Eco-rating System for Optimizing Pesticide Use at Farm Level Part 1, Theory and Development

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Abstract
A computer-based decision support system is described which aims to encourage and enhance sound environmental management within agriculture. Part of the system focuses on the management of pesticides on the farm, and can help to ensure that the farmer adopts practices which maximise crop production and profitability without jeopardising the environment. The approach taken looks at all aspects of farm pesticide use including crop applications, storage and waste disposal and the use of non-crop pesticides.

As a whole, the system can act as a informal environmental management system. An eco-rating is derived by comparing actual farm practices with what is perceived to be best practice for the site, to provide a measure of environmental performance. The first time the method is used these indices act as bench-marks against which the success of future improvements can be judged.

The system has three modes of operation. An “assessment mode” seeks to identify strengths and weakness in practices and regulatory compliance and to provide guidance on areas where improvements could be made. In support of this a second mode known as the “technical system” allows the user to explore ‘what-if’ scenarios in order to identify site specific best practice and aims to provide answers to the issues raised in the assessment mode. The third mode is a fully integrated hypertext information system containing a range of context-sensitively mapped text on agriculture and the environment which can be used on a stand-alone basis or accessed from any part of the software system.

1. Introduction
The use of pesticides to control agricultural diseases and pests is an important part of today’s farming. However, the benefits to be gained, such as inexpensive high quality produce, are often accompanied by environmental penalties. These include contamination of surface and ground waters, poisoning of wildlife (MAFF[1]), damage to non-target organisms, residues in foodstuffs and development of pesticide resistance.

Guidance and expertise is available from a range of sources including government published codes of practice (MAFF/HSC[2], MAFF[3]), suppliers and chemical companies, and can also be found in the popular farming press. However, this advice tends to be general and does not take specific account of any individual site profile. To gain this information the farmer needs to purchase expensive specialist advice on a regular basis. A farmer’s selection of a pesticide may be based upon perceived efficacy, cost and product familiarity, not the local environmental needs. The potential for environmental damage is highly site specific and does not depend solely on the environmental toxicity of the pesticide. It can, for example, also depend upon the equipment used, storage facilities, handling and waste management techniques, site suitability of the pesticide selected and application techniques as well as the local site profile (e.g. climate, soil type, underlying geology, proximity of surface and ground waters, provision of margins or buffer zones, biodiversity and environmental sensitivity).

Good environmental management within the agricultural industry relies heavily on voluntary actions based upon sound environmental knowledge. In the absence of continual specialist advice the farmer needs some other form of reliable information. A computer-based decision support system designed to encourage and enhance sound environmental management within arable farming is being designed and developed. The system uses an integrated approach to assess individually, all aspects of farming including fertiliser and pesticide use, soil sustainability, energy and water efficiency, farmland conservation and livestock management (Johnston and Lewis[4]; Newbold *et al*[5]; Tucker *et al*[6]).

2. Environmental management for agriculture
The system as a whole uses an eco-rating descriptor as a measure of good practice coupled with a report of the evaluation and recommendations. For each farm activity (use of fertilisers, pesticides,

energy, conservation, etc.) a separate rating is developed by comparison of actual performance with performance currently perceived as sound. A map of the farm's overall performance is then produced by comparing the various individual eco-ratings. This allows the farmer to identify, easily, areas which require improvement i.e. those with the lowest eco-ratings.

This decision support system has three modes of operation. The core of the system, *i.e.* the assessment, is supported by an operational mode known as the 'technical system'. This allows the user to explore 'what-if' scenarios, in a manner which poses no risk to the environment nor the farms economic viability, in order to identify ways to improve environmental performance and so the eco-rating. A further mode is a fully integrated hypertext information system which includes codes of practices, legislation and regulations and a glossary of terms.

The pesticide assessment routines described in this paper form just one part of the computerised system. The system does not rate, rank and so compare the environmental risks associated with one pesticide against another but determines a site specific eco-rating based upon all aspects of pesticide use including: field applications, suitability of selection with respect to the farm profile, a simplistic evaluation of the farmer's need to spray, handling, storage and waste management practices and application techniques. This eco-rating can then be used as a benchmark for measuring the success of future performance improvements.

3. Environmental impact assessment of pesticides

The presence of pesticide residues in surface and ground water sources has focused attention on factors which influence pesticide mobility, behaviour and fate, such as soil properties and processes. There is increasing evidence to suggest that the specific environmental and agricultural conditions which prevail during or shortly after pesticide application are critical in determining pesticide fate and behaviour and hence mobility. (Roberts and Kearney[7]) There is an inextricable link between pesticide applications, the soil hydrological cycle and the aquatic environment, and this needs to be taken into account in any environmental assessment.

