menten functions in the MANNER model.

It was also necessary to be able to account for the <u>interactions</u> between different management practices. For example, if housing management increased the ammonium-N component of the manure entering storage, the greater risk of ammonia volatilisation during storage would be greater. Similarly, if manure is composted, rather than stockpiled, the model would have to allow for the greater ammonia volatilisation risk. Thus, the database construction needed to address these, and other, issues by basing N loss on mineral N, total N and carbon content of the manures - using approaches that were developed under project OF0161.

The software was developed by the Environment Modelling and GIS Group (ADAS Wolverhampton), using the Microsoft Visual Basic (Version 6.0) programming language.

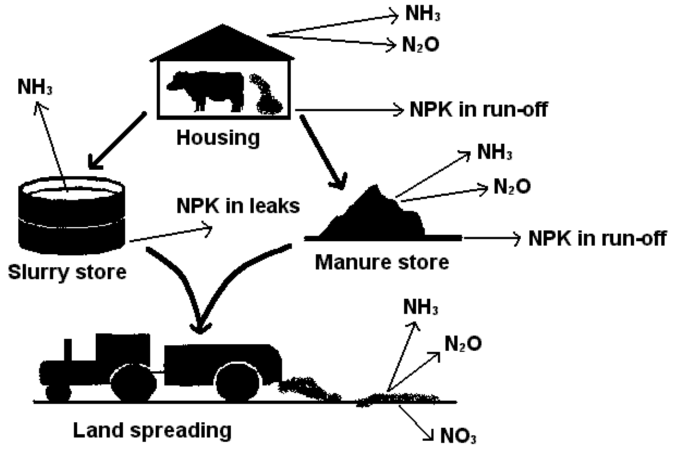

Figure 1. Typical stages in a manure production system.

Data evaluation

As well as evaluating the usefulness of the decision support system to organic farmers, there is clearly a need to assess whether the data outputs are sensible! To some extent this was ensured because the model was based around the current best available emission factors. To thoroughly test the model would require detailed measurements of losses across one or more organic farms. This is not currently available in the UK, though may become available if such projects are funded in the future. We therefore used three approaches:

1. Running example systems to see if output was sensible.
2. Comparing calculated manure nutrient concentrations with standard data.
3. Scenario testing, by observing the effects of changes to individual components to the overall system.

Management and responsibilities

The project was lead by ADAS, with the following responsibilities:

- project management
- model design
- database construction (emission factors, etc.)
- programming
- reporting

EFRC were sub-contracted as consultants to the program development, with the following responsibilities:

- assisting in model specification
- farmer focus group liaison and feedback
- end of project workshop

RESULTS – MODEL STRUCTURE

The Manure Model (MANMOD) DSS was developed to allow an iconographic-based model representation of individual farm manure management systems to be readily constructed from a library of system components using a 'drag and drop' operation (e.g. Fig. 2). In effect, the user can construct a diagram of connecting components or ‘nodes’ (e.g. manure source, housing system, storage system) that direct and limit the flow pathway of nutrients through the farming system. Each component or node represents a key stage of the system:

- manure source (factors include animal type and number)
- housing system (factors include amount of time in the house, amount of straw added)
- hard-standing area (factors include surface area, proportion of time used)
- storage system (factors include liquid or solid, covered or open)
- applicator (e.g. surface spread or injected)
- field system (e.g. soil-type)
- ‘environment’ node – defines monthly rainfall and date of end of drainage
- import and export nodes – allows manure transfer on or off the farm

Once the system has been constructed, pressing the calculation button calculates the following variates for each component of the system, which can be observed on screen by clicking on individual icons. Alternatively, the whole dataset can be exported for viewing and further analysis in Excel. The variates are:

- Output, i.e. the amounts of N, P and K that will be transferred from that component of the system to the next (e.g. from the house to the manure store)
- Balance, i.e. the amount residing in that component of the system. This is in fact the difference between input from a previous component of the system and that transferred out to the next component. For example, if manure was transferred from a house on a monthly basis to a manure store, but the manure was not spread to land until, say, the end of winter the balance would accumulate each month in the store until emptied. If all operations are done on a monthly system (for example, when testing theoretical systems), then the balance remains at zero each month.
- Losses. These are split into gaseous losses (ammonia only, and therefore affecting only N) and ‘leachate’. Whereas ammonia losses can occur at all stages of the process, leachate losses may not occur at all if the manure store is ‘contained’ or the leachate is collected. In fact, this should be best practice and so leachate losses during storage should rarely occur. If they do, then a loss of N, P and K is calculated.

