A KNOWLEDGE-BASED SYSTEM FOR PREDICTING THE ENVIRONMENTAL IMPACTS OF SYSTEM LEVEL CHANGES TO EUROPEAN AGRICULTURAL SYSTEMS

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ABSTRACT

Environmental impact assessments are routinely completed prior to initiating many industrial developments. Similar assessments are undertaken of many donor funded agricultural and rural development projects in the developing world. As increased international aid is being directed towards Eastern and Central Europe so there is increased pressure on donor agencies to assess the environmental impacts of their actions in these regions.

This paper describes a computer based system which predicts the environmental impacts which may arise from implementing change to a variety of European farming systems. The system, which was developed from a similar system aimed at assessing the impacts of change in tropical countries, identifies primary and higher order impacts associated with a range of projects via a rule-based causal network. In order to provide the user with further information on a range of topics related to the impacts identified by the rulebase, hypertext linkages are provided from the rulebase and a textual database. This database contains information on the underlying causal mechanisms of impacts, suggestions for potential mitigating activities, a glossary and a bibliography. Although the primary use of the system is in training, the potential for its use in the scoping phase of Environmental Impact Assessments is discussed.

INTRODUCTION

Although the relationships between agriculture and the environment have long been recognized, the primary causes for concern often vary with situation. For example, in most Western countries food production is adequate and agriculture is increasingly seen as a provider of non-market goods, e.g. biodiversity and landscape. In many developing countries however, food supply is insufficient and development projects are regularly initiated with the aim of increasing agricultural production. Although these projects may be successful in the short term, if they are badly designed or executed they can cause serious environmental degradation, which in turn may serve to reduce productivity.

The Food and Agriculture Organization of the United Nations (FAO) recognised that the people involved with developing and implementing development projects were generally economists and planners, who had little background in environmental science. For this reason they were generally unaware of the range of environmental impacts which may arise from development projects. FAO also recognised that planners cannot be expected to perform such tasks without adequate training in environmental science and environmental impact assessment. In part fulfillment of this training requirement FAO commissioned the production of the ECOZONE software, which predicts the environmental impacts of development projects in tropical regions. This suite of software, which is described in detail in Edwards-Jones & Gough (1994a,b) has been utilised in training over the last two years, and has proved to be a useful tool both within formal training courses / seminars and also for informal training. Further developments of the software have included translation into French and Spanish and the development of specific case-studies (e.g. Edwards-Jones & Abdel-Asiz, 1995).

Given the success of the ECOZONE concept in the developing world it was decided to develop a prototype system for use in Europe, particularly Eastern and Central Europe. Many of the countries in these regions are undergoing transition to full market economies, and the agricultural systems which have predominated over the last 40 years may undergo significant change during this transition. It was this prospect of poorly regulated, large scale change which triggered the initial investigation of training needs in the areas of agri-environment interactions and environmental impact assessment in Central and Eastern Europe. This paper describes the development, structure and potential use of software, named EurEco (European Ecozone) which was developed as a part of an FAO initiative in this area.

AIMS OF THE PROJECT

The aim of this project was to develop a computer based system that could be used for training agricultural planners and extension workers to be more aware of the environmental impacts which may arise from changing existing agricultural systems. In order to meet this aim it was decided that the system should:

a) Contain knowledge about a wide range of agricultural systems.
b) Be general enough to be suitable for training agricultural planners from all European countries.
c) Recognise (and represent) the complexity of environmental systems and be capable of demonstrating both the higher order and cross-sectoral effects of an impact and make explicit the interaction between environmental, economic and social systems.
d) Possess extensive explanation facilities.
e) Be a suitable for use in formal and informal training situations.

Summary of the approach adopted to the development of EurEco

As with ECOZONE, a knowledge-based approach was adopted for the development of EurEco. This approach was taken; firstly because suitable quantitative data in the domain of agri-environment interactions is scarce, but much qualitative data and experiential knowledge does exist within the knowledge-bases of individual domain experts. Secondly the large scale of the model meant that, even if suitable data had been available, a system based on numerical algorithms would have been extremely complex, large and expensive to develop. Subsequent to engineering a rulebase from the acquired knowledge, the rulebase was implemented on the computer as a causal network (Shachter & Kenley, 1989). This approach permitted accurate representation of the connectivity of environmental systems, whilst also being easily transcribed into computer code and simple to amend.

Simply predicting the likely impacts arising from any change to an agricultural system is unlikley to be adequate for training purposes, and it was a stated requirement of the sponsors that the system should contain extensive explanatory facilities. Hypertext links systems had been used in this manner in computer systems (Estep et al, 1989) hence it was decided to develop EurEco around two modules, a knowledge-base and a textual database, that would be connected via hypertext links.

Knowledge acquisition

Knowledge acquisition for EurEco was initially limited to text analysis. However, subsequent to the construction of an initial rule-base, the rules were checked and amended by domain specialists in FAO and SAC.