There are a number of different approaches used to assess the environmental impact of pesticides on the environment (Reus and Pak[8]; Higley and Wintersteen[9]; Kovach *et al*[10]; Hornsby[11]; Penrose *et al*[12]; Vereijken *et al*[13]) and also a number of simulation models (Wagenet and Rao[14]; Gustafson[15]). Each of these methodologies addresses a particular area of concern, such as groundwater (Gustafson[16]) or application equipment (Parkin *et al*[17]*).* Some systems are wider in their application such as the Danish PC Crop Protection system (Secher *et al*[18]) which addresses many issues associated with crop applications and the efficacy of pesticides. The computerised system being described in this paper, offers a broader approach still and considers a wide variety of parameters seen to effect the fate and transport of pesticides in the environment. It also includes both crop and non-crop applications and general management issues (e.g. storage, transportation and waste management) which are often neglected in other approaches. In addition, it acts as an informal environmental management system allowing pesticide use to be optimised and impacts controlled.

4. The eco-rating system

Within the computer system generally the numerical eco-rating methodology used normally spans a positive to negative scale, with a positive value reflecting an environmental gain and a negative value a loss. Zero could be interpreted as representing an environmentally neutral activity and possibly the threshold of sustainability. With respect to a farmer's use of crop pesticides the eco-rating spans negative to zero. Although it is appreciated that there may be financial gains due to increases in crop yield and quality, rarely is there an environmental gain from pesticide use. In some instances this may not be the case. Some environmental advances could be achieved by using herbicides which reduce the need to plough, and therefore lessen the risk of soil deterioration. This is considered within another part of the computer system concerned with soil sustainability and protection. As another example, pesticides could be used to environmental benefit, to clear a watercourse of aquatic weeds or to kill off proliferous non-native species. These latter actions are considered within the conservation audit.

Best practice does not always mean no resultant environmental impact and with respect to pesticide use the potential for impact will always be present to varying degrees. As there is a need to use pesticides on many occasions to protect yields and quality, the aim of the system is to try to achieve minimal use with maximum efficiency and so achieve eco-rating values tending towards zero.

Consequently, specific areas on the farm where a problem exists with respect to environmental performance will be highlighted by a large negative rating.

A wide range of issues and parameters affect the potential for environmental impact of a pesticide and similarly pesticides can impact on a range of environmental receptors. These issues are discussed in detail below. Within the computer system best practice, regulations and other influencing factors are stored as expert system type rules. Rules are grouped according to the effect (e.g. those which affect leaching or those which affect waste management). Each group of rules has a weighting factor assigned to it. The initial value of all weightings is set to unity consequently all environmental impacts are seen as equal thus avoiding the controversial debate surrounding impact equivalencies. However, the computer system allows the user the opportunity to over-ride the pre-set values and to assign values of their own, ranging from 1 to 5, which can then be used to reflect local priorities and policies.

Within the scoring system a further set of weighting factors have been used. These are called 'penalty factors' (F_p) and may not be adjusted by the system user.

Actual assessment is divided into three main parts (1) assessment of field by field applications taking into account the product formulation, associated label precautions, and physico-chemical parameters, (2) management practices such as method of application, storage, waste disposal, transportation and pollution risk minimisation and (3) the use of non-crop pesticides such as biocides, sheep dips and rodenticides etc.. These factors are assessed independently and individual eco-rating are derived.

4. 1. *Field by field applications*

A database has been established which holds information on over 500 pesticides including insecticides, herbicides, fungicides, and also growth regulators and adjuvants commonly used in agriculture. The active ingredients included in the database are those which have met MAFF/HSE approval, both on and off-label, under the 1986 Regulations for use in agriculture. In order to seek approval, manufacturers must supply detailed information about the product and include toxicological information. The physico-chemical parameters are held in the database under active ingredient and cross-referenced by brand name. The latter is included to facilitate the farmer's access to the relevant data and to allow brand specific data to be stored. The database also holds information on uses with approved crops, concentration of active ingredient in the formulation, maximum approved dose, maximum number of applications, harvest intervals and label precautions assigned by MAFF's Pesticide Safety Directorate. Much of the data have been obtained from the UK Pesticide Guide[19] and The Pesticide Manual Tenth Edition[20].

The pesticide eco-rating (P_f) for the field-by field assessment is mathematically derived using Eqn. 1, and is explained in detail below.

