MEASURES: MULTIPLE ENVIRONMENTAL OUTCOMES FROM AGRICULTURAL SYSTEMS.

J. E. ANNETTS, E. AUDSLEY, D. L. SANDARS, A. E. MILNE

Mathematics and Decision Systems Group, Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS, U.K.
E-mail janet.annetts@bbsrc.ac.uk, eric.audsley@bbsrc.ac.uk, daniel.sandars@bbsrc.ac.uk, alice.milne@bbsrc.ac.uk web site: http://www.sri.bbsrc.ac.uk/scigrps/SG9/Measures.htm

ABSTRACT

The interactions in farming systems between environmental outcomes, profitability and farm management are compex. The MEASURES project, funded by the UK Ministry of Agriculture, Food and Fisheries (MAFF), is developing a modelling framework to show such interactions. The framework is comprised of analyses performed using the Silsoe Whole Farm Model, in which relationships between environmental outcomes such as nitrate leaching, ammonia volatilisation and phosphorus loss have been developed from other models and data. The first analysis optimises farm profitability to assess the value of alternative slurry spreading techniques designed to reduce ammonia volatilisation, on mixed arable and dairy farms. The initial results show there is an apparent "law of diminishing returns" for ammonia abatement verse profit. The reduction in ammonia volatilisation leads to trade-offs and complimentary changes in other emissions and inputs, which are due in the main to changes in cattle numbers and cropping patterns.

INTRODUCTION

This paper describes the first results from the modelling in the MEASURES project (Multiple Environmental outcomes from Agricultural Systems). The objective is to develop a modelling framework, which includes a number of environmental effects such as nitrogen losses to air, water and soil, phosphorus loss.

There are three parts to the modelling framework. The first is the Silsoe Whole Farm Model, a farm planning model based on linear programming. This model has been developed to allow any number of environmental effects to be associated with different farm management techniques and cropping options, alongside profitability. This model can be used to analyse different farm scenarios allowing the interactions of the effects and farm management to be explored. The second is the development, from other models and data, of relationships to quantify each environmental effect depending upon the farm management. For example, nitrate leaching equations have been developed from IACR-Rothamsted's SUNDIAL and other models such as MANNER. The third element is the development of a visual presentation interface, which allows users to interrogate the results of different analyses when modelling typical or actual farms under different management strategies and mitigation options.

Thus the MEASURES modelling framework provides a consistent and integrated approach to help farmers and stakeholders to achieve multiple environmental objectives in a cost-effective way and to demonstrate the impact of current and future farming practices on the environment.

THE SILSOE WHOLE FARM MODEL

The Silsoe Whole Farm Model (Annetts & Audsley) is a PC-based linear programming model of a farm designed to determine the cropping, labour and machinery which optimises long-term profit or a multiple objective of profit, risk and environmental criteria. The model takes the whole system approach, including being able to fully adjust operation timings and crop rotations by the use of timeliness and rotational penalties; allowing workable hours to depend upon the type of operation, linking arable and livestock production by the use of crop by-products as feed, and application of animal waste to crops; scheduling grass as grazing, silage or both throughout the season. The model is ideal for examining the effect of changes on a farm such as crop gross margins, new crops, machinery or techniques. However, the model does not include the spatial aspect of a farm and thus cannot include spatial environmental impacts such as biodiversity or landscape features. Outcomes from the model are non-integer values, for example the number of machinery required each year, although it is possible to set integer limits to machinery numbers. The model has a comprehensive database, which covers most crops grown in the UK. However, users will normally wish to examine the data and adjust it to better describe their own conditions. Aspects such as soil type and annual rainfall can be changed which in turn effect crop yields, workablility of the soil and environmental impacts.

Figure 1 shows the complexity of Silsoe Whole Farm Model with regard to relationships within the model. Starting from the outer ring a user can choose the alternative cropping options available to the farm, and the farm's conditions such as soil type and weather. From this information the model determines the workability of the soil and hours available to work. A crop is defined by outputs of profit and environmental impacts, inputs, possible crop rotations and operations required as a set of sequenced operations and other non-sequenced ones, some of which are optional. The crop outputs and some inputs are altered depending upon operation timing, crop rotation and machinery system alternatives, which could include for example different machine sizes. Using linear programming, the optimum cropping, machinery and labour is calculated, to satisfy an objective of maximum profit, minimum environmental outcomes for a set profit, or some weighted combination of profit and environmental outcomes.