Software

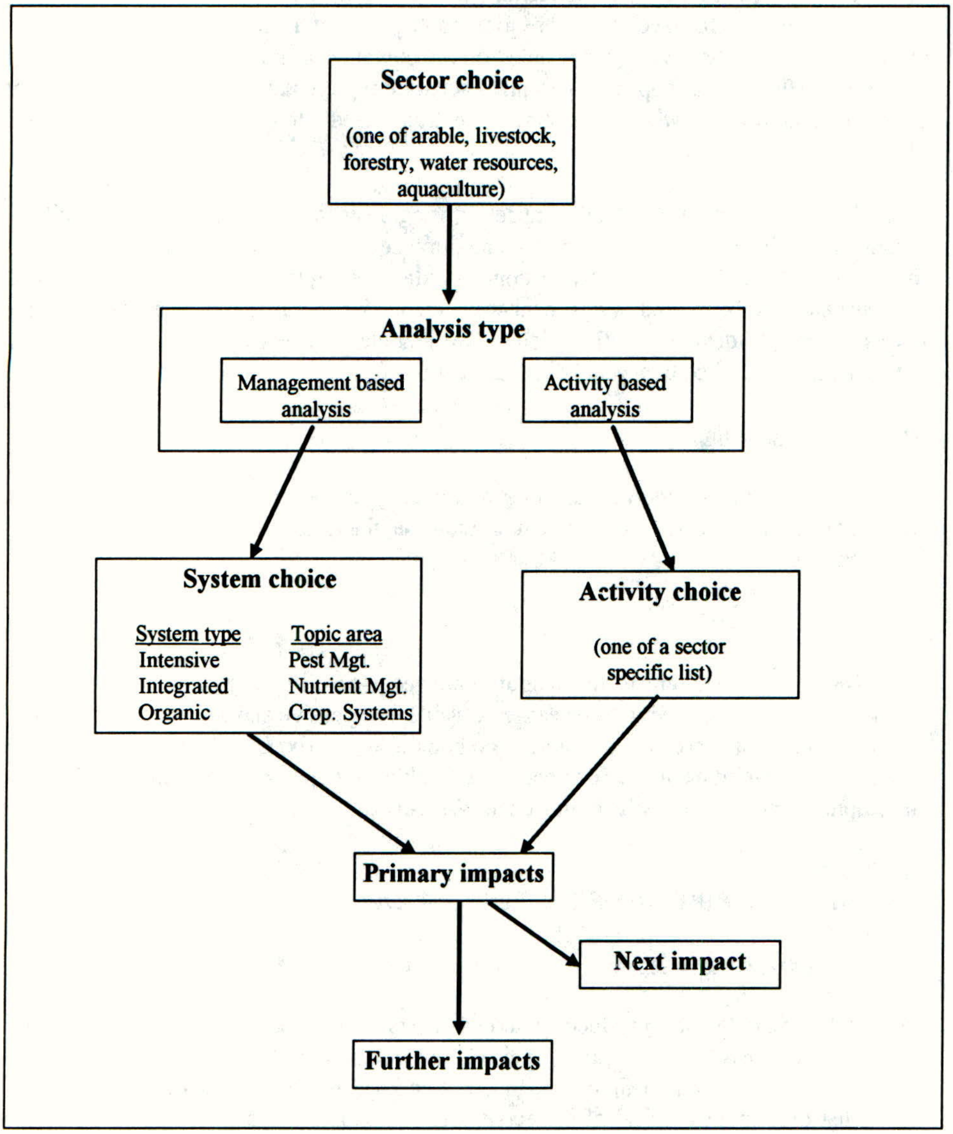
Due to the requirement to integrate knowledge-based systems with hypertext and the necessity for the software to be easily available, inexpensive and robust, it was decided to utilise the commercially available Toolbook (Asymetrix Corporation, Washington USA) as the development environment. Toolbook is an object-oriented, card/book-based development environment which runs under Windows.

GENERAL DESCRIPTION OF THE EurEco MODEL

The users view of the model

After viewing the introductory screens users of EurEco are required to select a sector for analysis. The sectors available include arable, livestock, forestry, water resources and aquaculture (Figure 1). In a conventional analysis the user is then presented with a list of activities typical of projects within the chosen sector. The use then selects one or more activities, and the software presents the primary impacts which may occur if those activities were undertaken. The user may then select one or more of these primary impacts for further analysis. This analysis may take one of two forms, either all further impacts arising from the selected primary impact are presented as one large tree, or if the 'Next Impact' facility is selected, it is possible to follow individual impact pathways one step at a time. These two options are analogous to a full search and a directed search.

FIGURE 1. A typical user's movement through EurEco



This activity based approach had proved appropriate for modelling interactions in all of the sectors in the ECOZONE software, however one of the perceived advantages of developing a similar model on a smaller scale was that a greater degree of detail could be incorporated into the model. For example it had been envisaged that EurEco would be able to detail the environmental impacts arising from management changes made to specific animal and cropping systems. It became apparent during the construction of

EurEco that while it remained appropriate to consider the environmental impacts arising from changes to livestock systems through the existing activity-based approach, this method was not appropriate for modelling the impacts arising from changes to cropping systems. This was because many of the practices undertaken within arable systems are common across crops. For example, many possible changes in pest and soil management and in the management of field margins all lead to broadly similar impacts regardless of the crop being grown. This overlap lead to a cluttered and confused user-interface and considerable repetition and redundancy within the rule base. For these reasons an alternative approach to the activity-based analysis was developed for the analysis of the environmental impacts arising from changes to cropping systems.