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

where:

$f(L_{SER})$ 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 of data for pesticide losses to air, via leaching and risks associated with bioaccumulation i.e. ($S_{air} + S_{leach} + S_{bio}$). The value of these functions are derived from the physico-chemical properties of the active ingredient (ai).

Q_n is the quantity of active ingredient n applied to the field in kg.

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

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

4.1.1. *Toxicity*

Toxicity towards humans, animals, birds, aquatic life, and bees is included in the assessment using the label precautions set out on each pesticide. These label precautions are based on information provided to MAFF by the manufacturer in order to obtain approval for use. They are used as a starting point in the development of the eco-rating system for pesticides (L). L is formulation specific.

Adjuvants are not classified as pesticides, but under the Control of Pesticides Regulations (MAFF/HSE[21]) there are very strict guidelines on their correct use. Adjuvant product labels must be consulted by the user for detailed compatibility with other chemical products and rates of use. Within this system their impact is considered by derivation of L, using label precautions in the same manner as pesticides.

MAFF currently use 85 different label precautions for crop applied pesticides. The majority of these can be associated with one or more specific sensitive environmental receptor groups (SER) e.g., bees, aquatics, birds, humans etc.. Scores are attributed according to the label precautions associated with the pesticide, and the scores within each SER are then summed and adjusted according to a penalty factor (F_p) depending on the local site variables and conditions under which the pesticide was applied. For example, if the field being assessed has surface water within 10 m of the field boundary then F_p attached to the use of a pesticide with aquatic precautions would be 1. If the sum of the label scores is -5 then L = -5. Whereas the same pesticide used in a field with no water would have a factor of zero and L = 0. If, however, the field where the pesticide was applied has an unsprayed margin or buffer zone separating the target area from any water courses the value of F_p ranges from 0.2 to 1. If the margin is equal to or in excess of the recommended 6 m width then the minimum F_p of 0.2 applies which effectively improves the score based on the labels appropriate to aquatics from -5 to -1. As the width of the boundary decreases from 6 m to 0 then the value of F_p increases from 0.2 to 1 giving a range of L values from -1 to -5. In the situation where no margins or buffer zones are in place and the list of precautions includes the statement ‘Extremely dangerous to fish...’ F_p = 2, doubling the L value from -5 to -10. Throughout the system the phrase surface water is used which in this context includes ponds, lakes, rivers, streams, ditches, boreholes and wetlands even if dry.

Site specific information required includes general farm and field data. The general farm data includes rainfall, and whether or not the farm is situated over a principal aquifer. Field data includes: field size, soil type, the presence of absence of environmentally sensitive features (e.g. watercourses, boreholes, woodlands, public areas, footpaths etc.), whether or not unsprayed margins or buffer zones are in place, metreological (e.g. windspeed) and soil conditions (e.g. approximate soil moisture levels) at the time of spraying and the pesticides applied, rate of application and pest being treated.

4.1.2. *Volatilisation and vapour pressure*

Another important physico-chemical property is volatility (Plimmer[22]) which is related to vapour pressure. Volatilisation is one of the principal pathways by which pesticides are lost from target areas after application (Roberts & Kearney[7]). The rate of loss by this pathway is often greater than that due to chemical degradation, runoff or leaching (Taylor & Spencer[23]) particularly when residues of volatile pesticides are exposed on moist soil or plant surfaces. Atmospheric transport and deposition are then responsible for delivering these pesticides back to earth often a considerable distance from the source and possibly over water or other sensitive feature. For compounds where the volatility is high, pesticides must be incorporated immediately into the soil otherwise they are vaporised into the surrounding atmosphere before they have a chance of controlling the pest. For compounds such as the ureas and triazines where the volatility is relatively low, this is not necessary.

The principal factors controlling the rate of volatilisation are: (1) the vapour pressure of the pesticide; (2) the distribution of the residues; and (3) the moisture status of the soil or plant surface.

Within this computer system the loss of pesticide active ingredients to atmosphere is based upon the vapour pressure. The vapour pressure of the active ingredient, assuming the farmer has average loam, at a temperature of 20^{o}C and a soil pH of 7, is stored in the database. This value is classified and scored (S_{air}) according to the five risk bands shown in Table 1.

4.1.3. *Risk of contamination to water supply*, *leachability/run-off*

Analyses of water supplies in England and Wales by individual water companies during 1990 and 1991 have been reported by the Drinking Water Inspectorate[24,25]. Forty-five different pesticides were detected at least once at concentrations >0.1 ug/l. Parameters which affect the probability of a pesticide contaminating water include its persistence in soil measured as the soil half-life (DT_{50}), capacity for adsorption on to soil, and a measure of leachability. Soil adsorption is expressed as K_{oc}, which is an equilibrium constant for partition of a compound between soil organic matter and water and so is used for modelling the environmental fate of chemicals. This information is not always readily available and often data needs to be expressed as a range due to its inter-dependence on other factors.

