SESSION 9B

HERBICIDES IN THE ENVIRONMENT: EXPOSURE, CONSEQUENCES AND RISK ASSESSMENT – PART 1

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Papers: 9B-1 to 9B-3

FOCUS surface water scenario development

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On behalf of FOCUS Working Group on Surface Water Scenarios (under the auspices of European Commission's DG Health and Consumer Protection).

ABSTRACT

The Authorisations Directive, 91/414/EC for the placing of Plant Protection Products on the market came into force in July 1993. In the Annexes, which give substance to the Directive, there is a clear need to provide Predicted Environmental Concentrations (PECs) as part of the process for assessing the risk to non-target organisms. In the specific context of organisms dwelling in surface water, the Annexes are also clear in the need to consider **all** appropriate input routes into surface water bodies. In the dossier preparation for the first list compounds most of the Agrochemical Industry concentrated on spray drift as the main route of entry into water bodies as this was readily quantified through the use of simple "models" based on empirical "drift tables", several sets of which exist at the National level. Little emphasis was put on the entry of pesticides into surface water via surface run-off/erosion and sub-soil drainflow and what work was done was carried out in an uncoordinated and unguided manner. In 1997 the fifth FOCUS (**FO**rum for the **C**oordination of pesticide fate models and their **US**e) workgroup was created with the remit to define "standard scenarios" for surface water exposure. This paper records the advances made by the group since then and gives an overall appraisal of the timeline for the completion of the work.

INTRODUCTION

In 1992 an ad-hoc group of regulatory, industry and academic "experts" met in Brussels to lay the foundations for the FOCUS (**FO**rum for the **C**oordination of pesticide fate models and their **US**e) groups. One of the remits of these groups has been to provide guidance to the Member States, the European Commission and the Agrochemical Industry on the role of modelling in the EU registratory process. The third of the FOCUS groups met to deal with surface water models and produced a report (DOC.6476/VI/96) which included an extensive review of available models and also proposed a "stepped" approach to exposure assessment, starting with simple "back of the envelope" calculations and increasing in complexity to sophisticated mechanistic modelling. The report also highlighted the importance of run-off/erosion and drainflow as entry routes into surface waters and the need for their inclusion in exposure calculations.

In 1997 the fifth FOCUS workgroup was created with the remit to define a limited number of "standard scenarios" for surface water exposure (not more than 10), representative of commercial agriculture across the EU. The workgroup of "expert scientists" numbering 16 in total (14 at any one time) have been drawn from Regulatory, Academic and Industrial backgrounds and have relevant expertise in modelling surface water issues. They represent 8 Member State Nations as well as the European Commission.

REVISED REMIT

Whilst the original remit of the workgroup was interpreted as the need to create up to 10 standard scenarios for modelling surface water exposure ("step 3" in a four step process defined by the first FOCUS Surface water workgroup, see Figure 2), it quickly became apparent that this could not be done without reference to the two preceding steps in order to ensure that the correct level of conservatism and realism was used at each step. Consequently, as these two more conservative assessment steps had not been defined in detail, the workgroup undertook this additional task. It was agreed that the assessments should be most conservative (least realistic, highest safety margins) at step 1 and become less conservative (more realistic) through the steps. Furthermore, the range of possible predicted exposure concentrations gets wider as the user proceeds through the steps, reflective of the wider range of climates, soils and agronomic practices in the "real world". The perceived ranges of predicted exposure concentrations for the different steps, compared to "reality" are shown in Figure 1. As part of the definition of the step 1 and 2 calculations the workgroup also recognised the need to provide guidance for the calculation of exposure concentrations in sediment (PEC_{sed}).

