A DECISION SUPPORT SYSTEM FOR ENVIRONMENTAL MANAGEMENT OF AGRICULTURE*

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ABSTRACT

The University of Hertfordshire, in collaboration with two UK agricultural establishments are developing a decision support system for environmental management in arable agriculture. The system aims to encourage and promote best practice. Significant environmental effects from arable agriculture arise from the use of fertilisers, pesticides and unsustainable soil management practices. The software's assessment routines determine eco-ratings and textual descriptions of performance by comparing actual practices with best practice. To provide a full farm assessment, other activities such as energy and water use, waste management and intensive livestock husbandry are also included. The system incorporates modules which allow 'what if' scenarios to be explored and a hypertext information system which includes legislation, codes of best practice, a science library, glossary, index, contacts database and information on formal environmental management and farm auditing.

1.0 INTRODUCTION

There have been dramatic changes during the last century to agricultural practices. The numbers of farm workers has decreased and dependency on farm technology and mechanisation has grown. The desire for greater productivity has committed many farmers to using techniques which sometimes have detrimental environmental effects (NRA, 1994). Farming practices are influenced significantly by social and economic factors and farmers are under considerable pressure to produce large quantities of good quality, cheap food. High crop yields rely heavily on the use of nitrogenous fertilisers and on pesticides. The consequential environmental impact is significant. A large proportion of the nitrogen used is leached from the soil causing nutrient enrichment in water bodies and contamination of drinking water supplies. Pesticides are contaminating water sources, there is concern regarding residue levels in fresh produce and some insects are resistant to certain pesticides. Changes

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in livestock practices have also caused environmental problems. Traditionally, livestock was pastured, mixed farms were common and animal wastes were rarely a problem. Today, however, intensive livestock practices, often mean there is insufficient land for spreading the manures produced, large volumes must be stored on site and the risk of causing a pollution incident is high.

Compared with many other industries, agriculture is relatively unregulated. It is probably the only industry which can legally spread potentially toxic chemicals directly to the land and a significant proportion of all farm inputs are wasted due to missing the target area, through drift, drainage, runoff and volatilisation. The need for the agricultural industry to apply best practice is very apparent. The introduction of environmental management systems such as BS7750 and the EU's Eco-Management and Auditing Scheme (EMAS) marked the beginning of a commitment to environmental management for many industries but not for agriculture, probably because market benefits are perceived as marginal and farmers see it as a time consuming, paper exercise.

There is no paucity of information on the environmental fate of pollutants, best practice and on environmental science in general. The problem seems to lie solely with technology transfer. Much of the information available is produced by scientists for scientists or for policy makers and not in a format readily suitable for farmers. There is a need for a decision support system available to the farming industry which will help them distil currently available information and produce a coherent action plan specifically designed for their own farm which will not jeopardise profitability.

2.0 COMPUTERISED ENVIRONMENTAL ASSESSMENT

Such a system is currently being developed by the University of Hertfordshire. As is the case with formal environmental management systems, the computerised system aims to enable quality environmental management, more specifically it is:

- generic in the context of arable agriculture;
- pro-active based upon the principles of anticipation and prevention;
- on going - seeking to encourage continuous improvements; and
- systematic based upon detailed documented procedures.

The system assesses current performance, encourages improvements, identifies significant effects and appropriate regulations, and determines estimates of emissions in the form of an inventory. Performance is measured by comparing actual practices with what is perceived to be best practice. The major activities of arable agriculture which significantly impact on the environment arise from the improper use of fertilisers, pesticides and from unsustainable soil practices. Consequently, the system focuses on these areas and these are described below. In order to ensure that whole farm assessments can be carried out and to give a more integrated approach to environmental protection other modules allow the more peripheral activities to be assessed such as energy and water efficiency, resource and waste management, farmland conservation and intensive livestock husbandry. Figure 1 shows the overall structure of the system. Individual eco-ratings are determined which are then weighted and aggregated to give a single index relating to the overall farm.

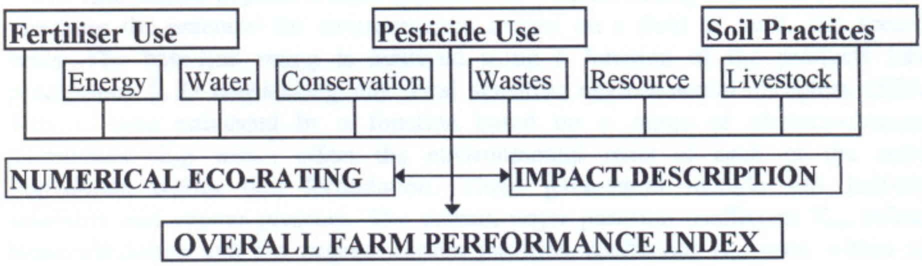

Figure 1: Computer System Structure

2.1 FERTILISER ASSESSMENT

The eco-rating for fertiliser use (F_F) is derived by comparing actual field by field applications of fertiliser (F_A) with official quantitative recommendations (F_R). These recommendations are based upon the economic optimum quantities of nutrients (N, P & K) required by the planned crop depending upon soil type and nutrient reserves. Using a simple relative error calculation a base-line eco-rating is derived. This is then enhanced by considering other factors (f(A)) such as application timing, rainfall, soil porosity, the proximity of surface and groundwaters to, simplistically establish a measure of environmental damage potential associated with fertiliser use. Other farm practices (f(P)) specifically the storage and handling of organic and inorganic fertilisers and machinery calibration are taken into consideration by using a checklist audit approach together with simple ranking and scoring techniques. Equation 1 illustrates the approach used overall. F_F is determined for each field. The overall farm rating is derived by summing the individual field ratings weighted by field size.

$$F_F = (\Sigma^{N,P,K}(F_R - F_A) / F_R) + f(A) + f(P) \qquad (1)$$

2.1 PESTICIDE ASSESSMENT

All pesticides in the UK carry mandatory label precautions (Whitehead, 1996) related to how and when that pesticide can be used. These precautions are established from comprehensive scientific data produced by the manufacture and assessed by the UK's Ministry of Agriculture, Fisheries and Food. Assessment of the farmers use of pesticides has been achieved using a multi-criteria approach based, amongst other things, on these label precautions. The assessment routines have been sub-divided into two main sections. Each section producing a separate sub-rating which is then weighted and summed to produce an overall field value.