As many of the physico-chemical parameters such as soil half-life and K_{oc} vary widely with soil conditions such as temperature and moisture, values have been selected and stored, within the pesticide database assuming the farmer has average loam, at a temperature of 20^{o}C and a soil pH of 7 e.g. mid-range values. In many cases data is only quoted in the literature for mid-range conditions and so a full data set for all conditions would be very difficult if not impossible to collate.

Gustafson[16] has combined two parameters, DT_{50} and K_{oc}, to assess the risk of contamination of water supplies using a groundwater ubiquity score (GUS) which is given in Eqn. 2.

$$GUS = \log DT_{50} \times (4 - \log K_{oc}) \quad (2)$$

Gustafson suggested that values for GUS below 1.8 represent compounds that do not leach. Compounds with a GUS value above 2.8 are potential leachers, and those in the region 1.8 to 2.8 show that a transition occurs from compounds likely to leach to those not likely to leach, and risk will depend on other factors such as soil type and environmental sensitivity.

In terms of potential contamination of groundwater, the eco-rating system takes into account solubility and the ease with which a chemical can pass into groundwater using GUS with data stored in the pesticide database. Scores, depending on the GUS value ranging from -10 for potential leachers to 0 for non-leachers, are assigned to the S_{leach} function for that pesticide active ingredient. Environmental problems associated with the contamination of surface waters are accounted for within the scoring function for product warning labels (L).

4.1.4. *Bioaccumulation potential, the octanol/water partition coefficient (K_{ow})*

The octanol/water partition coefficient, K_{ow}, is a measure of the distribution of a substance between a lipophilic phase (specifically, n-octanol) and the aqueous phase of the test system. K_{ow} is an indicator of the bioaccumulation potential of a compound in the fatty tissue of animals and the lipophilic portions of plants as well as the adsorption potential of a compound to the organic matter in soils. If the K_{ow} is high and the degradation rate low, the compound will accumulate in organisms of the food chain with successive increases in each step. For assessing the environmental fate K_{ow} is usually expressed in the logarithmic form (log P).

In assessing the bioaccumulation potential of a pesticide, a high log P, greater than 3, would indicate a greater affinity of the chemical to bioaccumulate/bioconcentrate in the food chain, a greater potential for sorption in soil, and a lower mobility. A lower log P, less than 2.7, means there is less affinity to bioaccumulate, and a greater potential for mobility. It also means there is a greater potential to biodegrade and to be metabolised by plants and animals. A mid-range log P 2.7 to 3, indicates that the chemical can go either way (Ney[26]). Within the computer system scores (S_{bio}) are assigned ranging from 0 for log P values less than 2.7, -5 for mid-range values and -10 for log P values greater than 3.

4.1.5. *Soil type/organic content*

The structure of the soil is an important factor in assessing the fate of pesticides. Soil contains many inorganic and organic compounds which are constantly being chemically and microbiologically transformed, and included in its organic compounds are humic substances, which are mainly negatively charged and possess a large surface area. Pesticides are adsorbed onto the surfaces, making it harder for them to be taken up by plants and micro-organisms and partially protecting them from chemical and enzymatic attack. Soil generally contains some 1 to 6% by weight of organic matter, but in peat soils this may reach some 95% of the dry weight. Within the computer system, soil types are classified into seven broad bands. These are sandy, shallow, deep silty, clay, organic mineral, other mineral and peaty. This simple classification has been selected for ease of interpretation by farmers.

Behavioural characteristics of soils under variable conditions, are stored as expert system rules within a knowledge base. Combining all these factors and the information supplied by the user such as moisture content which influences the pesticide activity and fate, the eco-rating system can be refined depending on site specific conditions or the farmer's practices. For example, the organic matter content will be increased if the farmer has applied manure, or the risk of leaching will be increased if the soil is sandy, or clay soils have baked and cracked in dry weather. These factors are considered by the use of penalty factors together with appropriate rules. For example the score derived for leaching S_{leach} is modified by a factor of 1.2 if the soil is sandy or a very dry clay.