In this so-called, management based analysis, users specify whether they are which to analyze conventional, organic or integrated cropping systems. Having made this selection users are then select a topic area for analysis. This may be one of pest management, soil and nutrient management or cropping systems. Having completed this selection the user is presented with a list of activities which may be undertaken in that topic area under that farming system. Some examples of the different activities available for pest management in the three farming systems are given in Table 1. After selecting one or more of these activities the user is able to identify the primary and further impacts of the activity in the manner described above. It is possible to enter the textual database from any stage of the impact identification process, and having found the relevant information, to return to the appropriate impact prediction screen.

<u>Representation of primary and higher order impacts in EurEco</u>

Primary and higher order impacts are presented to the user through a combination of numerical notation and paragraph indents. In this system the number signifies the level of impact, i.e. '1' for a primary impact caused directly by the project, and '2' for secondary impacts caused by a primary impact. See Table 2 for an example.

In reality the number of higher-order impacts is potentially vast and the knowledge within the system is structured in order to permit realistic simulation of this process, however when the system is in normal use no more than 5 levels of impacts are presented to the user. This limit was implemented in order to provide a balance between demonstrating the real complexity of environmental systems and the need to keep search times short.

<u>The hypertext information system (HTIS)</u>

In order to render the HTIS more amenable to search by inexperienced users it was partitioned in to several sections, and upon initial entry into the system the user may chose which section to enter. The main sections include a glossary which contains a brief definition/description of terms and phrases, a text encyclopaedia which contains textual information on sectors, activities and impacts as would be found in a normal book, and a section entitled "Mitigation" which discusses possible methods of avoiding or mitigating impacts of activities.

TABLE 1. Activities listed under three farming systems for the topic area of 'Pest Management'.

Farming system		
Intensive	Integrated	Organic
use of herbicides and pesticides	use of pest/disease resistant crop varieties	no use of synthetic pesticides
improved aerial pesticide application	use of biological controls	use of pest/disease resistant crop varieties
increased pesticide usage	reduced dose applications	use of biological controls
	decreased pesticide usage	
	improved pesticide timing	
	improved pesticide placement	
	improved vehicle pesticide application	
	use of integrated pest management	
	use of biodegradable pesticides	
	use of encapsulated pesticides	
	use of herbicides and pesticides	
	use of systemic pesticides	

DISCUSSION

Generally mathematical models are useful for modelling systems for which we have a good understanding and sufficient data to quantify relationships. Conversely knowledge-based systems are well suited for modelling systems of which we have a good understanding but little available data (Stone, 1992). For this reason knowledge-based systems are increasingly being used to model environmental systems at a relatively large spatial scale (e.g. Fedra et al, 1991). In this situation they utilise knowledge to make some general predictions which may be accurate, but are unlikely to be precise. For example compare the output of a model for predicting soil erosion on a certain study area with that of a knowledge-based systems, such as EurEco. The former will give a precise prediction which is only applicable to the defined study area, while the latter will give predictions which may be imprecise for any one situation, but which will be valid over many situations. While the lack of quantification may be a disadvantage in some situations, this disadvantage must be weighed against the difficulty of developing quantitative models which are equally applicable in all situations.

Given our current state of knowledge, it is almost impossible to imagine the development of generic models which would be able to predict the multi-dimensional impacts which typically arise from any development project. Until this becomes possible then knowledge-based systems probably have a role to play in training personnel about the likely environmental impacts arising from any change, and also perhaps in the so-called scoping stage of environmental impact assessment. In the scoping stage all possible impacts are identified and the important ones are selected for further study (Glasson et al, 1994). Knowledge-based systems, similar to, but probably slightly more sophisticated than, EurEco and ECOZONE, may play a useful role in this process.

TABLE 2. An example of the output of EurEco. Here the activity is "reduced dose applications" which may lead to five primary impacts. All five of these could be analysed further, but for the purposes of clarity only the further impacts arising from "decreased pesticide residues in soil" are shown.

Activity: reduced dose applications

Primary impacts
- 1,decreased pesticide in surface water
- 1,decreased pesticide in groundwater
- 1,decreased pesticide residues in soil
- 1,risk of poor control of pests
- 1,decreased production costs

Further impacts of: decreased pesticide residues in soil
- 2,improved wildlife habitat
- 2,decreased pesticide leaching
  - 3,decreased pesticide in drinking water
    - 4,improved human health
  - 3,decreased pesticide in surface water
    - 4,improved wildlife habitat,
  - 3,decreased pesticide in groundwater
    - 4,decreased pesticide in drinking water

Regardless of their use, whether it be for training or in scoping, the imprecise nature of the predictions of knowledge-based systems must be recognised, and human expertise will nearly always be required to interpret the output and put it in its local context. It was partly for this reason that the textual database was included within EurEco. The idea being that the knowledge-based systems would suggest all possible impacts, but with the aid of the information in the database, local experts could identify the more and less probable impacts for their situation. In this way a degree of precision could be brought into the predictions.

