Eco-rating System for Optimizing Pesticide Use at Farm Level Part 2, Evaluation, Examples and Piloting

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Abstract

The development of a decision support system aims to encourage farmers in the UK to adopt a more environmentally friendly approach to their daily activities. Part of the system concentrates on crop protection encouraging best practice and the principles of integrated pest management. The system compares actual practices on a field by field basis with what is perceived to be best practice and, using scoring techniques, derives numerical performance indices, known as eco-ratings, which lie on a defined scale. The conceptual framework of the system is designed such that by analysing past decisions it can help to identify strengths and weaknesses of current practices and so support future decisions and planning. This paper presents some of the evaluation work and provides examples and information on the scoring system used. The examples used illustrate the success of the system in providing the user with sufficient advice and information such that informed decisions regarding pesticide choice, application and general management can be made. An associated paper (Part 1) in this journal details the theory, design and development of the methodology.

1. Introduction

Within the UK, regulatory controls relating to pesticides are relatively strict. New pesticides must undergo a rigorous registration procedure, where the manufacturer must prove that the pesticide poses minimum risk to human health, safety and the environment. Pesticide users are required to comply with both the 1988 Control of Substances Hazardous to Health (COSHH) Regulations and the 1986 Control of Pesticide Regulations. These regulations are enforced by the Health and Safety Executive (HSE) via a programme of inspections of agricultural premises. The regulatory control of pesticides is strengthened further by the need for pesticide advisers to hold a certificate of competence issued by the British Agrochemical Standards and Inspection Scheme (BASIS) and for operators to also undergo training and certification. However, regardless of how disciplined the regulations are or how rigorously they are enforced, regulatory compliance offers only a minimum level of environmental protection. Only voluntary actions to adopt best practice and the willingness to change will enable farmers to meet the high standards in environmental protection demanded by today's society.

Despite the pressure on farmers from consumers, regulators and policy makers, the vast majority still rely heavily on chemical solutions for their pest problems and have little enthusiasm for change. Although there are alternatives, none are ideal. Biological controls, for example, using the parasitic wasp Encasia to control whitefly, offer one approach. This type of technique often works well within an enclosed environment such as a glasshouse however, outside in normal field conditions, they tend to be less reliable. As mechanical and manual operations are highly labour intensive they are very unpopular. Scientific advances towards more productive and disease resistant crop varieties, utilising biotechnology and developments in precision farming and improved sprayer technology will undoubtedly provide future benefits. However, the best hope at least in the short term, is that the principles of integrated pest management (IPM) (MAFF[1]) are adopted on a wider scale. IPM blends a series of good practice measures which are proactive and precautionary to reduce the use of pesticides.

One of the problems associated with pesticide selection is that the best product environmentally will depend upon site specific details such as farm activities, local meteorological and geological conditions and the absence or presence of environmentally sensitive features such as woodlands and surface water. Although, farmers can get their pesticide advice from their product supplier or from a consultant, many farmers prefer to make up their own minds and rely on past experiences, perceived efficacy and on the cost. Rarely do they also consider the level of environmental risk.

A practical, computer-based system, to support the environmental management of pesticides and to encourage more sustainable practices is under development. The system has been designed to be used by farmers and their advisers. The system acts as both a decision analysis and decision support system and uses an expert system type approach where site specific best practice and regulations are stored as rules. This paper reports examples and pilot results for the pesticide assessment system. Details regarding the theory and development have been published in a companion paper (Part 1) however, a summary is also given here. Whilst this paper is principally concerned with the use of chemical pesticides, the computer system provides a broader-based approach (Lewis *et al*[2]) involving all farming activities including crop production, resource management, conservation[3] and livestock husbandry. This allows a more integrated approach to environmental protection to be adopted.

The assessment system has not been designed to directly offer decision support or advice. Instead it methodically evaluates past decisions by applying a comprehensive set of best practice rules and so identifies how actual practices compare with best practice.

2. The pesticide system

Environmental performance relating to pesticide use is represented within the system by the determination of numerical performance indices known as eco-ratings. Assessment is divided into three main areas: (1) assessment of field applications; (2) management techniques and (3) non-crop use of pesticides such as biocides, sheep dips and rodenticides. Discrete eco-ratings are derived for each area.

Eqn. 1 is used to derive a pesticide eco-rating P_f for field applications. P_f is determined for each pesticide applied to the field crop and combined to give a field value. Each field value is then weighted by field size and aggregated to give a whole-farm value.

$$P_f = L_{SER} + \sum_{1}^{n} f(E_n \; Q_n) \qquad (1)$$

where:

L_{SER} is the eco-rating derived from the label precautions (L) depending upon the site specific sensitive environmental receptors (SER).

E_n is the sum of the scores derived in the evaluation the physico-chemical properties of the active ingredient n.