5. Whole farm assessment

L_{SER} is determined by summing the label precaution scores and is then adjusted according to rules describing best practice and regulations by using a set of penalty factors (F_p). For example, has the recommended number of applications or maximum dose been exceeded (F_p = 2 if true); has a pesticide with off-label approval been used near water (F_p = 2 if true); has the pesticide used had approval for the specific crop and pest (F_p = 5 if false)? Other factors such as weather conditions and wind speed are used to assess good practice with respect to the risk of drift. For example, spraying is inadvisable in a force 4 windspeed for pesticides generally, or a force 3 for herbicides (MAFF/HSC[2]). Under these conditions the user would be penalised by a significant decrease in the eco-rating. This is achieved by applying a penalty factor to the eco-rating score ranging from 1 to 5 depending upon the differential between actual spraying conditions and those described in the Pesticide Code[2] and on the presence or absence of sensitive environmental receptors such as surface water.

The individual scores (S_{air}, S_{leach}, S_{bio}) are summed to give E_n and weighted by the quantity (Q) of active ingredient (n) applied to the field. This process is repeated for each active ingredient in the formulation and the individual values summed. This total is then added to the score derived from the pesticide label precautions L_{SER}.

The eco-rating P_f is determined for each individual pesticide applied to the field. These values are aggregated to give a field value. The aggregation process is a simple average combined with the use of other penalty factors which are used in conjunction with a further set of rules. These penalty factors are used, for example, to highlight the risk of pest resistance. Field values are then weighted by field size. The arithmetic mean represents the farm value. Values, both field and farm, are then normalised to lie on the scale range -100 to 0 to aid interpretation and transparency to the farmer. This normalisation process simply multiplies the determined eco-rating by 100 divided by the minimum theoretical eco-rating.

This technique allows many different practices to be assessed. Tank mixes can be accommodated by treating each of the mix components as a separate application. However, the present version of the software does not include information on the manufacturers recommendations for tank mixes nor any special environmental issues which may arise. This may be addressed in future versions of the system. Low dosage applications are tackled as the eco-rating equation incorporates application rates. If an under-dosage occurs and the farmer has to re-spray to protect the crop then as the eco-rating is accumulated across all applications this too affects the eco-rating. Repeated applications of the same pesticide or pesticides from the same chemical group would attract a penalty factor for an increased risk of pest resistance developing. Other best practice issues such as selecting disease resistant varieties or opting for seed dressing would similarly be reflected in the final eco-rating as, presumably, less crop applications would be required.

6. Management techniques and non-crop applications

The potential for environmental impact of the farmer’s use of pesticides is also dependent on the general management and handling techniques and not just the physico-chemical parameters and the field-by-field application. This type of information tends to be qualitative and observational in nature. Consequently, a different approach to that described above, is needed to determine the eco-rating.

There are various methods of translating observational and qualitative data into numerical representations. One technique commonly used is scoring and ranking the responses to a specifically designed questionnaire often in the form of a checklist. This method provides a scale for measurement and judgement and can be used to convert complex information into a simpler format, by for example, awarding individual scores to individual questions centred around a main theme, and then aggregating the scores to produce an overall score or index. This technique has been used for various applications and in particular has found favour in the United States where it has been used to evaluate wetlands and wildlife habitats (Erickson[27]) This procedure has been used to score handling and management techniques for pesticide use. This area has been subdivided as shown in Table 2.

For each management area, a check list style multiple-choice questionnaire has been designed which includes the activities given in Table 2. A range of options are given from best practice to worst. Scores are appropriately assigned ranging from -10 for worst practice to zero for best practice. These scores are then summed and normalised to give an index of management best practice P_m. As an example consider the waste management of a concentrated pesticide product. Regardless of how careful stock is managed there may be occasions when un-used concentrate is no longer required and must be disposed of. There are a number of options available, some environmentally acceptable, others less so. Each option has an associated score. Those options considered to be best practice have a score of zero. Those options which deviate from best practice and which may result in environmental damage will have a negative score. Table 3 shows some of the options and associated scores. The scores are not visible to the user during use. The definition of best practice and so the scores are based upon information provided in the Code of Practice for the Safe Use of Pesticides[2]. Another valuable information source has been the British Crop Protection Council[28]. The scores have been attributed by expert consensus available within the collaborating organisations. The total score, which will depend upon the type and number of options selected, is then added to the scores for other waste management issues such as practices adopted for the disposal of dilute pesticides and empty containers. In some instances additional information is required before an assessment can be carried out. For example if diluted pesticide solutions are disposed of to the public sewer the assessment system will need information as to whether this has been done with or without a local authority or Environment Agency discharge consent. In these cases a second level checklist is used to collate the required data.