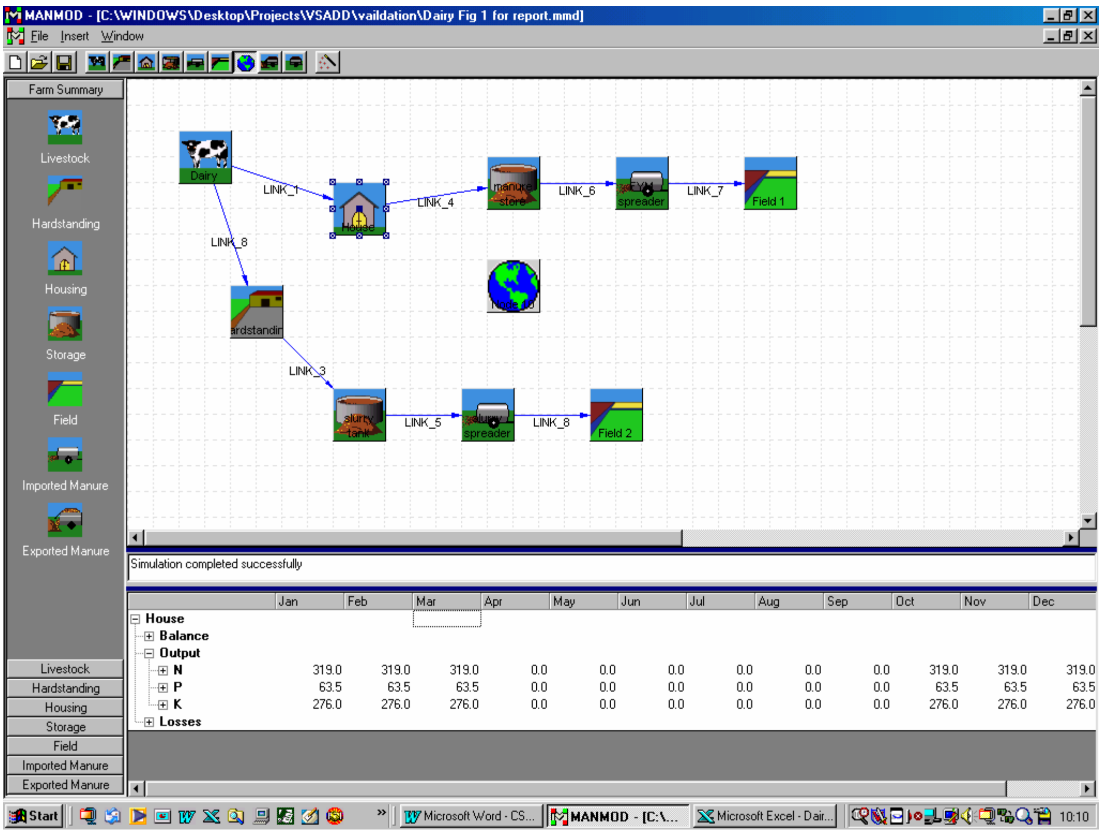

Figure 2. Use of icons and links to build a representation of a manure production system.

The properties of each node can be changed to reflect the management status of each stage (e.g. slurry store with cover). Simulation of the model provides a NPK nutrient balance at each node in the system, including details of any nutrient losses to the wider environment (e.g. ammonia volatilisation or nitrate leaching) as well as a whole farm summary. The model structure and model parameters can be easily modified within the DSS to allow rapid scenario testing.

In addition, to maximise technology transfer, the MANMOD model-engine has been developed as an ActiveX control. As an ActiveX control, the model-engine can be embedded into other development code and the functionality of MANMOD utilised. This can be either be visually: using the existing graphical user interface, or non-visually: where a model structure and parameterisation is built up directly in the code. By adopting this development approach, it ensures that the potential reuse of the scientific algorithms is maximised. It particularly facilitates scenario testing, where a model can be simulated multiple times with changes to parameters and structure.

Figure 2 describes the following system:

- 50 dairy cows housed October – March on a straw-based system (50 kg straw/animal/month)
- 20% of the time spent on open hardstanding, the remainder housed
- Liquid from hardstanding (including washing down and rainfall) collected in a slurry tank (tank is left open and does not crust).
- Manure from the house is stored in a contained manure store.
- Slurry is spread and incorporated within 24 hours.
- FYM is spread and left on the surface.

For simplicity, all operations are done on a monthly basis (e.g. housing mucked out, manure spread). However, the program has the capability such that these operations can be adjusted to any frequency (on whole months), to match actual practice. This was the approach used in the construction of the Elm Farm system during the final workshop (Fig. 3).

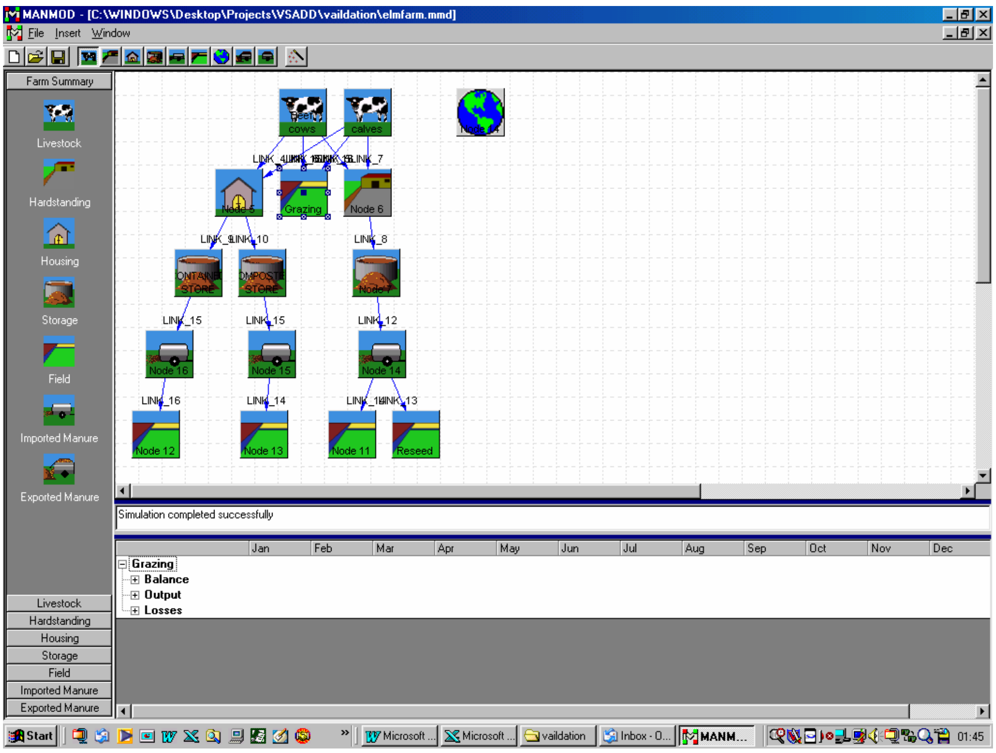

Figure 3. Representation of a manure production system at Elm Farm Research Centre.

The Elm Farm system, being a working system, is more complex than our first example. Nevertheless, we were able to build the system in MANMOD:

- 67 beef cattle and 65 calves.