Q_n is the quantity of active ingredient (n) applied to the field

n is the number of active ingredients in the product formulation.

The function (E_n Q_n) is derived for each active ingredient (1 to n) in the formulation and summed to provide a product total.

A system of 85 label warnings is currently in use for crop pesticides in the UK (BCPC[4]). The majority of these can be sub-divided into those affecting different non-target receptor groups such as animals, birds, bees and aquatic life, with some labels falling into more than one group. Each label has been assigned a numerical score representing the level of environmental hazard. Examples are given in Table 1. As an example a pesticide labelled as '*extremely dangerous to bees*' would have a typical L value of -10 allocated to the bees receptor group whereas one seen as '*harmful to bees*' would have an L value of -5. The scores within each receptor group are then summed and weighted according to the local site variables and conditions under which the pesticide was applied.

As a simple example, L for the herbicide mixture 'bentazone+cyanazine+2,4-DB' is derived from the scores associated with the labels: 5c, 6a, 6b, 36, 43, 53 and 78. For the non-target receptor group 'Humans' the score is derived from labels: 5c, 6a, 6b, 36, 78 (-3 + (-2) + (-2) + (-1) + (-2) = -10). For animals and birds the score is derived from labels 36 and 43 (-1 + (-2) = -3). There are no labels associated with bees (score = 0) and for aquatics, assuming there is surface water within a 10 m boundary of the field and no buffer zone, the score is derived from label 53 (-5). The total initial L value is then -10 + (-3) + (-5) = -18 when the weighting values of 1 are used.

Once the initial L value has been derived, practices are assessed for regulatory compliance and the eco-rating adjusted accordingly by a 'penalty factor' (F_p) to give the total L value. F_p varies from 1 to 5 where 1 represents complete regulatory compliance and 5 represents non-compliance in all tested areas.

The second part of the equation (E_n Q_n) is derived from the physico-chemical properties of the active ingredients within the product formulation. The value E_n is calculated for each active ingredient (n) within the product, weighted by the quantity within the formulation (Q_n) and summed.
A range of parameters have been chosen to reflect the environmental fate and potential for damage by the pesticide active ingredient. These include solubility, vapour pressure and soil half-life. The octanol-water partition coefficient K_{ow} is used to reflect bioaccumulation and the organic-carbon partition coefficient K_{oc} used within the GUS formula (Gustafson[5]) to represent mobility and groundwater risk. The data for each parameter is classified into one of five risk bands (very high, high, moderate, low and very low) and assigned an appropriate score value. E_n is determined by weighting and summing the parameter scores. The initial weighting for each property is set to 1 however this can be adjusted by the user to reflect local priorities if required.

The environmental risks associated with pesticide use come not only from applications but also from management practices. These include storage, handling, waste management, application techniques, pollution prevention activities and machinery calibration and can be recorded on a multiple choice checklist. A similar methodology has also been used to assess farmers' use of non-crop pesticides such as biocides and rodenticides.

3. Examples and testing

Complete validation of any computer model or other advisory system is impossible. Validation is normally intended to increase confidence in a technique with respect to its ability to successfully carry out a task. If it succeeds then its credibility increases. Validating a tool such as that described here is quite problematic in a real case-study situation. The eco-ratings derived are highly site specific, dependant upon site conditions and actual farming practices. Direct comparison of one situation or site with another is difficult. In addition, over the course of a growing season several pesticide applications are likely to be applied to the crop. The system averages these individual eco-ratings to derive a field value for the assessment period which represents the overall environmental performance. Consequently, performance highs and lows may be masked by the final numerical value, although the text report is pesticide specific. Unlike simulation models, expert systems cannot easily be tested against factual data. Experts themselves do not always agree. The best that can normally be done is to check that the conclusions and recommendations of the system broadly agree with a majority of expert thinking. The first testing stage of the system is, therefore, based on simplified hypothetical farm situations. Simple examples are used to demonstrate the range of values produced. Secondly, further examples compare pesticide active ingredients. Other examples seek to show how the system copes with environmental trade-offs and how the system can be used to ensure local policies are enforced by looking at a range of pesticides and their potential for leaching into groundwater.