ENVIRONMENTAL DATA

Currently there are five environmental outcomes modelled within the Silsoe Whole Farm Model. These are nitrate leaching, nitrous oxide loss, ammonia volatilisation, methane loss and phosphorus loss as erosion. These pollution issues have been included in particular because the first results shown from the MEASURES framework are assessing the value of reducing ammonia volatilisation by the use of different slurry spreading techniques on mixed arable/livestock farms.

Within the Silsoe Whole Farm Model, relationships between each crop and livestock, and changes thereof due to operations, machinery systems, crop rotation of each environmental outcome have been developed. In addition, changes to the expected crop inputs, such as nitrogen and phosphorus fertilisers are also included. This is especially important when considering the spreading of waste from livestock. The actual and perceived nutrient value of the waste will effect the farm management options chosen and the consequencial environmental outcomes.

The nitrogen cycle is a compex process, for which there are a number of models available looking at different aspects within the farming system. Three models were used in MEASURES to develop relationships between nitrogen losses and choice of arable cropping and grassland production, alternative slurry and manure spreading options, slurry storage and dairy production. These models are SUNDIAL, MANNER and NCYCLE. In addition for ammonia emissions there is also inventory data, which gives information per livestock head, due to grazing, housing, storage and landspreading of manure across the UK.

IACR-Rothamsted's SimUlation of Nitrogen Dynamics In Arable Land (SUNDIAL) (Smith et al., 1996) is a dynamic computer model of nitrogen turnover in the arable crop/soil system. It incorporates current scientific knowledge on the individual processes of nitrogen (N) turnover and integrates these processes to simulate what happens in the whole soil. The model has 14 compartments. There are 3 input compartments: atmospheric N, inorganic fertiliser N and organic manure N. There are 7 transformation compartments, into and out of which N flows. Nitrogen may leave the system by one of 4 output compartments: denitrification, leaching, volatilisation and harvested N. SUNDIAL was run for many combinations of crop rotations, soils, annual rainfalls, fertiliser applications, manure, crop cultivation types and sowing dates. The resulting outputs are decomposed into nitrate leaching due to soil type, rainfall, previous crop, current crop, timing and type of cultivation and planting, fertiliser applied and crop offtake. Thus providing appropriate relationships to fit within the framework of the Silsoe Whole Farm Model.

The ADAS MANure Nitrogen Evaluation Routine (MANNER) (Chambers et al., 1999) is a decision support system which predicts the plant availability of manure N following application to land. It draws together the latest UK research information on factors affecting the manure nitrogen availability to crops and losses of nitrogen via ammonia volatilisation and leaching. MANNER was used to produce a data set that examines the effects of soil and manure types, application techniques and rainfall on the amounts of nitrogen lost either to the atmosphere by volatilisation of ammonia or the leaching of nitrate.

NCYCLE (Jarvis et al., 1995) is a balance sheet calculation of changes in nitrogen due to a grass ley sward. Outputs include N losses of leaching, denitrification and volatilisation. The model includes partitioning of nitrogen into grass/clover uptake, amount consumed, animal outputs (meat, urine, dung). The model takes account of soil types, climate, drainage anmd soil texture, land use and age of sward. Thus for a grass crop estimates of nitrogen losses are made depending upon soil type, rainfall, livestock present, silaging and fertiliser applied.

Table 1 shows the data relating to each slurry spreading method. From splash plate to deep injection it is assumed that ammonia volatilisation is reduced for a given area of application as shown. In addition there is a fixed amount per head of animal of 17.3 kgN assumed due to housing and storage systems. The results shown in the following section are the changes for the whole system due to using a particular application, i.e. by including a particular system there will be consequences in terms of livestock numbers,cropping, etc.

FIRST RESULTS

The first results in the MEASURES framework concentrate on slurry spreading systems, in particular those which could be used to reduce ammonia volatilisation. By using the Silsoe Whole Farm Model to model alternative farm and system scenarios, an analysis is built up which can answer such questions as:

1. What are the environmental outcomes of the whole farm system to the introduction of an alternative slurry spreading system compared with the traditional splash plate method?
2. How does changing the slurry spreading method effect the overall net farm profit, cropping and livestock numbers?

3. If, due to investment in capital equipment, a farmer chooses to keep a fixed level of livestock, what is the effect on environmental outcomes, profit and arable cropping of each alternative slurry spreading system?