- Housed November-April, in fields during summer months (note in Fig. 3 that this grazing is also represented).
- When housed, the animals spent 50% of time in the house and 50% on hardstanding.
- Hardstanding washings collected and used as slurry.
- Solid manure split, some composted, some stockpiled.
- Manure and slurry stores cleared out in the spring,

RESULTS – CALCULATIONS UNDERLYING THE MODEL

General Information

The model maintains a running balance of nutrients (kg N, P and K) through the system, for both 'liquid' and 'solid' components. Urine and slurries are considered 'liquids' and faeces and FYM are considered 'solids'. Whilst data is presented to the user as a nutrient load (kg) in the summary sheet, the following information is also maintained in the underlying calculations throughout each stage of the model:

1. A concentration value for each nutrient in the material (e.g. NH_4-N, P, K, C, and organic N - 'Org N').
2. A volume or mass of the material (excreta/manure) in kg or litres.
3. Percentage dry matter of the excreta or manure.

The load can be calculated at any time from the concentration and volume. The model runs on a monthly time step.

The majority of default figures have been gathered from within ADAS existing databases and have mainly come from the NARSES database (J Webb, Pers. Comm). A summary of the calculation methodology at each stage of the model follows.

General Equations

Throughout the whole model, the following formulae are used to recalculate concentrations, volumes/masses and dry matter content at each step:

New volume (Vol_{new}):

$$Vol_{new} = Vol_1 + Vol_2$$

New concentration ($Conc_{new}$):

$$Conc_{new} = \frac{((Conc_1 \times Vol_1) + (Conc_2 \times Vol_2))}{Vol_{new}}$$

New dry matter content (DM_{new}):

$$DM_{new} = \frac{((DM_1 \times Vol_1) + (DM_2 \times Vol_2))}{Vol_{new}}$$

Where:
$Conc_1$ and Vol_1 and DM_1 = original concentration, volume and dry matter content
$Conc_2$ and Vol_2 and DM_2 = input concentration, volume and dry matter content

Livestock

When constructing a system, a separate node must be used for each livestock type. Then, for each node, the user must define the animal system by selecting 'livestock type' and then defining the number of livestock kept (on a monthly basis). Livestock definitions are in line with other databases to avoid confusion and to ensure some level of consistency between decision support systems:

Default values for the monthly volumes, nutrient concentrations and dry matter are extracted from the database for urine and faeces for the livestock type. Volumes are calculated for the total number of livestock

units. These calculated data are then passed through to the next stage of the model, which can be one or more of the following:
1. To field.
2. To hard standing.
3. To housing.

If some is passed, for example, straight to the field and some to the manure store, the approximate percentage that goes via each route can be defined by clicking on the lines linking the different icons (Fig. 2).

Hard Standing

The user must define the following information:
1. Whether the hard standing area a collecting or feeding yard (currently, this makes no difference to the calculation, due to lack of data, but at least the facility allows the calculations to be updated in the future should data allowing differentiation become available).
2. The yard surface area (m^2).
3. The wash down volume (litres/month).
4. The percentage of slurry that is removed monthly from the hard standing area.

Excreta on the hard standing area is treated as slurry. It is assumed that here is no leaching from the hard standing area, but that there is potential for gaseous emissions.

Volume/Mass Factors

The volume of slurry is assumed to increase over and above that which has come from the livestock, based upon:
1. The average monthly rainfall for the respective month is multiplied by the hard standing area to give a contributing volume (Vol_{rain}).
2. The monthly wash down volume is added to the contributing volume ($Vol_{washdown}$).

$$\text{Increase in volume} = Vol_{rain} + Vol_{washdown}$$

These additional contributing volumes from rainfall and washdown water reduce the dry matter percentage.

Dry Matter

Based on these additional inputs of water, the new dry matter percentage is calculated as follows:

$$MC_1 = 1 - DM_1$$

Where:
MC_1 and DM_1 = original moisture content and dry matter content

New moisture content (MC_{new}):

$$MC_{new} = \frac{Vol_2 + (MC_1 \times Vol_1)}{(Vol_1 + Vol_2)}$$

Where:
Vol_1 = original volume
Vol_2 and DM_2 = input volume and dry matter content

New DM (DM_{new}):

$$DM_{new} = 1 - MC_{new}$$

Currently, factors only exist for DAIRY COWS & HEIFERS in the collecting yard, further information is required to complete the database. This means that all animal types use these numbers.

Emission Factors

Emissions for the month are calculated by considering the overall volume of excreta generated for the month (including any non-livestock related volume increases). Emission factors (percentage of TAN going skyward) are calculated in the following way:

1. A factor for each livestock type has been extracted from the database. For each month a weighted average factor is calculated based upon:
   - The volume of each different livestock excreta type already existing in the hard standing area from the previous month (if there is any)
   - The volume of each different livestock excreta type entering the hard standing area from the back end of the livestock (if there is any).

2. The factor is a set percentage, which hasn't been derived from any exponential loss equation, e.g. the same percentage of TAN will be lost whatever the age of the slurry. This reflects our current state of knowledge.

Nothing in this node will allow the introduction of mitigation methods to reduce loss, other than changing the frequency of cleaning out and transferring to the manure store.

Housing

The user must define the following information:
1. Type of housing system: a slurry system or FYM system.
2. If a FYM system:
   i. The straw type being added
   ii. The monthly mass of straw added (kg/livestock unit/month)
3. If a slurry system:
   The type of slurry system (currently changing the slurry system type has no effect on losses)
4. The percentage of material removed monthly from the house

It is assumed that there are no leachate losses from housing, but that there are gaseous N losses.

Emission Factors

Emission Factors are calculated in exactly the same way as described in the Hardstanding section. The main abatement measures that can be adopted are cleaning frequency, and changing the amount of straw. Further data are needed for slurry system, which would then widen the choice of abatement methods.

Addition of Straw

The addition of straw has an effect on the system in a number of ways.
1. An increase in volume/mass of the material in the house depending upon the amount of straw added.
2. An additional load of C and Org N
3. A change the dry matter of material in the house. (Equations as above)
4. TAN ('Total ammoniacal N', previously defined) will be immobilised by the carbon within the straw – this will, in turn, decrease ammonia volatilisation.