To demonstrate the value of eco-ratings derived a number of examples are given in Table 2. The table shows six different pesticide applications to the same field. Local climatic conditions, soil types and soil moisture levels are identical for all applications. As are application techniques, application timings and regulatory compliance. A 6 m buffer zone, a non-sprayed region protecting the surface waters from the spray target area, is also in place.
The first four examples relate to approved applications, that is the pesticide has MAFF/HSC approval in the UK to treat the specified pest on the named crop. The low eco-rating calculated in examples 3 and 4 reflects the minimal label precautions associated with these pesticides compared with those in examples 1 and 2.
Despite having a relatively low mammalian toxicity when compared with cyanazine ($LD50_{rat}$ for deltamethrin is 5000 mg/kg and cyanzine is 258 mg/kg), deltamethrin shows a relatively high score value for L. Although there are similarities between the two chemicals, close inspection of the list however shows additional COSHH warnings (6a, 6b) identifying deltamethrin as an irritant as well as being harmful (5a, 5c). There is also a more significant aquatic warning (51). Deltamethrin has a very low score for the value of E_n Q_n due to the low rate applied and to its actual physico-chemical properties. For example cyanazine is much more soluble (171 mg/l at 20°C compared with 0.002 mg/l at 20°C for deltamethrin) and has a much higher vapour pressure (2 mPa compared with 0.013 mPa for deltamethrin).
The last two examples (5 and 6) show typical eco-ratings for unapproved applications. In example 5, carbetamide does not have approval to treat corn marigold weeds on oilseed rape. In the last example extreme mis-management is illustrated. Firstly it is highly likely that the pest has been mis-identified and secondly, pirimicarb currently only has approval to treat aphids on potatoes.

The differences between approved and an unapproved applications of carbetamide on oilseed rape is shown in examples 3 and 5 respectively.
These six examples demonstrate evaluation of perceived good and bad practice and the spread of eco-ratings across a range of pesticides from relatively benign chemicals (i.e. fatty acids) to those that may be more environmentally toxic (i.e. cyanazine).

Generally, an eco-rating numerically less than -40 can be associated with good practice. Higher values, closer to the zero point, can usually be linked with those pesticides which are less environmentally toxic, whilst those closer to the -40 point will be relatively more toxic. Eco-ratings in the range of -40 to -60 may not necessarily represent unapproved applications but may indicate that an alternative chemical or an adjustment in practices may be environmentally beneficial. Eco-ratings below -70 usually reflect poor practices, an undesirable operation or an illegal application. Figure 1 illustrates the eco-ratings scale for pesticides and how values may be interpreted.

Table 2 also illustrates how eco-ratings, for the same applications, would vary if the buffer zone was absent. The most significant changes are seen in example 2, deltamethrin as label warning 51 occurs (‘*Extremely dangerous to fish...’)* and the site has surface water close by. The eco-rating has now been pushed nearer the central part of the scale reflecting the aquatic risk and suggesting that improvements could be made. Less of an effect is seen on example 1 for cyanazine. The label precautions for cyanazine include 53 (‘*Harmful to fish...*’) whilst a risk does still exist, the risk is seen as less significant than for deltamethrin. No obvious change is seen in the last example as environmental performance was already extremely poor. In example 5, environmental mis-management has been compounded further and the eco-rating is now significantly increased highlighting the problem. The final column in the table gives the eco-rating values which would be derived if no surface water was within 10 m of the field boundary and no buffer zone is in place.

Faced with the problem of blight on potatoes there are a number of approved pesticides which could be used for control. Table 3 shows some of these and the eco-ratings derived in a hypothetical field situation. Best practice and regulatory compliance are assumed, enabling, for example purposes, the eco-rating system to be used to identify pesticides which for the site described may present the least environmental risk. Reus and Pak[6] used their ‘environmental yardstick’ in a similar manner, calculating ‘pollution points’ for a variety of pesticides including fungicides. The ‘environmental yardstick’ also identifies the fentin acetate/maneb combination as presenting a relatively high environmental risk. Quite a high proportion of fentin acetate is present in the main commercial brand and this active ingredient has both a relatively long soil half-life, vapour pressure (VP) and mammalian toxicity (soil half-life is approx. 140 d, VP = 1.9 mPa and $LD50_{rat}$ = 220 mg/kg all values depending on soil type and conditions).

A further example is given in Table 4 showing comparison of the eco-ratings determined for a range of insecticides which may be used to control aphids on cereal crops. Again all the values derived lie above the -60 point, however some pesticides appear more environmentally friendly than others, in particular esfenvalerate. The system does not directly seek to advise farmers on what pesticide to use in any given situation, rather it seeks to provide sufficient information so that the user can make an informed choice.

Contamination of drinking water supplies with pesticides is a cause for concern. Pesticides tend to reach groundwaters by leaching through the soil and underlying rocks or by being carried into the aquifer with contaminated surface waters. Not all pesticides found in drinking water have an agricultural source but many do. Water companies across the UK carry out extensive monitoring programmes to test for unacceptable levels of pesticides. Occurrence depends upon the pattern of usage within the water catchment, the amount and frequency applied, and rainfall events as well as on the physico-chemical properties of the chemical which control its leachability.