Using a similar approach to that described for management techniques the farmer's use of pesticides off the field can also be assessed. The system includes the use of: wood preservatives, sheep dips, other livestock treatments, rodenticides and granular baits, fogs, mists, smokes, plant and seed dressing and dips and the use of pesticides generally around the farm such as in food stores, on refuse tips and manure heaps. Most of the issues raised by the general pesticide management audit apply equally to non-crop pesticides as to crop pesticides (e.g. storage, waste management) consequently the non-crop audits tend to be simpler and more specific to the application. Table 4 shows part of the audit used to assess the special requirements of sheep dips. The main source of information on sheep dip best practice has been the Health and Safety Executive[29].

7. The technical system

The technical part of the computer system does not interact with the evaluation and scoring system but has been designed to assist the user to identify practical, cost-effective ways of improving their eco-rating. With respect to pesticides, a simple but effective module, *'The Pesticide Informer'* has been developed which helps the user identify the most appropriate, approved pesticide for a specific job which will have the minimum environmental impact. Assistance on pesticide waste management, specifically waste minimisation and approved disposal of concentrates, dilute solutions and empty containers, is available within the '*Waste Management Advisor'* module.

The Pesticide Informer aims to highlight any environmental risk associated with specific pesticides. Scores are not assigned to individual pesticides but an icon system is used for visual clarity. For example, if the pesticide presents a high risk to aquatic species a fish-icon is shown, if a high risk to bees exists then a bee-icon is displayed. Other icons highlight the risk to groundwater, birds, wildlife, farm animals and humans, specifically organophosphates and carbamates. A further icon identifies pesticides subject to the 1972 Poisons Act, the Poisons List order 1982 or the Poisons Rules 1982. This aids identification of those pesticides which are highly toxic to humans and those to which special regulations apply regarding, in the context of this system, storage but also to sale and supply.

Icons are displayed according to the pesticide label precautions assigned by the Pesticide Safety Directorate of MAFF and the GUS[16] formula is used to determine the groundwater risk. This approach offers the user a simple, quick, visual means of identifying a pesticide suitable for the site which will control the pest minimising harm to the local environment.

8. The information system

The information system comprises a large range of hypertext files, text which is context-sensitively mapped allowing the user to navigate through the text following a chain of thought, providing instant, on-line access to a wide range of information relating to pesticides and how to minimise their impact on the environment. Within the Legislation database, summaries of various laws and regulations can be found including: The Food and Environmental Protection Act 1985, The Control of Pesticides Regulations 1986 and the 'Authorisation' directive. The Codes of Practice Library includes the three MAFF Codes of Good Agricultural Practice (MAFF[3]) and the Pesticides Code of Practice (MAFF/HSC[2]) as well as a range of other appropriate codes and guidance notes. The Science Library comprises around twenty short texts including a file presenting a brief introduction on minimising the environmental impact of pesticides.

9. Discussion and conclusions

The pesticide assessment methodology and the eco-rating derived are unique and they incorporate a wide range of features.

With respect to the field by field assessments of pesticide use, as the system is based on label precautions it indirectly utilises detailed research and development carried out by the pesticide manufacturer in order to seek MAFF/HSE approval. Consequently the eco-rating is both formulation specific and site specific unlike most other pesticide impact assessment methodologies. In addition a large range of variables are considered which affect the fate and transport of pesticides in the environment. The system does not rate, rank or compare pesticides specifically, but considers each pesticide and its local environmental impact on an individual basis.

The system is broad based considering general farm practices such as handling, storage and waste management practices, which if carried out improperly can significantly increase the risk of a negative environmental impact. It also assesses regulatory compliance by incorporating regulations into the rule base.

The indices derived cannot be used to compare one farm with another due to its site specificity. The computer system as a whole, however, can be used like an informal environmental management system. The first time the method is used a bench mark is derived against which the success of future environmental improvements can be measured. This research project is essentially an exercise in technology transfer. Current understanding of how pesticides interact with the environment has been utilised to define best practice on a site specific basis. Conclusions of the system are presented in a manner which aims to be easily interpreted and transparent to the user.

The computer system has been designed to run on an IBM compatible PC running under the WINDOWS operating system version 3.1 or better. Ideally a Pentium processor is required however the system will fully operate on a 486 processor albeit a little slow. Current plans are that the system will be commercially available from early 1998.