Although EurEco is clearly subject to some important limitations, such as a lack of quantification of impacts, both in terms of importance and magnitude, and the assumption that interactions within environmental systems may be modelled in a purely deterministic manner, the potential of such systems for training has been demonstrated with the

ECOZONE software. However it must be noted, that to date official training activities utilising EurEco have been limited. The view of an international workshop which considered the immediate agricultural training needs of Eastern and Central Europe was that the requirement for training in extension and basic production techniques was far more important than that in agri-environment interactions. It appears however, as though this attitude is starting to change and the EurEco software is scheduled to be used in an FAO training initiative in Slovakia in July 1995. Despite this recent development, the attitudes in Eastern and Central Europe to agri-environment interactions provides an interesting contrast to that in many African and Asian countries. The latter are regularly faced with the immediacy of environmental degradation, and are keen to develop more environmentally benign agricultural systems.

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THE IMPLICATIONS OF IMPROVING THE CONSERVATION VALUE OF FIELD MARGINS ON CROP PRODUCTION.

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ABSTRACT

Two field studies were conducted in Shropshire and Leicestershire during 1993/94 to quantify the effects of field margin management on cereal production. In the first, it was demonstrated experimentally that growing the crop up to the field margin gave a greater overall yield. Crops adjacent to a wildflower/grass strip yielded the next highest, whilst the poorest yield was obtained from a conservation headland adjacent to a sterile strip.

In the second study, a survey of winter wheat headlands revealed that grain yields were significantly less at the crop edge compared to 12 m into the crop, whilst weed biomass was significantly greater near to the field margin and decreased on moving towards the centre of the field.

INTRODUCTION

Field margins are a prominent feature of farm landscapes in Britain. However, the increase in agricultural productivity over the last thirty years has had a dramatic effect on these semi-natural areas, particularly in terms of hedgerow removal. Many thousands of kilometres of hedgerows have been removed to facilitate the operation of larger machinery (Barr *et al.*, 1993). The mis-application of fertiliser and the application of herbicides, either deliberately, or accidentally through spray drift, have seriously reduced the botanical diversity found both at the base of remaining hedgerows and within arable fields. The loss of certain primary producers has been shown to have severe implications on important food chains and has resulted in a serious reduction in the number of species, for example gamebirds (Sotherton & Rands, 1987). However, the requirements for agriculture and wildlife may be complimentary, since the maintenance of a diverse, perennial ground flora will also discourage weed populations within the boundary, as well as supporting a wider variety of birds and beneficial insects (Marshall, 1988; Lakhani, 1994; Morris & Webb, 1987).

Crop yields from the headland area are often lower than that of the midfield (Boatman & Sotherton, 1988; Speller *et al.*, 1992; Sparkes *et al.*, 1994). The headland is used for turning agricultural machinery during cultivation, drilling, spraying and harvesting operations, which may directly lead to crop damage, soil compaction, double application of seed, fertilisers and pesticides. Shading by tall boundary vegetation and competition for water from tree and shrub roots may also cause additional yield losses (Fielder, 1987). However, in some cases the crop may benefit from the shelter effect of hedges which may in turn increase yields (Marshall, 1967).

Various methods of field margin management have been proposed, but have focused mainly on wildlife conservation, and limited efforts have been made at quantifying the effects of management strategies on crop production. This paper describes preliminary results from the first year of two experiments which aims to redress this balance. Results are also presented for a survey of winter wheat headland grain yields and weed amounts.

MATERIALS AND METHODS

Field margin management experiment

A replicated field experiment was conducted within winter wheat headlands (cultivar Hunter) at two locations, the Harper Adams College Farm, Shropshire and the Loddington Estate, Leicestershire. The aims of the experiment were to investigate the effects of field margin management practices on crop production. The experimental treatments were: (i) Cropping up to the field margin with a fully sprayed headland. (ii) Cropping up to the field margin with a conservation headland. (iii) Leaving a 1 m wide strip next to the field margin to naturally regenerate. (iv) A 1 m wide sterile strip with a fully sprayed headland. (v) A 1 m wide sterile strip with a conservation headland. (vi) A 1 m wide strip planted with a mixture of perennial grasses and wildflowers.

Plots were marked out in the headland areas in a randomised block design, with three blocks of six treatments at each site. Plots measured 14 m x 12 m at the Shropshire site, and 10 m x 12 m at the Leicestershire site. Permanent and destructive quadrats (0.25 m^2) were established in the plots at 0, 1, 2, 3, 4 and 11.5 m from the field margin. The plots were assessed at Zadoks growth stage 31 and 59 (Tottmann, 1987) and at harvest. Estimates of percentage ground cover by each species present were recorded within the permanent quadrats at each assessment date. All vegetation within the destructive quadrats was cut by hand at ground level and the crop and the weeds separated and weighed at each assessment date for the Leicestershire trial. At the Shropshire site quadrats were cut by hand at GS31 and GS59, at harvest the plots were harvested with a plot combine and subsamples of grain were collected.

Survey

A detailed survey of winter wheat headlands was conducted during August 1994. Sixteen headlands were sampled, nine in Shropshire and seven in Leicestershire. A series of four transects were set out at each site, running at right angles to the field boundary, from the crop edge to 12 m into the field. Quadrats (0.25 m^2) were placed along the transects at 0, 1, 2, 3, 4, and 11.5 m from the crop edge. All vegetation within the quadrats was harvested and separated into crop or weeds. It was noted whether the headland was a turning or non-turning headland, and the aspect of the site was recorded.

RESULTS

Field margin management experiments

The experiment was analysed using ANOVA at each site.