The eco-rating system can be used to help ensure that the risk of pesticides leaching to groundwater is reduced by highlighting those chemicals which are easily leached. The Drinking Water Inspectorate[7] supported by data from various other sources including water companies (SWS[8], Newbold & Lewis[9]) provide a comprehensive list of some of the pesticides which are included in these monitoring programmes and which are extensively used. Table 5 divides this list into those which commonly contravene the prescribed concentration or value (PCV) and those which do so less frequently. The table also includes those pesticides which lie mid-way between the two extremes.

The eco-ratings have been calculated under the same site conditions as described in Tables 2 to 4 using an application rate of 1 l/ha however, the weighting factor assigned to groundwater protection and leaching has been increased from 1 to 5 to specifically identify those pesticides which may be more susceptible to leaching. The system shows a significant degree of success in identifying those pesticides which, ideally, should be avoided if groundwater quality is to be protected.

The eco-ratings determined for those pesticides commonly found are all, except for isoproturon, below -70 and would immediately highlight these chemicals as being undesirable. Isoproturon is the exception here failing to fully reflect its frequent exceedence of the PCV. The frequent occurrence of isoproturon in water is thought to be due to its wide use and relatively low cost. The eco-rating derived is partly due to the assigned label precautions and partly due to the intermediate GUS value (around 2.4) which is used to determine the risk to groundwater (Gustafson[5]). Pesticides detected frequently in groundwater generally have GUS values greater than 2.8, whereas those with values below 1.8 are rarely detected above the PCV. The eco-ratings determined for those pesticides which are not commonly identified above the acceptable limit are all well above the -40 point. However, the pesticides in the intermediate category are less well identified. Whether or not they appear in drinking waters at a level to cause concern will ultimately depend on the local usage pattern, rainfall etc..

The type of environmental impact that may occur and its intensity and significance will always depend on the specific site details prevailing at the chosen spraying time and on local decisions. For example if a pesticide presents a risk to honey bees whether or not an impact occurs and its intensity will depend upon whether or not honey bees are present, which in turn will depend on the time of year and whether there are flowering plants nearby. However, in some cases the situation becomes more complex. If a farmer delays spraying a low dosage of a pesticide due to adverse weather conditions increasing the risk of drift, a higher dosage may be required later when weather conditions have improved in order to control a higher level of pest infestation. Would the environmental impact have been less if spraying took place earlier despite weather conditions? There is no direct, single answer as the impacts in both situations will depend upon a number of variables. These include the environmental toxicity of the pesticide, how far spraying conditions, in the first instance, were from ideal, how greater a dose is required in the latter situation and whether or not there are local environmental receptors which may be sensitive to that particular pesticide. Table 6 shows a set of hypothetical situations illustrating how the system would behave. It should be remembered however that the system is designed to evaluate past decisions and not to advise directly on pesticide usage. These examples compare the pesticide carbetamide with cyanazine which appears from the eco-rating system to be relatively more environmentally toxic.

Carbetamide using a low application rate in a force 4 wind would give an eco-rating of -22. Delaying spraying until more favourable weather but using a greater dosage gives an eco-rating of -16. Realistically there is very little difference in the derived values. The lower value in example 1 is due to the breach in MAFF/HSC code guidelines[11]. However, in the last three examples with a more toxic pesticide the eco-ratings give a very different result. Spraying in a strong wind with a low application rate gives an eco-rating of -83. Whilst waiting for better conditions but using a higher application rate gives an eco-rating of -34. The very low eco-rating in example 4 (-83) reflects the increased risk of environmental damage associated with a potentially high risk of drift of an environmentally toxic pesticide (either as fine liquid, vapour or dust) in an area with surface water, caused by non-compliance with the pesticide code[11]. The risk of drift is related to a number of factors including droplet size, fine droplets can often be carried long distances by wind. The eco-ratings in Table 6 have been determined assuming constant application conditions, in some conditions it may be better to work in a stronger wind speed with a coarser spray. Within the software droplet size is not considered but is an area for future development. These results offer only an example of how the system can respond when asked for support on such issues. In all situations the user is referred to the code of practice[11] and to their BASIS adviser.

One of the most important issues regarding pesticide use is efficacy, particularly with the use of dosages below that recommended. Whilst environmental gains are undoubtedly seen if low doses are used and prove successful, if the pest is not properly controlled and a further more concentrated dose is applied then any gains are lost due to the total higher dose and additional problems such as pest resistance may be seen. In addition regulations regarding maximum applications may be breached. The software handles these problems effectively by checking to see if the number of applications of a particular pesticide have exceed the regulations and if any have been below the recommended dose. If both are true then penalty factors are applied accordingly.