This paper has summarised the theory, design and development of the methodology. One of the difficulties encountered in developing such a system is that no matter how detailed the approach, it will always be a simplification of the real world. The development process began with the identification of the significant issues and then the assigning of largely arbitrary scores. Scores and weighting then had to be adjusted and balanced to obtained the desired accounting effect but still reflect the common consensus of expert opinion. Problems have been encountered regarding the fine balancing of scores to account for any positive or negative environmental trade-offs which might occur. The system needed to be able to adequately respond to questions which are difficult to resolve such as '*with respect to the risk to surface water, is it environmentally equivalent to use a relatively toxic pesticide with a buffer zone as to use a relatively benign one without a buffer?'* Other questions regarding efficacy also needed reasonable answers such as '*is it environmentally better to delay spraying a low dose of pesticide whilst metreological conditions such as wind speed are unfavourable and so risk having to use a more potent pesticide or a higher dosage to control a more intense problem later?'* The answers to both these types of questions depend entirely on site specific details, its environmental sensitivity, conditions at the time of spraying and how far they digress from ideal, plus the environmental toxicity of the pesticide. The answers are rarely straight forward. An associated paper (Part 2) presenting evaluation work and providing examples and information on the scoring system utilised, illustrating the values of eco-rating derived for a range of pesticides used in a theoretical farm situation has also been produced and seeks to answers some of the issues discussed here.

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References

[1] **MAFF** Pesticide poisoning of animals 1994. Report of the environmental panel of the advisory committee on pesticides. London. PB 2351, 1995.

[2] **MAFF/HSC** Pesticides: Code of practice for the safe use of pesticides on farms and holdings. HMSO, London, 1990.

[3] **MAFF** Codes of good agricultural practice (Air, Water and Soil) HMSO, London, 1991,1992,1993.

[4] **Johnston, A.R. & Lewis, K.A.** 1995 Effectiveness of environmental performance measures in ensuring sustainable development: the water and agricultural industries highlighted. Sustainable Development 1995, **3**(3): 140-148.

[5] **Newbold, M.J., Lewis, K.A., Tzilivakis, J., Finch, J., Kähö, T., Skinner, J.A., and Bardon, K.S**. The options for informal environmental management: the agricultural industry highlighted. Proceedings from Eco-Management and Auditing Conference, Leeds July 1996.

[6] **Tucker, P., Lewis, K.A. and Skinner, J.S**. Environmental management in agriculture: an expert system approach. Eco-Management and Auditing. **3**: March 1996.

[7] **Roberts, T.R and Kearney, P.C.** Environmental behaviour of agrochemicals. Vol. 9 Progress in pesticide biochemistry and toxicology, J.Wiley & Sons, 1995.

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

[9] **Higley, L.G. and Wintersteen, W.K**. A novel approach to environmental risk assessment of pesticides as a basis for incorporating environmental costs into economic injury levels. American Entomologist, 1992, **38**: 34-39

[10] **Kovach, J., Petzoldt, C., Degni, J. And Tette, J.** A method to measure the environmental impact of pesticides. New York's Food and Life Sciences, 1992, Bulletin **139.** New York State Agricultural Experimental Station, Geneva, New York, USA.

[11] **Hornsby, A.G.** Site-specific pesticide recommendations: the final step in environmental impact prevention. Weed Technology 1992, **6**: 736-742

[12] **Penrose, L.J., Thwaite, W.G. and Bower, C.C.** Rating index as a basis for decision making on pesticide use reduction and for accreditation of fruit produced under integrated pest management. Crop Protection 1994, **13**: 146-152.

[13] **Vereijken, P., Wijnands, F. And Stol, W.** Progress Report 2. Designing and testing prototypes. Progress reports of the research network on integrated and ecological arable systems for EU and associated countries (Concerted action AIR 3 - CT920755). AB-DLO, Wageningen, The Netherlands, 1995.

[14] **Wagenet, R.J. and Rao, P.S.C**. Modelling pesticide fate in soils. Pesticides in the soil environment, 1990 Soil Science Society of America Book Series, No. 2: 351-399 Madison, WI, USA.

[15] **Gustafson, D.I.** New advances in predicting pesticide fate and transport. Environmental behaviour of pesticides and regulatory aspects, 1994, 453-458. Copin, A., Houins, G., Pussemier, L. And Salembier, J.F. (eds.) European Study Service, 1994, Rixensart, Belgium

[16] **Gustafson, D.I.** Groundwater ubiquity score: a simple method for assessing pesticide leachability. Environmental Toxicology and Chemistry, 1989, **8**: 39-357

[17] **Parkin, C.S., Gilbert, A.J., Southcombe, E.S.E., & Marshall, C.J.** The British Crop Protection scheme for the classification of pesticide application equipment by hzard. Crop Protection, 1994, **13**(4): 281-285

[18] **Secher, B.J.M., Jorgensen, L.N., Murali, N.S. & Boll, P.S.** Field validation of a decision support system for the control of pests and diseases in cereals in Denmark. Pesticide Science, 1995, **45**(2): 195-199

[19] **Anon** The UK Pesticide Guide Ed. R. Whitehead. CABI/BCPC, 1997

[20] **Anon** The Pesticide Manual Tenth Edition. The British Crop Protection Council.