SPRAY DRIFT

Spray drift had been perceived as the most significant entry route to surface waters for the compounds evaluated under list 1 and, therefore, was an important consideration for the workgroup. From the list 1 experiences, however, a number of shortcomings were identified; overspray was an unacceptable and illegal practice and should not be considered a realistic exposure route, drift deposition at the 95th percentile was too conservative, drift deposition for multiple applications each at the 95th percentile was extremely conservative and drift data for S. European agricultural practices (*e.g.* aerial application) was absent. The workgroup also agreed that all relevant published spray drift data should be considered for use in the new drift tables, however, when the data were evaluated only the work of Ganzelmeier *et al,* (1995) and the US Spray Drift Task Force (SDTF) AgDRIFT v 1.11 Model met the publication criteria and were used. After debate (and following the example of the FOCUS groundwater scenarios workgroup) the workgroup adopted the 90th percentile as a "realistic worst case" exposure level for drift events. The group also agreed that for multiple applications in a season, the total exposure from drift should be at the 90th percentile. To this end the drift data of Ganzelmeier *et al* were recalculated to provide 90th percentile drift values for single spray events and appropriate percentiles such that 2 to 15 sequential applications resulted in a cumulative probability of 90th percentile. Data for aerial applications were also taken from the SDTF and were included in the drift tables. However, after presentation of the workgroup concepts at a workshop held in Bilthoven in 1998 and discussions between workgroup members and scientists of the Federal Institute of the Ministry of Agriculture, Forestry and Fisheries (BBA), new official drift tables were released by BBA (2000) which included drift data for 5 crop classes (arable, vines, orchard fruit, hops and vegetables with vines and orchards further differentiated according to early and late growth stage and vegetables differentiated according to crop height) for distances of up to 250 m from the edge of the crop. Drift data were calculated at the 90th percentile for single applications and also for up to 7 sequential applications such that the cumulative probability of 90th percentile was achieved. The workgroup agreed to adopt these data rather than to create another slightly different data set based on the earlier drift data.

The final product used for estimating drift loadings within the FOCUS surface water process was an Excel spreadsheet calculator based on a regression analysis of the various drift data sets, such that the drift at user defined distances from the edge of the field can be calculated. Drift loadings for up to 25 sequential applications can be calculated (after 7 the loadings are the same) for up to 28 crops plus a no-drift option. The calculator also allows the integration of spray drift over various widths of water body as required by surface water models (*eg*. EXAMS or TOXSWA) and will give appropriate "width averaged" loadings. The calculator has also been included as an integral part of the scenario management tool SWASH (see later).

STEP 1 AND 2

The conceptual starting point for the step 1 and 2 calculations was the standard "EU" ditch that was used for the surface water assessments for the compounds on the first list and was a static ditch (no dilution from flowing water) of 30 cm depth. In order to allow an estimate of exposure concentrations in sediment, a 5 cm deep sediment layer was added and after much discussion the organic carbon content and bulk density of this layer was set to 5 % and 1.5 $g.l^{-1}$. These values cover both the requirements for the sediment used in the sediment dwelling eco-toxicology tests and the laboratory water/sediment studies. A 5:1 field scaling factor was also applied for the area of treated field impacting on the water body. These constraints were applied at both steps 1 and 2.

At step 1 the application rate was the maximum season's usage applied as single dose. One exception to this was agreed when the DT_{50} in water for the compound is less than a third of the interval between treatments. In this case a single application should be assessed because there is no possibility of accumulation of residues in the ditch. As described above, spray drift was considered at the 90th percentile for a single application and varied with crop. No-spray zones between the edge of the crop and the water body were fixed at 1m for row crops and 3 m for tall crops. Run-off/erosion and/or drainflow were also considered as a single non-specific loading and was fixed at a value of 10% for all calculations. The loading to the ditch also occurred on the day of application. Clearly this reflects a very "worst case" situation! All of the compound is in the water phase for the first 24 hours and is then partitioned between the water and sediment phases. This is driven by the average soil Koc value. Degradation subsequently occurs in both the water and sediment phases. For step 2 calculations a number of refinements were included. Applications were made sequentially at rates and intervals representative of real use. This allowed degradation and partitioning to occur between applications, thus reducing the exposure in the water column. Spray drift was considered separately for each treatment but the sum of the spray drift represents the 90th percentile loading. No spray zones were still fixed as before. Four days after the last treatment, a percentage of the residue remaining on the treated field is then added to the ditch as a run-off/erosion or drainage input and is added directly to the sediment layer of the ditch. The magnitude of this loss is dependant on season and zone (North EU or South EU) of use and was set by expert judgement plus some calibration based on the results of the step 3 calculations. As with step 1, partitioning to sediment occurred after 24 hours and degradation occurred in both sediment and water phases.