The potential for environmental damage is not influenced by pesticide choice and application alone. Significant risks can be associated with general pesticide management such as how the pesticides are stored, how they are transported around the farm, how they are prepared, waste management and the importance placed on staff training and awareness. Environmental risks can be minimised if pre- and post- application activities are carried out efficiently such as monitoring weather conditions, identification of threshold levels below which crop damage can be tolerated, using disease resistant varieties where ever possible and ensuring that equipment is regularly serviced, maintained and calibrated.
Best practice for these types of activities are widely available in a range of publications including the Code for the Protection of Soil[10] and the Code for the Safe Use of Pesticides[11]. Both give clear, general guidance, on pesticide best practice. Many other organisations also offer practical guidelines (e.g. IOBC[12], FWAG[13]). Due to the non-quantitative nature of the data which needs to be handled, the eco-rating system uses a different approach. A multiple choice check-list audit presents the user with a range of questions, each having a number of response options reflecting quality of practice. Each of these options has an associated score. The eco-ratings are then derived by weighting and summing scores. Again the weighting factor for each activity is pre-set to 1, but this can be amended by the user if required.

The assessment system methodically evaluates past decisions by applying a comprehensive set of best practice rules to identify highs and lows in environmental performance. A second software mode supports the evaluation process and this includes the '*Pesticide Informer*'. This aims to highlight any environmental risk associated with a particular pesticide. The user is asked to select from a list the crop being grown and the pest which needs controlling. A list of MAFF/HSC approved pesticides which may be used for control is then displayed. As the mouse is clicked on this list a series of icons are displayed which highlight a particular risk. For example if the pesticide presents a risk to bees then a bee icon is displayed or, similarly, if the pesticide carries a risk to fish then a fish icon is displayed. Consequently this system offers an effective, quick and visual means of identifying pesticides which will help minimise the environmental impact. Table 7 show the icons which are displayed for aphids on potatoes.

4. Piloting

The first version of the pesticide system is now complete and currently undergoing field trials and testing. Testing is taking place on several levels. Initially, comprehensive in-house testing has been carried out to test the system with data provided by farmers. This has tested its ability to cope with the quantity, format and types of data readily available at farm level. Secondly, on-farm testing has been and will continue to be carried out. Several farms in the south east of England are helping the trials. In the first instance, this has been aimed at ensuring that the system clearly identified good and poor performance and gave the same message as the code of practice (MAFF & HSC[11]). In addition the trials aimed to ensure that the software was relatively simple to use, that the on-screen instructions were clear and not ambiguous and that the reports encouraged rather than demoralised farmers whilst still identifying areas where performance was less than ideal. Examples of the results were put to a range of experts and potential users for their reactions. Refinements and amendments are being made to the reports and scoring system as required. Consequently, the scoring process and assigned scores are subject to future changes. The system has been successfully demonstrated during meetings of farmers organised by groups such as the Farming and Wildlife Advisory Group (FWAG) where farmers and their advisers have had hands-on experience of the software. This has lead to a number of additional farms being included in the trials. On a further level a working group of farmers has been set up to test the robustness and performance of the software. Discussions are also ongoing which, hopefully, will enable the system to be tested further with the help and co-operation of two major supermarket chains.
Finally, the software and the scientific rational behind its development has been shown to the financial sponsors, the Pesticide Safety Directorate of MAFF, environmental quality regulators including the Environmental Agency and other government departments which have consequently resulted in active discussions and debate on how the system could be improved still further and how it could best be introduced into the industry. It is anticipated that the first full version of the system will be available from early 1998 however, smaller sub-sections of the system such as the '*Pesticide Informer*' may be available earlier.

5. Discussion and conclusion

In order to encourage the uptake of sound environmental practices within agriculture greater awareness regarding the possible environmental, health, safety and business benefits to be gained, both short term and long term, is required. Entrenched beliefs that environmental protection is too expensive needs to be addressed and ways of encouraging and motivating farmers and growers to improve their practices need to be identified. To this end, decision support systems and self-assessment techniques can be used as a basis for guiding change. This view is strongly supported by various organisations such as LEAF[14] who have developed an audit questionnaire aimed at farmers to help them identify areas where environmental improvements could be made and by the Agricultural and Industry Working Group of the Advisory Committee on Business and the Environment[15] who strongly advocate the adoption of environmental assessment tools arguing that the use of these tools would place the industry in a strong position to avoid stricter regulations.

The pesticide system described here is part of a broader system designed to be used by consultants and farmers to review environmental performance and to monitor progress towards improvements. The system has been designed to be pro-active based upon the principles of anticipation and prevention and is based upon detailed documented procedures and guidelines for best agricultural practice. The eco-rating system provides a scale for measurement and judgement and is used to convert quite complex information into a simpler format to aid interpretation and transparency. With respect to pesticides and crop protection the software helps ensure that the system user is presented with all the necessary information to make an informed choice regarding which pesticide to use and how to use it such that the crop is protected, regulations are met and the risk of causing environmental damage is minimised.