GS31 and GS59

At GS31 and GS59 treatment has a significant effect on total crop dry weight (GS31 Shropshire $F_{5,50}$=6.904, P<0.001 & GS31 Leicestershire $F_{5,50}$=5.839, P<0.001, GS59 Shropshire $F_{5,50}$=12.341, P<0.001 & GS59 Leicestershire $F_{5,50}$=3.163, P<0.05). On both occasions the crop to the edge sprayed and the crop to the edge conservation treatments yielded higher than the other treatments (Table 1). Quadrat position was highly significant (GS31 Shropshire $F_{5,50}$=88.490, P<0.001 & GS31 Leicestershire $F_{5,50}$=6.523, P<0.001, GS59 Shropshire $F_{5,50}$=85.650, P<0.001 & GS59 Leicestershire $F_{5,50}$=35.414, P<0.001), with crop dry weights generally increasing with distance from the crop edge (Table 2).

There were significant differences between treatments for weed dry weight at GS31 and GS59 (GS31 Shropshire $F_{5,50}$=4.972, P<0.001 & GS31 Leicestershire $F_{5,50}$=4.043, P<0.01, GS59 Shropshire $F_{5,50}$=4.176, P<0.01 & GS59 Leicestershire $F_{5,50}$=3.117, P<0.05) (Table 1). Quadrat position was significant (GS31 Shropshire $F_{5,50}$=3.025, P<0.05 & GS31 Leicestershire $F_{5,50}$=9.453, P<0.001, GS59 Shropshire $F_{5,50}$=15.889, P<0.001 & GS59 Leicestershire $F_{5,50}$=5.167, P<0.001) and weed dry weights were generally greater from the headland area than from the quadrats positioned at 11.5-12 m from the crop edge (Table 2).

TABLE 1. Mean crop (whole plant) and weed dry weights (g/m^2) for each treatment at GS31 and GS59

		Treatment						
		Crop to edge sprayed	Crop to edge conserv.	Natural regen.	Sterile strip sprayed	Sterile strip conserv.	Wildflower /grass	LSD*
GS31								
Shrops.	Crop	98.15	106.00	78.27	80.13	78.39	74.69	3.33
	Weed	12.04	10.03	14.95	7.75	5.94	9.54	4.11
Leics.	Crop	52.43	56.20	38.72	39.10	28.55	40.16	12.08
	Weed	8.98	6.92	5.06	4.23	7.93	3.07	3.27
GS59								
Shrops.	Crop	672.33	614.54	464.44	481.00	440.82	513.93	75.54
	Weed	32.53	41.40	73.53	41.47	40.61	48.93	20.14
Leics.	Crop	594.03	587.68	479.00	541.91	495.13	484.14	87.78
	Weed	20.56	41.37	18.92	15.03	37.43	22.67	17.57

(* Least significant difference between treatment means at P<0.05, 34d.f.)

TABLE 2. Effect of distance from crop edge on mean crop and weed dry weights (g/m^2)

		Distance from crop edge (m)						
		0-0.5	1-1.5	2-2.5	3-3.5	4-4.5	11.5-12	LSD*
GS31								
Shrops.	Crop	18.02	44.10	88.65	109.36	117.87	137.64	47.15
	Weed	8.90	13.22	9.01	9.23	6.98	12.90	13.72
Leics.	Crop	28.01	51.32	48.07	34.82	37.46	55.50	40.34
	Weed	7.57	4.30	5.25	5.99	11.75	1.33	10.92
GS59								
Shrops.	Crop	178.34	273.70	633.74	647.63	693.59	760.06	252.16
	Weed	81.67	81.97	32.96	33.78	27.48	20.59	67.24
Leics.	Crop	208.62	498.57	602.85	542.16	616.78	718.88	283.01
	Weed	36.64	23.81	28.72	23.38	41.58	1.85	58.65

(* Least significant difference between distance means at P<0.05, 4 d.f.)

Harvest

At harvest, treatment had a significant effect on grain yield at the Leicestershire site ($F_{5,50}$=7.053, P<0.001). The crop to the edge fully sprayed and the crop to the edge conservation treatments yielded higher than the other treatments. The conservation headland marginally outyielded the conventional crop to the edge headland. Of the remaining treatments, the headland next to the grass / wildflower strip yielded the highest, whilst the conservation headland next to the sterile strip produced the poorest yield (Table 3). Similar results were obtained at the Shropshire site, though differences between treatments were not significant. The Shropshire site was harvested using a plot combine and so detailed quadrat yields are not available. Combine yields are not presented here. Quadrat position was highly significant at the Leicestershire site ($F_{5,50}$=50.358, P<0.001), with grain yield increasing on moving away from the crop edge for all treatments (Table 3).

Assessments of weed dry weight were only made for the Leicestershire site. The amount of weed material differed between treatments ($F_{5,50}$=19.471, P<0.001). The two conservation headland treatments contained the most weed material, whilst the remaining treatments contained relatively few weeds. Quadrat position was significant ($F_{5,50}$=3.186, P<0.05), weed dry weights once again decreased on moving away from the crop edge for all treatments (Table 3).