Immobilisation of TAN

The calculated immobilisation of N by added straw follows the same methodology outlined in the NARSES database. A total load of TAN is calculated as being immobilised. The model has been written such that different rates of immobilisation will occur depending upon the excreta livestock source. However, in practice, all the rates are the same for every livestock class. Following the NARSES model, it is assumed that for each 150 kg of straw added into the house, 1 kg of TAN is immobilised.

For any month, immobilisation is calculated based upon the total mass of straw already in the manure from the previous month and the total amount of straw added in the particular month. Immobilisation calculates the load loss of TAN, however this load is then added to the Org N. Total N, therefore, remains the same, but the removal of TAN by immobilisation 'protects' this from loss by ammonia volatilisation.

Storage

The user must define the following information:

1. Type of storage: a slurry system or FYM system.
2. If a FYM system:
   i. Is it contained, composted or a field heap?
   ii. For abatement: is it covered or uncovered?
   iii. The surface area of the heap?.
3. If a slurry system:
   i. Is it a slurry tank or lagoon?
   ii. For abatement: is it uncovered, covered or crusted?
   iii. The surface area of the tank?
4. The percentage of material removed monthly from the store.

It is assumed that losses both by leaching and gaseous emission are possible in this stage of the system.

Volume/Mass Factors

If it is a slurry store, and the store is uncovered, it is assumed that the volume of slurry will increase with rainfall. Figures for average monthly rainfall are multiplied by the surface area of the open store to calculate an additional incoming volume.

Emission Factors

Emission Factors are calculated in exactly the same way as described in the hard standing section. However, abatement measures can be implemented here to reduce emissions. Factors have been gathered from the NARSES database for this.

Immobilisation

Immobilisation follows the same rules as described in the housing section. However, immobilisation is assumed at a reduced rate of 0.6 (this figure can be changed depending upon the livestock excreta type mixed in with the FYM but as with the NARSES spreadsheet it is assumed constant for all livestock types). Rates of immobilisation do not drop off with age of material.

Composting

If the storage system is FYM, then composting will occur if it is either a field heap or being actively composted. The following factors occur:

i. Actively composting will reduce the volume/mass by 15% per month
ii. In a field heap the volume/mass is reduced by 10% per month.

In the process of composting the concentration of carbon is reduced but the concentration of remaining nutrients increase (as a result of the reduction in volume and mass). Composting has the effect that the load of carbon is reduced (e.g. CO_2 loss) but the load of the other nutrients remain the same.

Composting Emissions

If the system is being 'actively composted' then any new material being added the composting pile will also be affected by N loss as ammonia. It is assumed that the gaseous emissions occur from only the new input material to the heap, because the ammonia loss profile is such that the greatest proportion of loss occurs in the first weeks [5]. The NH_3 emitted depends upon the C:N ratio of the FYM in the store. The C:N ratio is calculated as shown below, which was derived from the data summary provided by [1].

$$\text{Ratio} = \frac{C_{conc}}{(NH_4\text{-}N_{conc} + \text{Org-}N_{conc})}$$

$$\text{TAN emitted} = 73.5 - (2.603 \times \text{Ratio})$$

If TAN emitted < 0 TAN emitted = 0

Leachate from composting (or liquid losses)

If the FYM store is composted or a field heap there will be losses of leachate. Losses at this stage are only based on the input material each month. It is assumed that leachate losses affect NH_4-N and potassium only. In the calculations, the volume/mass of the material in the store is reduced. The concentrations of the NH_4-N and K decrease (this has the effect of reducing the load of K and NH_4-N) and the concentrations of OrgN, C, P increase (having the effect of maintaining the same load).

Other leaching (or liquid losses)

Leaching losses occur every month from a FYM heap if it is uncovered and is either a field heap or is being composted. Contained FYM pile is assumed not to have losses of leachate.

Leachate affects all nutrients. The total volume of water entering the heap is calculated on a monthly basis from average monthly rainfall figures and the surface area of the FYM pile. This water is assumed to mix perfectly with all material in the store. The volume of water entering the store is presumed to leave the store, maintaining the original volume/mass. The addition of this water effectively dilutes the concentration of all the nutrients.

This part of the calculation is probably the least robust, because it is unlikely that the water would mix completely with the manure heap. It would probably run off the dry crust and/or only infiltrate into the top few cm. We recognise that this aspect needs further work.

Fields

The equations defined in MANNER [9] used to calculate the losses at the field stage of the model from gaseous emissions and leaching. It is assumed that (a) there are only significant losses of N and (b) that there is no carry through from one month to another at this stage. Each input into a Field node is dealt with one at a time and the sum of the total losses to emissions and leachate calculated at the end.

Emissions

With the exception of poultry, emission factors are calculated as a weighted proportion of the individual livestock excreta in the material being applied to the field.

RESULTS – FARMER/ADVISOR FEEDBACK

Workshops were held at the start and end of the project. The aim of the first wokshop was to discuss with a small group of farmers and advisors their thoughts on the value of a manure management DSS, and their specific requirements for such a system. The day was structured as follows:

- Technical background to manure management issues.
- Aim of the MANMOD DSS.
- Examples of working DSS.
- SPREADS and MANNER.
- Discussion about the proposed MANMOD, wish list, practicalities, etc.

Work arising from a previous desk study on manure management on organic farms was presented, including the main issues of nutrient losses. The aim was to highlight the size of NPK losses, critical areas of management that affected these and practical solutions for reducing losses. The concept of MANMOD was then presented. Two working examples of DSSs were presented: MANNER [9] and SPREADS [11]. MANNER was a good example of a system that had one goal (calculation of N supply after field applications of manure) and did it well. It was out there in the agricultural industry and being used. Its user friendly interfaces meant that it was straightforward to use and that it was therefore more likely to be used. The SPREADS system was an example of how Windows-based software could be used to construct quite complex systems (in this case, representing the logistics of manure spreading) simply using drag and drop icons. The idea of demonstrating this software was that it was likely that the same approach would be used for the MANMOD system: linking, for example, animals to housing, to manure storage, to field heaps, to field applications. Participants were encouraged to work through real examples and get a feel for the intuitive nature of the programs.