The testing and piloting work is ongoing and will undoubtedly result in modifications and adjustments to the scoring system used. Some workers in the fields of scoring and ranking have criticised these types of techniques as being overly simplistic (Thompson[16]). However, such methods can provide an essential starting point and sometimes the only practical means, for systems whose underlying complexities are not fully understood or agreed (Tucker *et al*[17]). The disadvantages of this technique are mainly associated with the arbitrary nature of assigning scores. However, if this is kept in mind, scoring methods, if uniformly applied, can be designed to successfully compare a variety of different environmental performance areas.

All mathematical models, decision support systems and other similar software offer only a simplification of the real world. They often attract criticism for omitting some influencing detail or for being over simplistic. In a system as broad and as integrated as that described here, the purpose of the software needs to be carefully borne in mind. The system aims to encourage safer, more environmentally friendly practices and to provide access to information which much of the farming industry finds difficult to obtain or to interpret.

Undoubtedly, some accuracy has been lost in using mid-range values for the physico-chemical parameters of pesticides, for awarding scores based upon broad parameter bands, for averaging farm values and for eventually normalising the values obtained. In the context of the first two the unavailability and unreliability of pesticide data would have resulted in information gaps causing major problems with the assessment system and consequently limiting its use. In the latter cases the researchers concluded that interpretation and transparency of the system were of paramount importance as was the use of only readily available farm and field input data. Any other data required by the system needed to be held in databases. The most important factor was that the system identified accurately performance highs and lows and that the eco-ratings derived varied reasonably to reflect changes in practices both good and bad. The purpose of the system is not to offer direct advice to farmers but to evaluate the course of action taken and the resultant environmental impact and report findings such that the farmer can learn from past experiences.

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References

[1] **MAFF**, Ministry of Agriculture, Fisheries and Food, Pesticides and Integrated Farming. MAFF Publications PB 2489, 1996, London.

[2] **Lewis, K. A., Tzilivakis, J, and Bardon, KS** Environmental best practice advisory system for agriculture. Proceedings of the European Federation of Information Technology in Agriculture (EFITA) conference, Copenhagen, Denmark. June 1997

[3] **Lewis, K.A., Tzilivakis, J., Skinner J.A., Finch, J., Kaho, T., Newbold, M.J. and Bardon, K.S.** Scoring and ranking farmland conservation activities to evaluate environmental performance and encourage sustainable farming. Sustainable Development. In press due Aug 1997

[4] **BCPC**, British Crop Protection Council, The 1997 Pesticide Guide, Whitehead, R. *Ed.* CAB International

[5] **Gustafson, D. I.** Groundwater ubiquity score: a simple method for assessing pesticide leachability, Environmental Toxicology and Chemistry, 1989, **8**: 339-357

[6] **Reus, J. A. & Pak, G. A.W.A.** An environmental yardstick for pesticides. *Mededelingen van de Faculteit van de Landbouwwetenschappen, University of Gent.* 1993, **58**(2a): 249-255

[7] **Anon.** The quality of water is sustained, Pesticide News **25**, September 1994, 18

[8] **SWS,** Southern Water Services Drinking water quality report, 1994

[9] **Newbold, M. J. & Lewis K.A.** Private communications from Wessex Water, Three Valley's Water and Welsh Water regarding pesticide monitoring programmes. 1996

[10] **MAFF,** Ministry of Agriculture, Fisheries and Food, Code of Good Agricultural Practice for the Protection of Soil, MAFF Publications PB 0617, 1993, London.

[11] **MAFF & HSC,** Ministry of Agriculture, Fisheries and Food and the Health and Safety Commission, Code for the Safe Use of Pesticides on Farms and Holdings. HMSO Publications, 1990, London.

[12] **IOBC,** International Organisation for Biological and Integrated Control of Noxious Animals and Plants. Commission "IP-Guidelines" Integrated production: principles and technical guidelines. Bulletin OILB, 1993, **16**(1)

[13] **FWAG,** Farming and Wildlife Advisory Group**,** Farming and pesticides advisory leaflet, undated

[14] **LEAF,** Linking the Environment and Farming, The LEAF environmental audit, 1997

[15] **ACBE,** Advisory Committee on Business and the Environment, 6th Progress report, 1996

[16] **Thompson, M. A.** Determining impact significance in EIA: a review of 24 methodologies. Journal of Environmental Management. 1990, 30

[17] **Tucker, P., Lewis, K.A., and Skinner, J.A.** Environmental management in agriculture: an expert system approach. Eco-Management and Auditing, 1995, **3**(1): 9-13