TABLE 3. Mean grain yield and weed dry weights at harvest for the Leicestershire site

		Distance from crop edge (m)						
		0-0.5	1-1.5	2-2.5	3-3.5	4-4.5	11.5-12	treatment mean
Crop to edge sprayed	yield t/ha	4.57	6.02	5.77	6.55	7.19	6.55	6.11
	weeds g/m^2	33.31	6.33	0.80	1.68	1.17	1.81	7.52
Crop to edge conserv.	yield t/ha	5.54	5.84	6.64	5.97	6.87	8.13	6.50
	weeds g/m^2	36.91	43.81	32.09	50.29	46.71	1.00	35.14
Natural regen.	yield t/ha	-	5.38	5.35	6.20	6.78	6.77	5.08
	weeds g/m^2	16.28	5.53	65.69	2.23	23.08	5.21	9.67
Sterile strip sprayed	yield t/ha	-	6.02	5.84	6.13	6.82	7.43	5.37
	weeds g/m^2	40.32	0.39	10.08	3.76	38.01	1.87	15.74
Sterile strip conserv.	yield t/ha	-	5.92	4.63	4.99	5.25	6.35	4.52
	weeds g/m^2	26.76	109.19	123.55	101.60	147.35	11.60	86.67
Wildflower /grass	yield t/ha	-	5.23	6.11	5.50	7.77	8.39	5.50
	weeds g/m^2	18.51	7.99	2.15	2.12	13.12	14.05	9.66

(Least significant difference between treatment means : yield = 0.76, P<0.05, 34 d.f.)
(Least significant difference between treatment means : weeds = 20.17, P<0.05, 34 d.f.)

Survey

Both grain yield and weed dry weights varied significantly between sites (Grain yield $F_{15,225}$=23.674, P<0.001, weed dry weight $F_{15,225}$=18.832, P<0.001), grain yields ranged from 5.13 t/ha to 9.56 t/ha, whilst weed dry weights varied from 4.09 g/m^2 to 113.19 g/m^2. Quadrat position was highly significant for grain yield ($F_{5,225}$=54.293, P<0.001) and weed dry weight ($F_{5,225}$=19.766, P<0.001). Grain yield became significantly greater as distance from the field edge increased, while weed dry weights decreased on moving away from the crop edge (Figure 1). There was a significant interaction between site and quadrat position for both grain yield and weed dry weight. Differences in yield were recorded between headland and main field (11.5-12 m) quadrats (Table 4). Differences ranged from a reduction in yield of 47 % on the headland to an increase of 13 %, though usually the headland yielded less compared to the main field. Weed dry weights were greater from the headland area compared to the main field quadrats, especially for site 16 which was a conservation headland, and so would be expected to contain a greater amount of weed material.

There was no significant difference between turning and non-turning headlands. Aspect had a significant effect, with north facing headlands yielding slightly higher than south facing ones ($F_{1,228}$=30.287, P<0.001).

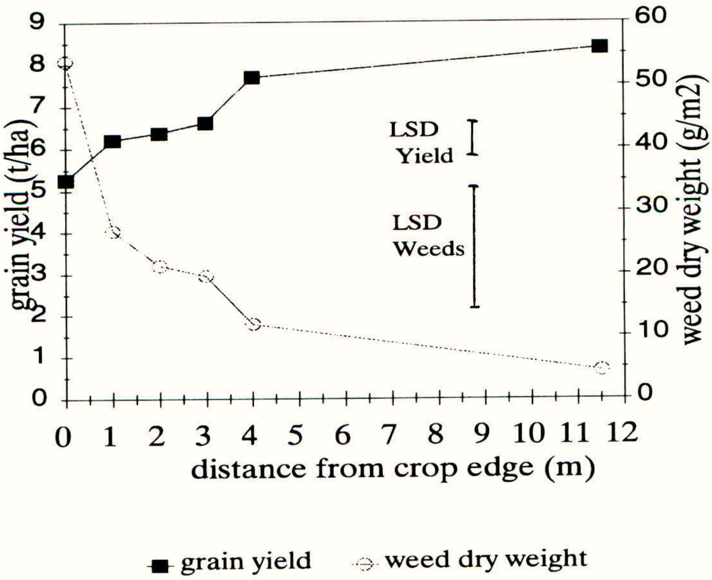

Figure 1 Survey mean grain yields and mean weed dry weights for sixteen sites

TABLE 4. Difference between headland and main field quadrat yields for 16 sites

Site	Mean Headland Yield (t/ha)	Mean Field Yield (t/ha)	% Difference
1	5.80	5.13	+13.06
2	4.60	5.70	-19.23
3	4.62	8.77	-47.32
4	7.18	8.15	-11.90
5	5.03	6.03	-16.58
6	7.07	7.51	- 5.86
7	6.04	8.42	-28.27
8	7.43	9.31	-20.24
9	6.33	9.68	-34.57
10	7.54	7.92	- 4.80
11	7.45	9.26	-19.57
12	6.25	8.34	-25.01
13	7.30	9.07	-19.56
14	6.04	8.61	-29.85
15	9.25	11.10	-16.70
16	4.98	8.96	-44.42
Mean	6.43	8.37	-23.12

Sites 1-9 were in Shropshire, sites 10-16 were in Leicestershire.