Following on from these examples, a discussion about the concept of a MANMOD DSS yielded the following observations:
- Anything that helped to make better use of the nutrients is a good thing providing that it was user friendly.
- It would help in planning, it would help explore a variety of options quickly (‘what if’ questions), though it may only be used once at the planning stage, for example.
- It was noted that ‘what if’ options were likely to be limited due to the constraints placed on farms through the organic regulations.
- Possible link to conversion planning?
- It could help with ‘traceability’ – i.e. demonstrating that best practices were being adopted and quantifying losses as a result.
- It could assist with field recording.
- It would need on-farm validation to raise its credibility.

The second workshop was held after the prototype had been developed, and it was used as an opportunity to demonstrate, primarily to organic advisors the structure of the DSS. As a part of the exercise, a part of the Elm Farm animal production system was used to test the effectiveness of the software in being able to represent the system. The constructed system is shown in Figure 3 (above). The following observations were made as a result of this exercise:
- The approach is a relatively quick and simple way of constructing manure management systems. However, it is still quite complex, given the complexity of many management systems.
- It may be that it is a better tool for advisers so that they can use it for several clients and become more familiar with the tool, compared with a farmer who might use it as a one-off during planning.
- Even at its simplest, some detailed information is required – and in units that the farmer may not be familiar with. For example, washdown volume for the hardstanding, amount of straw (kg/animal/month), etc. However, this is not really a reason for not pursuing this information if it will provide an improvement in management. One point for future consideration would be to include imperial measurements as an option (not included in this prototype).
- Its value is the option to scenario test. However, this is reliant on the model being sufficiently refined to be able to fairly represent the changes in response to the system. Further data are required to improve some of these aspects, as already described.

We therefore concluded from this exercise that the MANMOD DSS had potential, but there are some points still to tackle in any future development.

RESULTS – MODEL OUTPUT

Example systems

As an example of systems, a theoretical ‘simple’ system was constructed, as described in Figure 2. The N flows with comments are shown in Figure 4. Table 1 summarises the N losses. The system was such that there were no leachate losses (other than leaching of N after field application), and so P and K were retained throughout the system. Ammonia losses represented the majority of N lost, occurring at each stage of the manure management system.

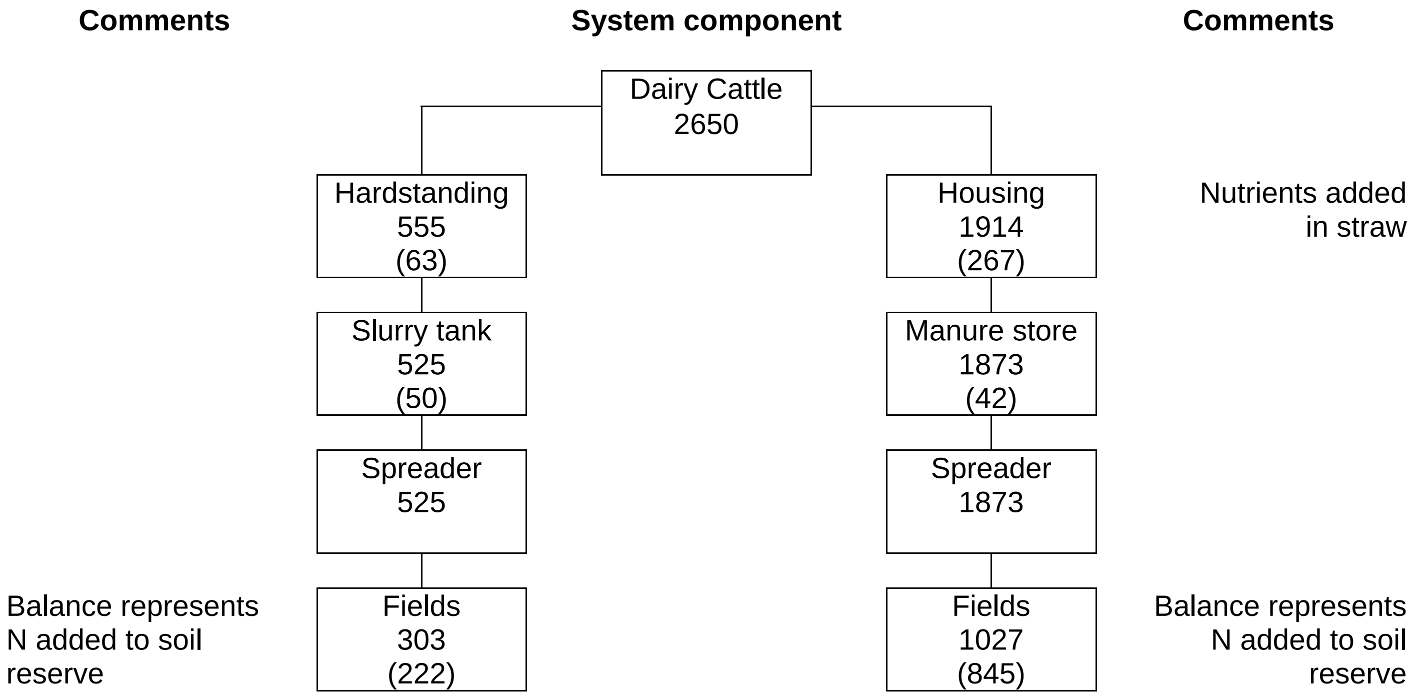

Figure 4. N flows (kg) calculated by MANMOD, based on a 50 dairy cow system described in Figure 2. Numbers not in parentheses are the annual N outputs after losses (numbers in parentheses).

Table 1. Summary of nutrients outputs from the dairy cow system (kg). Note the numbers do not balance because the excreted amount takes no account of nutrients added in rainfall and straw.

	Excreted	**Lost**	**Balance**
N	2650	1489	1330
P	476	0	496
K	2070	0	2156

Table 2. Calculated effects on N losses (kg) of storing the manure and delaying application until spring ('scenario 2'), compared with the original strategy of monthly applications through winter (based on the example system in Figure 2), 'scenario 1'.