Table 1: Examples of label precautions and assigned scores

Label number	Description	Assigned score
1	Product contains an anticholinesterase organophosphate compound	-10
2	Product contains and anticholinesterase carbamate compound	-10
3 (a,b,c)	Very toxic	-10
5 (a,b,c)	Harmful	-3
6 (a,b,c)	Irritant	-2
12c	Flammable	-1
36	Keep away from food, drink and animal feedstuffs	-1
37	keep out of reach of children	-2
43	Keep livestock out of treated areas	-2
45	Dangerous to game, wild birds and animals	-7
46	Harmful to game, wild birds and animals	-5
47	Harmful to animals	-5
48/a	Extremely dangerous to bees	-10
49	Dangerous to bees	-7
50	Harmful to bees	-5
51	Extremely dangerous to fish	-10
52	Dangerous to fish	-7
53	Harmful to fish	-5
54	Do not contaminate ponds, waterways or ditches/Harmful to fish or other aquatic life	-3
58-71	Storage and disposal warnings, score per warning	-1
78	If you feel unwell seek medical advice	-2

Table 2: Examples of derived eco-rating in differing situations

Hypothetical field conditions: Sandy soil, 10 ha in area, over chalk aquifer, surface waters within 10 m of field boundary, slightly moist soil, light breeze, pesticides applied in spring.

	Crop	Pesticide applied	Active ingredients kg/ha	Typical label precautions (brand specific) (BCPC, 1997)	Pest being controlled	Comments	Total L_{SER}	E_n Q_n	Total P_f with buffer per cent	Total P_f without buffer per cent	Total P_f no buffer, no water per cent
1	Linseed	cyanazine	0.5	A, C, 5a, 5c, 18, 21, 28, 29, 36, 37, 53, 63, 66, 70, 78	Annual grasses	Approved application	-18	-18	-36	-40	-34
2	Oilseed rape	deltamethrin	0.01	A, C, H, 5a, 5c, 6a, 6b, 12c, 16, 18, 21, 28, 29, 36, 37, 48, 51, 60, 66, 70, 78	Aphids	Approved application	-25	-2	-27	-35	-22
3	Oilseed rape	carbetamide	0.7	30, 54, 63, 67	Annual grasses	Approved application	-3	-13	-16	-19	-15
4	Brussel Sprouts	fatty acids	0.5	29, 53, 60, 63, 65	Whitefly	Approved application	-4	-2	-6	-10	-5
5	Oilseed rape	carbetamide	0.7	30, 54, 63, 67	Corn marigold	Illegal application	-38	-12	-50	-82	-42
6	Main crop Potatoes	pirimicarb	0.5	A, C, D, H, J, M, 2, 5c, 18, 21, 29, 36, 37, 41, 52, 63, 67, 70, 78	Bean beetle	Illegal application	-72	-27	-99	-100	-99

Table 3: Examples of derived eco-rating for fungicides used on potatoes

Hypothetical field conditions: Sandy soil over chalk aquifer. 10 ha in area, treating blight on maincrop potatoes, surface waters nearby, slightly moist soil, fungicides applied in spring at a rate of 1 l/ha product.

Fungicide & label precautions	**Total P_f per cent**
benalaxyl & mancozeb A, 6a, 18, 21, 29, 35, 36, 37, 52, 62, 63, 67	-35
chlorothalonil A, C, 6a, 6b, 6c, 9, 18, 22, 25, 26, 27, 28, 29, 36, 37, 52, 54a, 63, 66, 70	-40
chlorothalonil & propamocarb hydrochloride A, C, H, 6a, 9, 10a, 18, 21, 24, 28, 29, 36, 37, 52, 54a, 63, 66, 70	-45
chlorothalonil & cymoxanil A, C, 6a, 6b, 6c, 9, 14, 18, 21, 28, 29, 36, 37, 52, 63, 65	-38
cymoxanil & mancozeb A, 6a, 6b, 6c, 18, 21, 28, 29, 36, 37, 53, 63, 65	-38
maneb A, D, 6c, 10a, 18, 21, 29, 36, 37, 52, 63, 67	-37
fentin acetate & maneb A, C, H, J, M, 5c, 6a, 6b, 6c, 14, 16, 18, 22, 28, 29, 35, 36, 37, 41, 53, 64, 67, 70, 78	-58

Table 4: Examples of derived eco-rating for insecticides used on cereals

Hypothetical field conditions: Sandy soil over chalk aquifer. 10 ha in area, surface waters nearby, slightly moist soil, applied in spring, 6 m buffer zone.