DISCUSSION

Results for the first year show that although the average yield at the field edge is low, taking 1 m out of production, either by creating a sterile strip of bare ground, or by sowing or leaving to natural regeneration significantly reduced overall yields. May *et al.* (1994) recorded similar findings where the lowest wheat yields occurred where the crop was grown with a sterile strip and the highest where wheat was grown up to the field edge. However, the amount of income that is lost due to a lower yield when the outer 1 m of the field is taken out of crop production may be outweighed by other benefits of creating what is essentially an extended field margin. For example, the expansion of the perennial ground flora at field edges, either using sown species or natural regeneration, can help to control annual weed species of hedgerows such as *Galium aparine* and *Bromus sterilis*, which may invade adjacent crops (Marshall, 1989), and also enhance populations of beneficial insects by providing suitable overwintering sites (Thomas *et al.*, 1991).

Generally the headland areas tended to yield less than the main field. This suggests that losses incurred by reducing inputs into this area would be proportionally less than if inputs were reduced on another part of the field.

The survey showed that there was no difference between turning and non-turning headlands. Aspect had a significant effect, with north facing headlands yielding slightly higher than south facing ones. This may have been because north facing headlands received more shelter, this agrees with Marshall (1967) who found that the sheltering effects of hedges can lead to increased yields in some circumstances.

The field margin management experiments are being repeated at the same sites during 1994/95. As well as recording crop yield and weed dry weights, measurements will also be made of soil compaction and the fertiliser spread pattern over the headland area to attempt to find out what factors affect yield differences over the headland area.

A second survey of winter wheat headlands will be conducted in 1995. This time the sampling distance will be extended to 30 m into the field. The survey area will also be widened to cover calcareous soils, which make up a large amount of the cereal area in the U.K.

From these observations it is aimed to produce recommendations for a more integrated approach to the management of field margins to improve their conservation value, whilst still meeting the agricultural objective of economic crop production.

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SLUG DAMAGE TO CLOVER AND WHEAT GROWN SINGLY AND IN MIXTURES

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ABSTRACT

Feeding damage by the grey field slug, *Derocerus reticulatum*, was compared on two cultivars of white clover (*Trifolium repens*) and on three growth stages of wheat (*Triticum vulgare*), grown singly or as mixtures in controlled environment conditions. Slug damage to both clover and wheat, irrespective of clover cultivar or wheat growth stage,was significantly less in mixtures than in single (monoculture)plantings. The greatest reduction in damage to wheat at all growth stages occurred in wheat-clover mixtures with clover cv.Milkanova (50-60% less than in wheat monocultures). This clover cultivar was slightly more susceptible to slug damage than the other clover, cv.Donna, used in the experiment.

INTRODUCTION

Growing successive crops of winter wheat with a permanent companion crop of white clover may have considerable potential as a continuous low-input, dual purpose (bicropping) production system for grain and animal fodder or silage. Once established, the wheat component of the system is harvested for grain in the usual way and the wheat straw baled and removed. The flush of clover growth after harvest is then grazed or cut for silage in autumn and the next crop of winter wheat direct-drilled into this close-cropped sward to repeat the cycle. Nitrogen fixation by the permanent ground cover of clover provides most of the nitrogen required by the developing wheat crop and allows substantial reduction in the use of inorganic fertiliser (Jones & Clements, 1993).

Evidence from recent field experiments suggests that bicropped wheat is also less prone to damage by some invertebrate pests (e.g. slugs and aphids) and fungal pathogens (e.g. *Septoria* and *Fusarium*) and, thus, may require fewer pesticide inputs than wheat grown in conventional monoculture (Deadman & Soleimani, 1994; Clements & Kendall, 1995). However, further research is needed on the epidemiology of pests and pathogens in crop mixtures, in order to fully exploit and maximise the potential benefits of bicropping on pest and disease control.

Slugs can destroy large areas of winter wheat, especially in less intensive farming systems, by feeding on seeds and seedlings at crop establishment (Glen *et al.*, 1994). Thus, crop management practices that tend to reduce slug damage are of considerable interest. A controlled environment experiment was done at Long Ashton in 1994 to investigate and compare slug grazing on wheat at different growth stages when planted in monoculture or with slug-susceptible and slug-resistant white clovers.

MATERIALS & METHODS

Five replicates of eleven clover, wheat and clover-wheat mixtures (Table 1) were grown in covered propagator trays (22 x 15 cm) in John Innes compost (loam, peat, grit mixture, 6:4:2 m/V) with VitaxQ4 nutrients (3.3 g/l at pH 6.5). Initially the trays were kept in a controlled environment room at 18°C day (8h light) and 15°C night (16h dark) in order to establish the various plant populations. The two white clover cultivars, cv. Milkanova (slug- susceptible) and cv. Donna (slug-resistant), were sown first. After 14 days, the clover seedlings in each tray were thinned to three rows of five plants, corresponding to a field seed-rate of 10kg/ha. The three growth stages of wheat (cv. Hereward) were then established in their respective trays by sowing seed 10 days, 5 days and 1 day before the start of the experiment.

TABLE 1. Summary of multifactorial treatments of two cultivars of white clover (cv. Donna and cv. Milkanova) and three growth stages of winter wheat (cv. Hereward).