Ed. Clive Tomlin. Crop Protection Publications, 1995.
[21] **MAFF/HSE** Control of Pesticides Regulations, HMSO, London, 1986.
[22] **Plimmer, J.R.,** 'Volatility', in Herbicides - Chemistry, Degradation and Mode of Action (Eds. Kearney P.C., and Kaufamnn, D.D.), 2nd edn, Vol 2, Dekker, New York, 1975, 891
[23] **Taylor, A.W. & Spencer, W.F.** Volatilisation and vapour transport processes. Pesticides in the soil environment. Soil Science Society of America book series, no 2: 213-269 Madison, WI, USA
[24] **DWI** Drinking Water 1990. A report by the chief inspector, Drinking Water Inspectorate, 1991 HMSO, London
[25] **DWI** Drinking Water 1991. A report by the chief inspector, Drinking Water Inspectorate, 1992 HMSO, London
[26] **Ney, R.E. Jr.** Where did that chemical go? A practical guide to chemical fate and transport in the environment. Van Nostrand Reinhold, 1990
[27] **Erickson, P.A.** A practical guide to environmental assessment. Academic Press. 1994
[28] **Anon** Using Pesticides. A complete guide to safe, effective spraying. The British Crop Protection Council and ATB Landbase. 1996
[29] **Anon** Sheep Dipping, Leaflet AS29. Health and Safety Executive, Sudbury, 1994.

Table 1: Risk bands for assessing vapour pressure

Risk score	**0**	**-2**	**-5**	**-10**	**-20**
Vapour pressure (mPa)	$<1 \times 10^{-8}$	1×10^{-8} to 1×10^{-6}	1×10^{-6} to 1×10^{-4}	1×10^{-4} to 1×10^{-2}	$>1 \times 10^{-2}$

Table 2: Management techniques considered with the general pesticide audit

Management area	**Activities**	**Examples**
General management	Store room facilities	Provision of sump; wash room facilities, adequate shelving etc.
	Stock control	Regular stock checks; bulk purchases etc.
	Record keeping	Health records; application records etc.
	Health and safety and emergencies	COSHH[1]; fire and spill procedures.
	Staff training and awareness	Handling certification. Certificates of Competence.
	Machinery calibration and maintenance	Servicing and checking.
Waste management	Handling and disposal	Pesticide disposal; empty containers etc.
Need to spray	Pre-application activities	Informing neighbours and bee keepers; assessing infestation etc.
	Use of non-chemical controls	Bio, sticky traps, disease resistant varieties
Application (general)	Application techniques	Hydraulic, aerial, twin fluid nozzle, etc.
	Equipment, PPE[2] and PPC[3]	Provision; maintenance.
	Pollution abatement techniques	Use of buffer zones; not spraying field margins, etc.
Non-crop pesticides (biocides, rodenticides, aerosols; fumigants; seed and plant dressings, etc.)	Usage, handling and general management	Health and safety factors; risk to non-target species; pollution prevention activities.

Notes:
[1] COSHH - Control of Substances Hazardous to Health
[2] PPE - Personal Protective Equipment
[3] PPC - Personal Protective Clothing

Table 3: Part of the pesticide waste check-list audit

How do you dispose of your unwanted pesticide concentrate?	
☐ Send back to supplier	(0)
☐ Public sewer	(-7)
☐ Use specialist waste contractor	(0)
☐ Wash down sink/drain	(-7)
☐ Use soak-away or ditch	(-10)
☐ Spray undiluted to land	(-10)
☐ Spray diluted to land	(-5)
source [2,3,28]	

Table 4: Sheep dip issues considered

Issue	Audit questions
Location of dipping facilities	Inside/outside & sheltered/outside & exposed Proximity to sensitive features such as water
Facilities	Good features such as: Race to guide sheep/entry slope/ Efficient bath size/supply of clean water/splash boards Bad features such as: Plug for drainage/use of river or pond water/inefficient size
Personal protective equipment	Equipment and clothing utilised during preparation, operations and disposal. Maintenance of such
Practices	Good and bad features: Dipping ill, wet or pregnant sheep/dipping in adverse weather conditions/health and safety issues/how soon shearing occurs/waste disposal/grazing delay etc.

Table Captions

Table 1: Risk bands used for assessing vapour pressure

Table 2: Management techniques considered within the general pesticide audit

Table 3: Part of the pesticide waste check-list audit

Table 4: Sheep dip issues considered