	Scenario 1		**Scenario 2**	
	Slurry	**FYM**	**Slurry**	**FYM**
Housing	-	267	-	267
Hardstanding	63	-	63	-
Storage	50	42	164	168
Field	222	845	295	58
Total	1489		1014	

The conclusion was that about 50% of the N excreted by the animals was lost to the wider environment (although some additional N was added to the system in straw). However, a large proportion of this was lost after field application because manure was (a) left on the soil surface, thus increasing volatilisation risk, and (b) applied throughout the early autumn, thus increasing nitrate leaching risk. When the model was rerun, applying all of the manure in April with rapid incorporation, total field losses of N decreased to 65 kg, but there was an increase in ammonia losses from storage (Table 2). Thus, at least, the model seems good at representing the trade off between losses at different stages of the production cycle and also demonstrates the leaky nature of the production cycle, at least in terms of N. Further scenario testing of individual components of the production cycle is described later.

Figure 5 shows the calculated N flows for the Elm Farm system. Whereas there appears to be substantial N losses through the system, all of the excreted P and K is transferred to the fields (*c*. 650 kg/ha P and 3500 kg/ha K).

System component

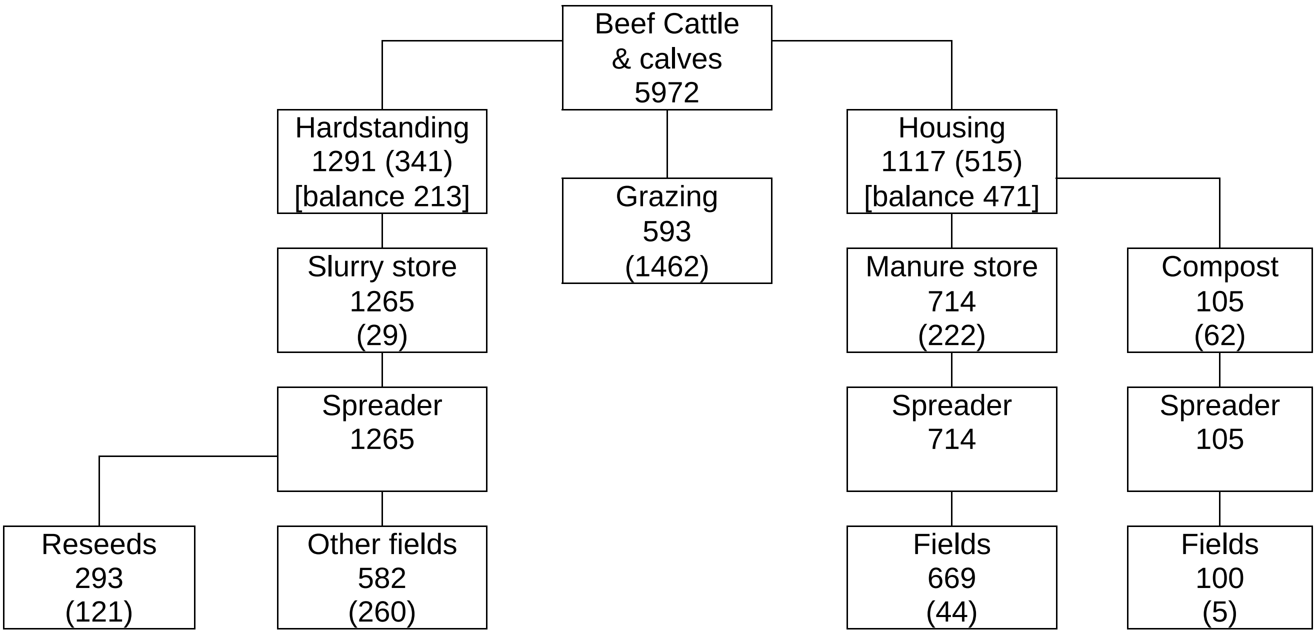

Figure 5. N flows (kg) calculated by MANMOD, based on the Elm Farm beef system. Numbers not in parentheses are the annual N outputs after losses (numbers in parentheses). Numbers in square brackets represents N still in the building because it was specified that not all material was removed.

Comparing with manure analysis

To check if the output were sensible, a simple dairy system was run in MANMOD, first using the assumption that it was a slurry system, and then a straw based system. By drilling down through the output screen for the manure store it was possible to determine the calculated nutrient contents of slurry (kg/m^3) and FYM (kg/t). Results are shown in Table 3, which expresses results both in absolute terms and as nutrient ratios (with respect to N).

Table 3. Comparison of calculated cattle manure nutrient composition with standard values as published in RB209. Also included for comparison is typical values for cattle manure from organic holdings [12].

(a) nutrient content (kg/m^3 or kg/t)

Manure	Source	N	P_2O_5	K_2O
FYM	Manmod	4.8	2.1	4.9
	RB209	6.0	3.5	7.2
	Organic	5.2	2.9	6.3
Slurry	Manmod	4.1	2.3	5.2
	RB209 (10% DM)	4.0	2.0	5.0
	Organic (8% DM)	2.5	1.2	2.5

(b) nutrient ratios

Manure	Source	N	P_2O_5	K_2O
FYM	Manmod	1	0.5	1.0
	RB209	1	0.6	1.3
	Organic	1	0.6	1.2
Slurry	Manmod	1	0.6	1.3
	RB209 (10% DM)	1	0.5	1.2
	Organic	1	0.5	1.0

This was a challenging test, given the transformations that MANMOD has to model. Despite this, the comparison with standard values in RB209 [13] was reasonable. However, given the variability associated with manure composition, it may have been fortuitous. The comparison was better for 'conventional' slurry. This was not surprising given that a slurry system is more straightforward, and does not have the complicating factors of interactions with straw during housing and manure storage. The FYM calculation seemed to consistently underestimate nutrient content for N, P and K. One possible reason could be the mass loss calculation, and this needs further investigation.