Treatment No.	Clover cultivar	Wheat growth stage (Zadocks)	
1	Donna	(no wheat)	
2	Donna	Seed	(GS03)
3	Donna	1 leaf	(GS10)
4	Donna	3 leaf	(GS13)
5	Milkanova	(no wheat)	
6	Milkanova	Seed	(GS03)
7	Milkanova	1 leaf	(GS10)
8	Milkanova	3 leaf	(GS13)
9	(no clover)	Seed	(GS03)
10	(no clover)	1 leaf	(GS10)
11	(no clover)	3 leaf	(GS13)

Grey field slugs (*Derocerus reticulatum*) were collected from bran bait traps in fields of winter wheat at Long Ashton and kept for 1-2 weeks at 10°C in covered plastic sandwich boxes (16 x 28 x 9 cm) lined with moist cotton wool (about 30 slugs/box) until the start of the experiment. Every three days the slugs were fed a fresh mixture of the two clover cultivars used in the experiment and, at the same time, any uneaten leaves and dead slugs were removed.

The experiment was done in a controlled environment chamber at 10°C with a 10h light, 14h dark cycle and high relative humidity. One adult slug of known weight was put into each propagator tray and allowed to feed for 14 days. After this period, the slug was removed and re-weighed. The amount of feeding damage to each of the clover and/or wheat plants in each tray was estimated visually to obtain the percent leaf or seed tissue grazed. Treatments were compared by analysis of variance in Genstat 5, using a logit transformation of the percent tissue damage/plant.

RESULTS

Changes in slug weight during the experiment did not differ significantly between the experimental treatments.

Slug grazing/plant was consistently greater on clover cv. Milkanova than on cv. Donna irrespective of the presence or absence of wheat or the growth stage of wheat, although the overall difference in susceptibility to damage of the two clover cultivars was not significant (Table 2A). Both cultivars had significantly more tissue damage/plant in the absence of wheat than in the presence of wheat, with least damage where wheat seeds were present (Table 2B). The percentage of clover plants damaged in each treatment followed a similar pattern (Table 2).

Wheat seed was always the most susceptible growth stage to slugs with progressively less damage/plant at GS10 and GS13, irrespective of the presence or absence of clover (Table 3A). All growth stages of wheat suffered most slug grazing (tissue damage/plant) in the absence of clover (i.e. in monoculture) and least in the wheat-Milkanova mixtures, with the wheat-Donna mixtures intermediate (Table 3B). As for clover, the percentage of wheat plants damaged by slugs in each treatment corresponded with the amount of tissue damage/plant (Table 3).

TABLE 2. Mean percent area of clover leaf tissue grazed by slugs (expressed as logits with back-transformed percentages in brackets) and the percentage of clover plants damaged.

	Treatment (see Table 1)		Tissue damage/plant		% Plants damaged
A.	1,2,3,4	Donna	-3.995	(1.3)	9.3
	5,6,7,8	Milkanova	-3.852	(1.6)	10.2
		s.e.d. (df=98)	0.1017		0.599
B.	1,5	Clover (no wheat)	-3.552	(2.3)	12.0
	4,8	Clover + wheat GS13	-3.839	(1.6)	10.3
	3,7	Clover + wheat GS10	-3.951	(1.4)	9.6
	2,6	Clover + wheat seed	-4.353	(0.8)	7.8
		s.e.d. (df=98)	0.144		0.85

TABLE 3. Mean percent area of wheat seed or leaf tissue grazed by slugs (expressed as logits with back-transformed percentages in brackets) and the percentage of wheat plants damaged.

	Treatment (see Table 1)		Tissue damage/plant		% Plants damaged
A.	4,8,11	Wheat GS13	-4.729	(0.4)	27.7
	3,7,10	Wheat GS10	-4.532	(0.6)	21.1
	2,6,9	Wheat seed	-4.107	(1.1)	31.4
		s.e.d. (df=112)	0.1838		4.3
B.	9,10,11	Wheat (no clover)	-4.217	(1.0)	35.0
	2,3,4	Wheat + Donna	-4.348	(0.8)	28.4
	5,6,7	Wheat + Milkanova	-4.804	(0.3)	16.8
		s.e.d. (df=112)	0.1838		4.3

DISCUSSION

In our experiments, slug damage to winter wheat (cv. Hereward) seed and seedlings was significantly reduced to 30-80% of that in wheat monoculture by the presence of a companion crop of white clover. The greatest reductions in damage to wheat (30-50%) occurred in wheat-clover mixtures with a slug susceptible clover, cv. Milkanova. Hence, choice of clover cultivar may be important for the integrated control of slug damage in less-intensive (low-input) wheat-clover bicrops. In view of these laboratory findings, several wheat-clover mixtures are currently being tested in small plot field experiments to determine their relative susceptibility to slugs and other pests.

Our results provide evidence that crop mixtures (i.e. increased plant diversity) in arable cropping systems could be beneficial for integrated pest management, at least for a generalist herbivore like the grey field slug (*Derocerus reticulatum*). In this case, the reduced levels of damage to both wheat and clover when grown in mixtures can be explained as a dilution effect whereby the total amount of herbivory (or damage) is spread between two plant species; this probably reduces the specific damage to each component of the cropping mixture. This conclusion is supported by the measurements of slug weight before and after the experiment. These data indicate that the overall level of herbivory in each of the experimental treatments was not significantly different.

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