The first section applies to field applications. The eco-rating (P_c) is determined by assessing the potential for environmental impact on a field by field, site specific basis. The base-line rating is achieved using a function of the products label precautions (LR) considering any local sensitive environmental receptors (SER). This is then enhanced by a function based on a range of physico-chemical parameters (E_{ai}) which effect the environmental risks of each of the active ingredients within that formulation. These parameters include soil half-life, solubility and vapour pressure. The octanol-water partition coefficient K_{ow} reflects bioaccumulation and the organic-carbon partition coefficient K_{oc} used within the GUS formula (Gustafson, 1989) is used to represent mobility and groundwater risk. E_{ai} is determined for each active ingredient within the formulation. These values, weighted by the amount of active ingredient applied (Q), are then summed. P_c is determined for each pesticide applied to the field during the growing season being assessed and summed. The full equation (2) is given below where α is a scaling factor. Field specific eco-ratings are then weighted by field size and summed to give a farm value.

$$P_c = f(LR, SER) + \alpha \left(\sum^{ai} f(E_{ai} \cdot Q) \right) \qquad (2)$$

A further section of the pesticide system examines non-crop and management practices. This includes storage, waste management, pre- and post-application activities (e.g. machinery calibration, assessing infestation levels, use of protective clothing and equipment and actual application method). The farm use of non-crop pesticides such as rodenticides and biocides are also examined. Again a check-list, multiple choice approach has been used together with a simple ranking and scoring system.

2.3 ASSESSING SOIL SUSTAINABILITY AND PERIPHERAL ACTIVITIES

Two of the main issues representing soil sustainability (S_s) are maintenance of soil nutrient and organic matter levels and protection of soil structure. A knowledge base of best practice derived from the Code of Practice for the Protection of Soil (MAFF, 1993) and from heuristics elicited from experts was used to compare actual practices with those seen as environmentally sound to determine an eco-rating of soil sustainability. This value is then further refined using a simple risk assessment of soil erosion based upon parameters such as soil type, crop cover, average rainfall and protection practices. (Chambers *et al*, 1992).

Similar approaches to those described above have been used to assess peripheral arable farming activities such as water and energy efficiency, resource and waste management, conservation and livestock husbandry. The main body of these assessment routines uses a check-list approach to rank and score actual practices.

Although the eco-ratings provide the system user with an elementary indicator of environmental performance, the software goes much further towards environmental assessment. Each rule has associated 'consequences' attached to it. For example where excess nitrogen has been applied to the land an estimate of the amount of nitrate leaching from the soil can be determined as can the amount of money wasted. With respect to energy assessment, as well as evaluating efficiency, estimates of air pollutant emissions (carbon dioxide, carbon monoxide, sulphur dioxide and oxides of nitrogen) are derived.

3.0 SUPPORT SOFTWARE

In support of the assessment routines, the computer system incorporates a number of modules to explore 'what-if' scenarios. These include a module to study how inorganic nutrient requirements change with crop, soil type, soil fertility and the amount of animal manures added. Another example is a module which highlights the environmental risk associated with different pesticides.

A hypertext information system is fully integrated across the software which provides instant on-line access to codes of practice, legislation and regulation, glossaries, index and a contacts databases. Figure 2 shows a schematic diagram of the integrated structure of the decision support system as a whole.

The system described here helps to encourage sound environmental practice within arable agriculture. The simplistic, yet novel, approach in deriving the eco-rating value allows quantitative, qualitative and heuristical data to be utilised all of which is easily obtainable by the farmer or integrated into the system within the knowledge and data bases. On a more practical level the eco-ratings are farm specific indicators of environmental performance and may be seen as charting the progress towards sustainability.

4.0 CONCLUSION

The system is designed to be used by consultants and farmers to review environmental performance and to monitor progress. The system is broadly comparable with the aims and objectives of more formal environmental management systems such as the UK's standard BS7750, the European Unions EMAS and the forthcoming ISO14001 in that it helps identify priority areas for action, encourages continuous improvements and allows monitoring in the light of targets and objectives.

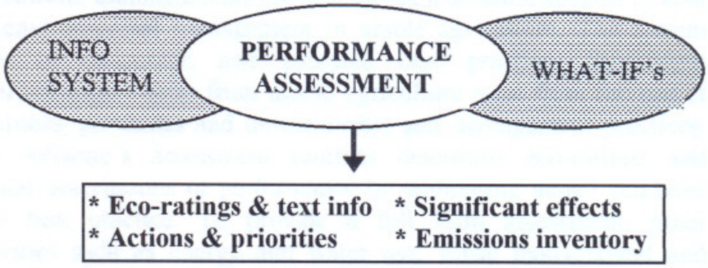

Figure 2: Decision Support Schematic

5.0 ACKNOWLEDGEMENT

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