The farm scenarios used in this analysis are for 3 soil types, 3 rainfalls and 6 different slurry spreading methods. For each scenario the model is used to calculate 2 solutions. The first allows the model to choose the arable and grassland cropping from a range of alternatives and the numbers of livestock to a minimum of 150. The second fixes the numbers of livestock at 150, which in turn fixes the amount of waste to be applied.

Figure 2 shows the interactions between environmental outcomes, crop inputs, profit and livestock numbers for each slurry spreading scenario. As expected the ammonia volatilisation decreases through the range of spreading methods. However part of the reduction can be explained by the decreasing numbers of livestock which are profitable. Allowing the livestock numbers to change has shown that ammonia volatilisation can be decreased by 30% for the shallow injection compared with the splash plate. By assessing the second solution where cow numbers are fixed to 150, 12% of this decrease is due to decreasing cow numbers and 18% is due to application and cropping differences.

As cow numbers are decreasing, the arable area is increasing resulting in an overall increase of nitrate leaching across the spreading methods. Due to increasing costs involved with the new technologies of spreading techniques the model shows a decrease in profitability. Figure 3 shows how net annual profit is being traded against savings of environmental outcomes. That is, for the farmer to implement the slurry spreading systems which reduce ammonia volatilisation, even by altering cropping and livestock to maximise the profitibility of the whole system, the costs are such that there is a reduction in farm profit.

CONCLUSIONS AND DISCUSSION

The initial results show there is an apparent "law of diminishing returns" for ammonia abatement verse profit. The reduction in ammonia volatilisation leads to trade-offs and complimentary changes in other emissions and inputs, which are due in the main to changes in cattle numbers and cropping patterns.

Using the MEASURES modelling framework, it will be possible to explore the enconomic and environmental impacts of a range of questions. The framework will allow detailed examination of results to establish understanding of conclusions from analyses. Graphs and tables held in the framework will show the interactions and trade-offs within a particular analysis, with supported html text. The details of the modelling background and science will also be available within the framework.

REFERENCES

Annetts, J. E., Audsley, E. (submitted) Multiple objective linear programming for environmental farm planning. Journal of the Operational Research Society.

Chambers, B. J., Lord, E. I., Nicholson, F. A., and Smith, K. A. (1999) Predicting Nitrogen Availability and Losses Following Land Application of Manures : MANNER. Soil Use and Management, 15:137-143

Jarvis, S.C., Scholefield, D. and Pain, B.F. (1995) Nitrogen cycling in grazing systems. In: Bacon, P. (Ed.) Nitrogen fertilization and the environment, Marcel Dekker, New York.

Smith, J.U., Bradbury, N.J. & Addiscott, T.M. (1996) SUNDIAL: A PC-based system for simulating nitrogen dynamics in arable land. Agronomy Journal 88:38-43