Standard values for manure from an organic holding [12] were also compared with MANMOD output. These manures tend to have a smaller nutrient concentration. Shepherd *et al*. [12] hypothesised that this may be due to smaller NPK inputs in organic diets. For FYM, because MANMOD calculated smaller nutrient concentrations than those reported in RB209, and because concentrations are smaller for the organically produced manures, there appeared better agreement between MANMOD and organically produced manures. However, the better agreement between calculated nutrient contents and those from organic holdings was pure coincidence, given that nutrient excretion rates in the model are based on 'conventional' livestock. This is further supported by the fact that the organically produced slurry had nutrient concentrations of about a half of those calculated by MANMOD. This is explored more in the 'discussion'.

Scenario testing

To further test if MANMOD was sufficiently sophisticated to be able to determine differences between changes in management, the basic system, as defined in Figure 2, was adjusted in individual elements to observe the changes in N fluxes. None of the practices had effects on P and K fluxes. The tested factors were:

1. Converting to a full slurry system, compared with a straw based system.
2. Increasing the amount of straw in the house (solid manure system) (Table 5).
3. Composting vs stockpiling solid manure (Table 5).
4. Covering the slurry store (Table 6).

Converting to a slurry system increased ammonia losses during the housing and storage (open slurry store) phase (Table 4). Increasing the amount of straw only had a small effect on the N losses before land-spreading (Table5). The calculation method assumes only a relatively small amount of N immobilisation during the housing and storage phases. A 10-fold increase in straw addition decreased ammonia losses in the model by 4% when the manure was stockpiled. Further experimental data are required to confirm the assumptions in our calculation.

The largest effect came from composting the manure, compared with stockpiled (undisturbed) manure (Table 5). This is because of the active composting (stirring/heating) encouraging ammonia loss. This is clearly critical to the N balance of the system. The basis of the calculation was described above and was supported by the scientific literature [1]. However, this is so critical that the relationship should be further confirmed.

The slurry store management had a significant effect on ammonia losses during this phase. Compared with an open store, a 'covered store' decreased losses to 80% and a 'crusted' slurry halved N losses.

Table 4. Calculated effects on annual N loss (kg) of switching from a straw based system to an all slurry system.

	Slurry system	Straw system
Housing	394	267
Hardstanding	63	63
Storage	189	92
Total	646	422

Table 5. Calculated effects on annual N loss (kg) of increasing the straw bedding per animal, assuming house cleared twice and the manure store is emptied at the end of winter. Also includes the comparison of stockpiled (S) and composted (C) manure.

Straw per animal per month (kg):	**10**		**50**		**100**	
Total straw in house (tonnes):	**3**		**15**		**30**	
Manure management:	**S**	**C**	**S**	**C**	**S**	**C**
Housing	463	463	460	460	456	456
Storage	109	608	102	562	94	510
Total	572	1071	562	1022	550	966

DISCUSSION

Manure management systems can vary in complexity depending on the farming system. A simple system would be, for example, an intensive poultry unit where the chicken manure may be collected, stockpiled and then spread or exported off farm on a regular basis. At the other extreme, a mixed livestock enterprise might involve different animal manures being managed separately and in different ways. It is our observation, whilst collecting information on manure management practices on organic farms (Defra project OF0161), that manure management on organic farms may be complex.

To allow calculation of nutrient flows, it is important to be able to quickly represent the system so as to allow completion of the underlying calculations. With any decision support system there is the balance between level of detail required for robust calculation and the level that can easily and quickly be entered by the user. The MANMOD system tries to represent complex systems, but by using the icon-based approach originally developed for SPREADS [11], it does allow systems to be built relatively easily. This was demonstrated at the workshop, where the Elm Farm system could be assembled in about 30 minutes. However, it may be that the DSS is better suited to use by consultants:

- More chance of using it on a regular basis with a range of clients. Would therefore be come more familiar with it with regular use.
- Individual farms might only need to use it occasionally – at the planning stage, or when considering changes in practice, for example.

One option to simplify the process would also be to add a library of 'typical' manure production systems, which could be edited to take account of individual circumstances.

Although we have been able to develop a prototype system in this short-term project, the complexity of the systems that we are trying to represent means that this is a good starting point but further work is required. In particular, the following points can be made.

Because manure management systems are complex systems to model, there are many points where there is scope for discrepancy between calculated and actual data. Consequently, the outputs are difficult to validate quickly. This is because:

- There are numerous interactions, so that care has to be taken when validating a single element.
- There are few systems experiments that would allow validation of the output.

However, mainly driven by the need to develop ammonia policy, Defra are now funding several projects on manure management which, when complete, will provide information to validate the MANMOD output.

Consequently, in this short-term project, we took the approach of starting to investigate the output from MANMOD by scenario testing and comparing with manure nutrient contents. We recognise that there would still be considerable validation to undertake, but the detail needed was outside the scope and resource of this project.

In general, the output looked sensible in terms of NPK flows through the systems and it demonstrated the interactions between management factors and different parts of the management process. For example, if ammonium-N was retained in store (by covering the slurry store), then this was at risk of loss after land spreading. Where N was immobilised by adding more straw to FYM, this decreased the risk of subsequent losses.

Development of MANMOD, like all models,has shown where information is particularly lacking. In some areas, these are crucial to the manure production cycle and will impact substantially on calculations if the wrong assumptions are used. These include:

- Immobilisation of N by added straw. In the house, a model run showed that increasing straw amount by 10-fold, had <5% difference on immobilisation. This needs further investigation.
- Effect of composting: calculations were based on the thorough review undertaken as a part of project OF0161 (e.g. Figure 6). Nevertheless, the large amounts of ammonia volatilisation predicted by the calculation need further independent validation.