Insecticide & label precautions	**Active ingredient kg/ha**	**Total P_f per cent**
cypermethrin A, C, 6a, 6b, 12c, 14, 18, 21, 24, 28, 29, 36, 37, 48, 51, 54a, 63, 66, 70, 78	0.03	-27
chlorpyrifos A, C, 1, 5a, 5c, 6a, 6b, 12c, 14, 18, 21, 28, 29, 35, 36, 37, 48, 52, 63, 66, 70, 78	0.5	-50
deltamethrin A, C, H, 5a, 5c, 6a, 6b, 12c, 16, 18, 21, 28, 29, 36, 37, 48, 51, 60, 61, 66, 70, 78	0.01	-27
dimethoate A, C, H, J, M, 1, 5a, 5c, 10a, 12c, 14, 16, 18, 23, 25, 28, 29, 35, 36, 37, 41, 46, 49, 52, 60, 64, 66, 70, 78	0.4	-52
esfenvalerate A, C, H, 5c, 6a, 6b, 16, 18, 21, 28, 29, 36, 37, 48a, 51, 63, 66, 70, 78	0.25	-23
pirimicarb A, C, D, H, J, M, 2, 5c, 18, 21, 29, 36, 37, 41, 53, 63, 67, 70, 78	0.5	-48
demeton-S-methyl A, C, H, M, 1, 4a, 4b, 4c, 12c, 14, 16, 18, 21, 23, 24, 25, 26, 27, 28, 29, 35, 36, 37, 41, 46, 50, 53, 64, 66, 70, 79	0.6	-56

Table 5: Agricultural pesticides in water

Pesticides commonly found	**Total P_f per cent**	**Pesticides found occasionally**	**Total P_f per cent**	**Pesticides not commonly found**	**Total P_f per cent**
atrazine	-77	linuron	-45	ioxynil	-25
simazine	-73	2,4-D	-24	bromoxynil	-26
chlorotoluone	-99	tri-allate	-29	malathion	-36
isoproturon	-45	MCPA	-65	triadimefon	-17

Table 6: Dealing with environmental trade-offs

Hypothetical field fonditions: Sandy soil over chalk aquifer. 10 ha in area, surface waters nearby, slightly moist soil, applied in spring, 6 m buffer zone. oilseed rape/annual grasses

	Pesticides	**Relative Env. Toxicity**	**Wind speed**	**Application rate l/ha**	**Total P_f per cent**
1	carbetamide	Low	force 4	0.25	-22
2	carbetamide	Low	force 3	0.25	-15
3	carbetamide	Low	force 2	1.0	-16
4	cyanazine	High	force 4	0.25	-83
5	cyanazine	High	force 3	0.25	-52
6	cyanazine	High	force 2	1.0	-34

Table 7: The 'Pesticide Informer' for aphids on maincrop potatoes

Pesticides which may be used	Bee icon	Animal/ bird icon	Fish icon	Ground water	Position	Other message
aldicarb	X	√	√	√	√	√
deltamethrin+pirimicarb	√	√	√	√	X	√
demeton-S-methyl	√	√	X	X	√	√
dimethoate	√	√	√	X	X	√
disulfoton	X	√	√	X	√	√
lambda-cyhalothrin	√	X	√	X	X	X
malathion	√	X	X	X	X	√
oxamyl	X	√	√	X	√	√
phorate	X	√	√	X	√	√
pirimicarb	X	√	√	√	X	√

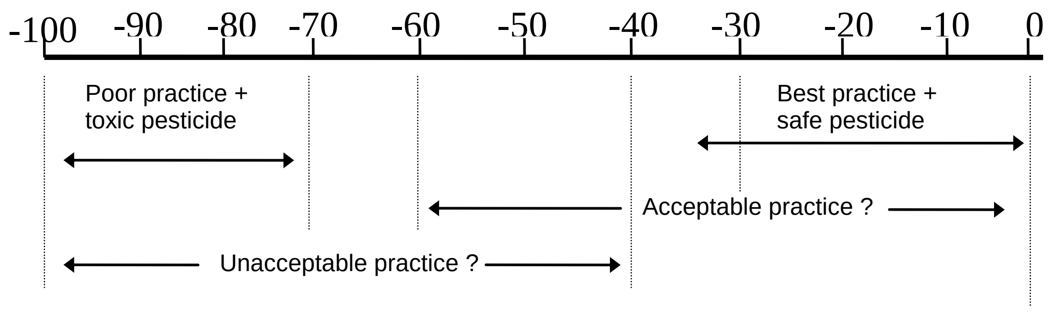

Figure 1: The eco-rating scale

Figure Captions

Figure 1: The eco-rating scale

Table Captions

Table 1: Examples of label precautions and assigned scoring values

Table 2: Examples of derived eco-rating in differing situations

Table 3: Examples of derived eco-rating for fungicides used on potatoes

Table 4: Examples of derived eco-rating for insecticides used on cereals

Table 5: Agricultural pesticides in water

Table 6: Dealing with environmental trade-offs

Table 7: The ‘Pesticide Informer’ - aphids on maincrop potatoes