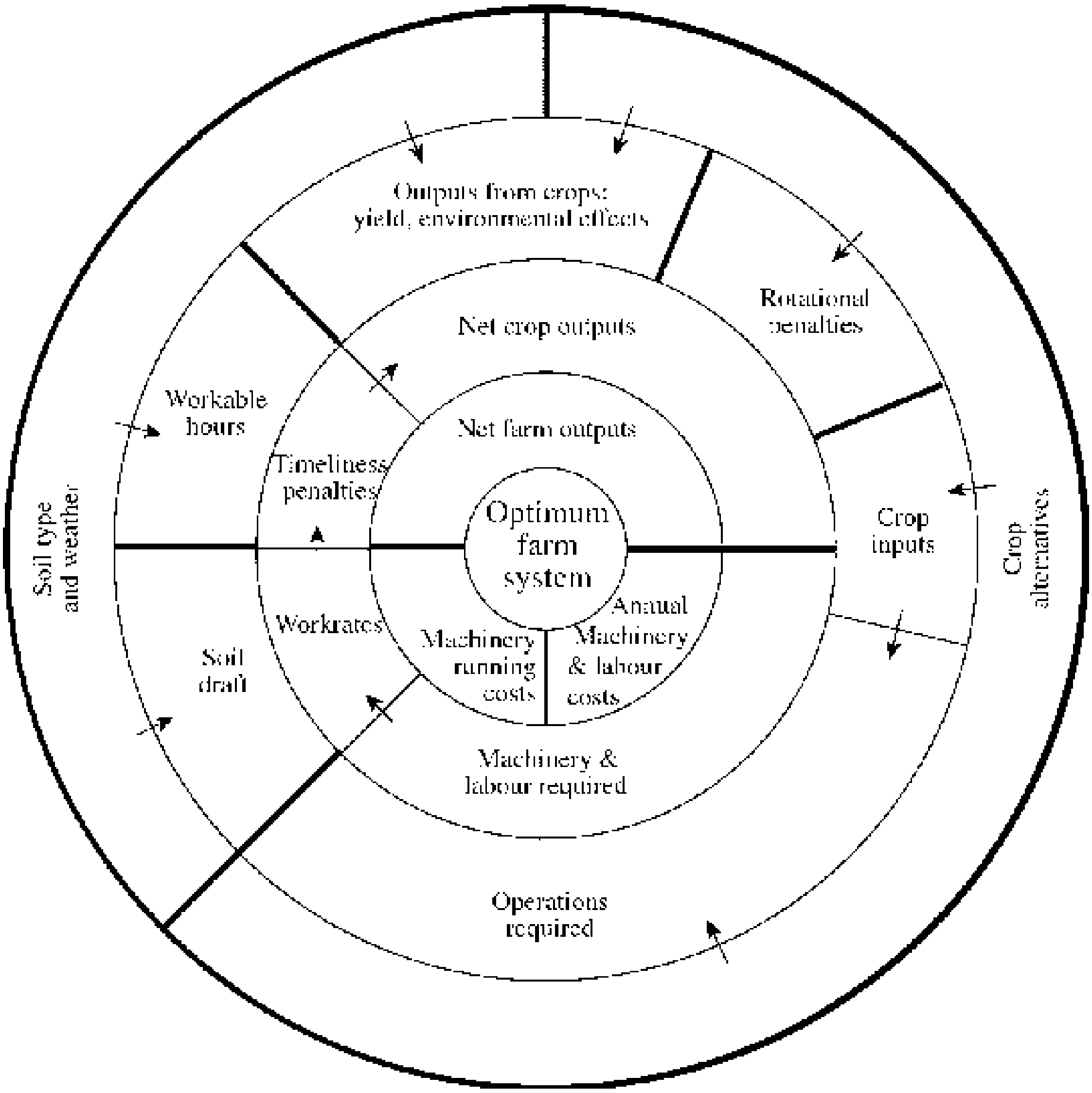

FIGURE 1. Input data and relationships within the Silsoe Whole Farm Model

TABLE 1. Slurry spreading system definitions in terms of ammonia volatilisation, workrates, power requirements and capital costs.

System	Ammonia volatilisation. w.r.t. splash plate system per ha applied	Workrate hours/ ha	Power requirements, kWh	Capital Cost, £
Splash plate	100% all	0.42	40	8169
Boom spreader	95% all	0.42	50	15144
Trailing pipe spreader	55% arable	0.46	40	13569
Trailing shoe spreader	45% grassland	0.54	70	13569
Shallow injection	20% grassland, 30% arable	0.917	90	15669
Direct ground injection	20% grassland	0.54	65	15669
Deep injection	5% grassland, 10% arable	1.183	90	13169