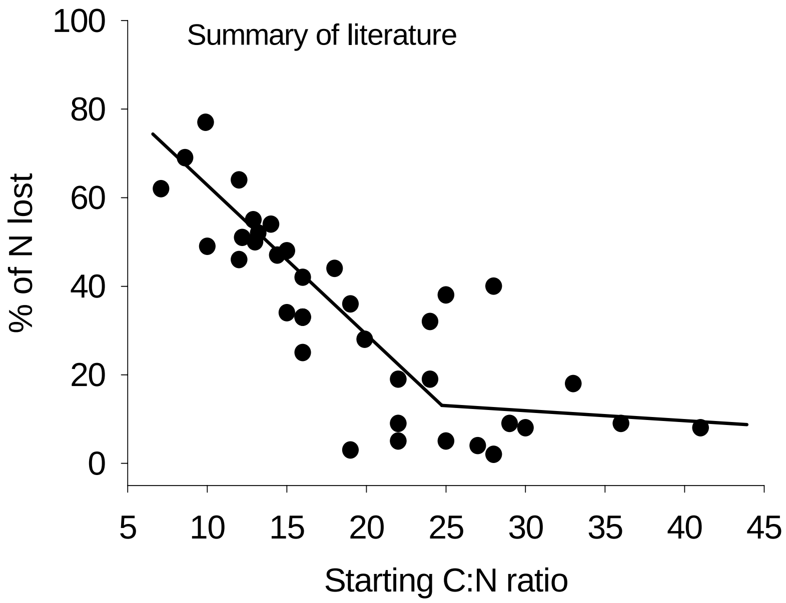

Figure 6. Effects of C:N ratio on ammonia losses in composting FYM, based on a review of experiments [1].

To a large extent, risks were minimised by using approaches developed for other databases/models wherever possible. Hence the use of MANNER approaches for field losses [9]. We also made full use of the NARSES database and emission factors. However, the model is lacking in two respects.

Firstly, it does not take account of gaseous N losses other than ammonia. The original specification was to include N_2O as an important greenhouse gas. However, there were insufficient data to allow a meaningful inclusion of this loss pathway. We could have included emission factors taken from the UK inventory [3], but these would offer little scope for testing mitigation methods since they are not refined enough for this purpose. Since N_2O emissions are rarely of agronomic significance in their size, then the omission of this process is less important. It may be that denitrification and conversion to di-nitrogen gas is a larger loss pathway in some circumstances (anaerobic, moist conditions). This is sometimes cited as a reason for discrepancies between calculated and measured N balances. However, again, data are lacking so that the inclusion of this pathway could not be justified.

Secondly, MANMOD, was originally intended for organic producers. Whereas loss <u>processes</u> are the same under organic and conventional systems [14], the major driver for the calculated nutrient flows is the NPK excretion rates from the animals at the start of the production process. Currently, the MANMOD database has excretion rates for conventionally reared stock, because these are the only data available. Shepherd *et al*. [12] hypothesised that excretion rates should be less (based on manure analysis), but there are insufficient data to build a sufficiently comprehensive dataset to support MANMOD.

Given the importance of this aspect on subsequent calculations, we must therefore conclude that although MANMOD might work as a DSS, it is not yet strictly applicable to the organic sector. One approach that might be a short-term solution would be to reduce nutrient excretion rates across the board by x%, where x is based on the limited available information to date. Further work to support this approach would be needed. Based on manure analysis [12], this reduction could be as much as 20%.

Nitrogen is the most difficult of the nutrients to account for because of the potential losses from the system as ammonia (and nitrate, after field application). Generally, MANMOD assumes good practice in that all leachate from manure during storage is collected and used, rather than entering the wider environment. Therefore, MANMOD is at its simplest for P and K because it is essentially maintaining a balance sheet of these nutrients through the manure production system, with some estimate of partitioning between slurry and FYM.

CONCLUSIONS

Most of the effort in this short-term project was spent on three aspects:
- Developing databases and the underlying model calculations.
- Developing the software for the prototype system.
- Limited validation of the output.

Whereas the loss processes are the same for organic and conventional systems, the starting point for MANMOD is the nutrient excretion by the livestock. Because of lack of data for organic livestock, these rates are based on conventionally reared stock. Therefore, they are not entirely appropriate for organic producers.

The software has been developed such that manure systems can quickly be constructed using drag and drop icons. This has proven to be an effective method of representing complex systems. The underlying calculations are based on existing approaches wherever possible. However, the model has also developed new algorithms where necessary, based on literature. These need further validation.

The output from the model on test runs looks sensible and appears to represent interactions between management processes in an logical manner. Agreement of predicted manure nutrient concentrations for cattle FYM and slurry was reasonable, but was poor for organically produced manure – presumably because of the problems with nutrient excretion rates, as discussed above.

The aim of the project was to produce a prototype system. We have done this but, because of the complexity of the systems that we are trying to represent, we recognise that much more detailed validation of the model is required before it a can be disseminated. One of the problems was that there were few data that could be used for validation, but there are now several Defra-funded studies that could be used in any future work.

CONSEQUENCES FOR DEFRA

This DSS starts to show the interactions between different components of a manure management system, such that retaining N in one part of the system may have consequences for losses at a later stage and *vice versa*. Most of the N losses occur as ammonia. Given Defra's need to develop ammonia policy, this DSS has a potential role in providing management advice for mitigation methods as well as being a tool for farmers and advisers. However, further development work is required for it to used for either aspect.

The original intention was that the DSS would primarily be used to provide better advice to organic producers, though more work is required on producing a database of nutrient excretion rates for organic livestock.

FUTURE WORK

The following activities would be warranted to build upon the progress made to date:
1. Further, more detailed validation against real data.
2. Improve parts of the model where data were lacking, but are becoming available in other experiments.
3. Further checking of the software and produce a user manual.
4. Produce a technology transfer plan.

PROJECT OUTPUTS

1. Platform presentations and talks:

- Organic Research Conference, Aberystwyth, Spring 2002.
- British Society of Animal Science, York, Spring 2003.
- Poster to be presented at the BGS/COR organic conference, spring 2004.

2. Papers, reports:

Shepherd, M.A., Webb, J. & Philipps, L. (2002). Tools for managing manure nutrients. In: *Research in Context, Proceedings of the UK Organic Research 2002 Conference* (Ed J. Powell), pp. 165-168.

Shepherd, M.A. (2003). Managing manures in organic farming. *Proceedings of the British Society of Animal Science*, pp. 240. BSAS.

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