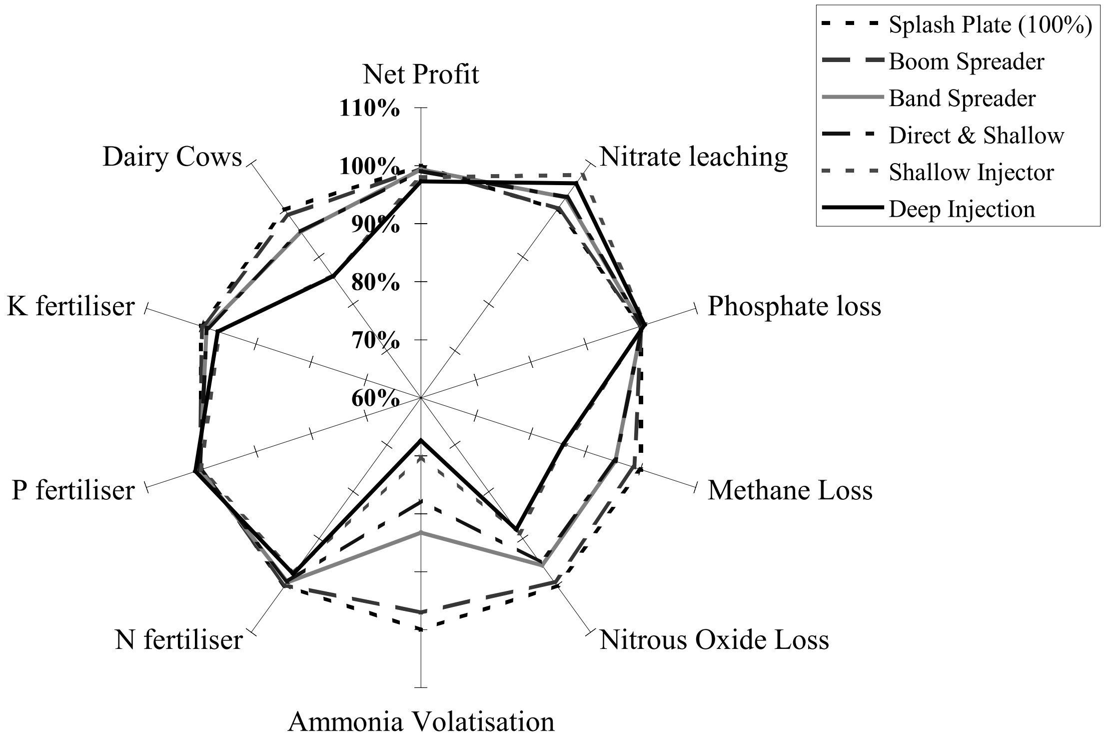

FIGURE 2. Interactions between environmental outcomes, profitability, cow numbers and crop inputs of the whole farm system under different slurry spreading systems.

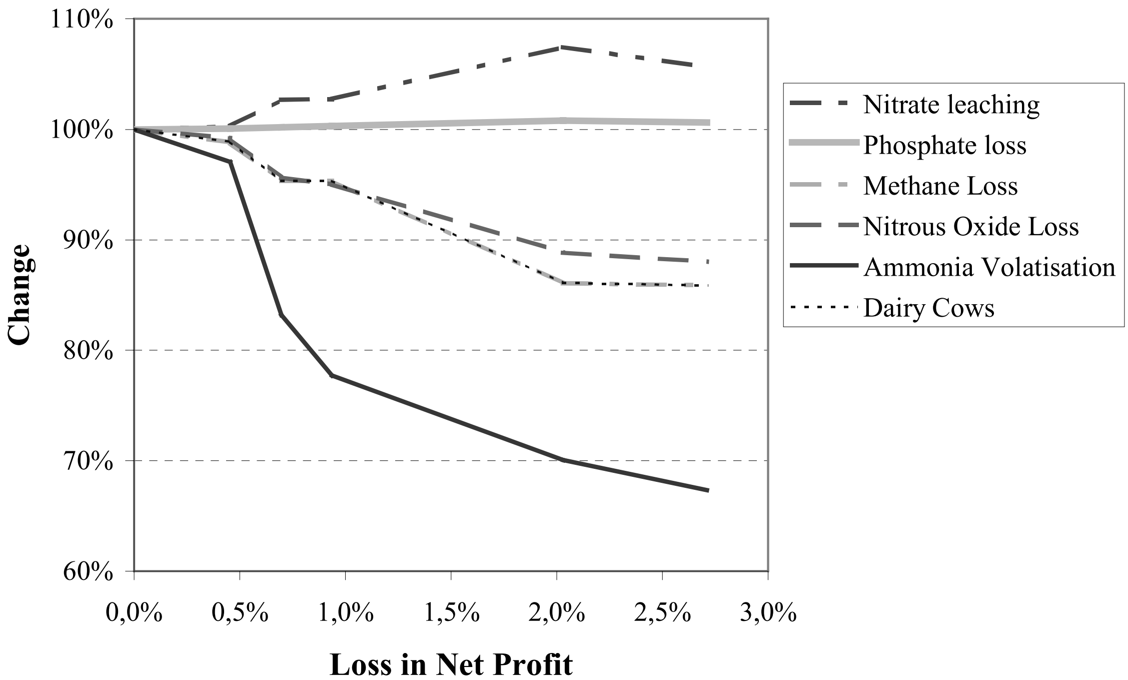

FIGURE 3. Trading net profit for environmental impacts