The original versions of the step 1 and 2 calculators were Excel spreadsheets. It soon became apparent that these fell foul of the users PC operating system and version of MS Windows/Excel being used and, therefore, the decision was made to encode the tool in Visual Basic and this has made it much more system independent. The new tool is windows driven with drop down menus for selecting different options. Both the step 1 and 2 calculations have been encoded and both calculations can be conducted automatically and, therefore, because of the ease of conducting the more sophisticated step 2 calculations, the step 1 calculations are almost redundant. Output from the calculator is presented in tabular and graphical form which capture the input values and assumptions, calculate initial exposure concentrations as well as "time weighted average" concentrations for both water and sediment and finally present graphs of the exposure concentration with time.

STEP 3 "STANDARD SCENARIOS"

The step 3 scenarios were developed following a number of basic principles; there should be no more than 10 and these should be broadly representative of EU agriculture, the scenarios should take into account all relevant entry routes, target crops, surface water bodies, topography, soils and climates, the scenarios should reflect realistic combinations of run-off/erosion and drainage and wherever possible the scenarios should include conditions representative of a field test site with monitoring data to allow validation of scenarios. Digitised data characterising landscape, land use, climate and soils were collected together to allow a pragmatic approach to scenario selection based on available data and scientific judgement. Only arable agricultural areas were considered and land was broadly characterised into drainage (by recharge) and run-off/erosion (based on spring daily rainfall) areas. Appropriate soil type, slopes and crops were then obtained for these areas. In the absence of digitised data, dominant water bodies (ponds, ditches or streams) associated with the scenarios were determined from detailed topographic maps. At the end of this process 6 drainage and 4 run-off/erosion scenarios had been identified. The broad characteristics of the scenarios are shown in Table 1. The extent of the scenarios in European agriculture has been evaluated and found to vary between 1 and 12% of total EU agricultural land with all scenarios representing a total of 42%.

The approach to defining the water bodies was equally pragmatic given the absence of hard data and was governed in part by expert judgement, available literature references and some practical requirements from the models. The characteristics and scenario associations of the various water bodies are shown in Table 2.

Weather data associated with the scenarios was taken from Meteorology stations located near the representative field sites. Daily data for 20 years periods were obtained from the EU sponsored MARS project (Vossen & Meyer-Roux, 1995). The data were evaluated and weather years were selected which were representative of 50th percentile run-off and drainage years.

MODEL SELECTION AND PARAMETERISATION

Having defined the characteristics of the scenarios and associated water bodies, the workgroup was faced with the prospect of parameterising a wide range of possible models (*eg*. PELMO and PRZM for run-off, TOXSWA and EXAMS for surface water fate *etc*.). After much deliberation it was decided to parameterise only three models, MACRO for drainage, PRZM-3 for run-off/erosion and TOXSWA for surface water fate. This was not to state that other models were not equally applicable but rather a practical consideration to limit the workload.

The scenarios for MACRO and PRZM were parameterised based on actual field sites broadly representative of the scenarios. The field sites also generally represented national notional worst case examples for surface water exposure and included such locations as Brimstone (UK, DEFRA site), Lanna (Sweden, Swedish Land University site), Skousbo (Denmark, DEPA site), Vredepeel (Netherlands) and Roujan (France, INRA site). Data for soil properties, slope, drainage systems, cropping *etc*. were taken from these sites. For surface water fate, a new version of the TOXSWA model has been developed which has dynamic hydrology and is capable of simulating a water body of fluctuating height. This has particular importance for fast moving and seasonally dry streams associated with the run-off/erosion scenarios and also some of the drainage scenarios. This model uses the run-off and drainage losses as the driver for the water height in the water body. It also simulates an "upstream catchment" that feeds water into the water body of interest and which contains a percentage of untreated field, thus providing diluting water. The sizes of the "upstream catchments" vary between the scenarios.

All of the models are DOS based and have "user friendly" shells to improve ease of use and to present interfaces with similar styles. The shells for MACRO and PRZM were developed to select a crop first, this dictates the available scenarios which can then be run individually or in batch mode after entry of pesticide properties, use rates and timings. Output from these models can be visualised from the model shells but the most important output files are those which subsequently become input files for the TOXSWA model and these are automatically formatted. Links between PRZM, MACRO and TOXSWA are "loose" so all models exist as separate items. The TOXSWA model requires appropriate MACRO or PRZM hourly loadings files, spray drift loadings (from the drift calculator) and pesticide properties for behaviour in a water body (taken from a lab water/sediment study). Computation times for the models vary dramatically with the PRZM model completing a 30 year simulation in under 5 minutes, the MACRO model completing a 7 year simulation in 30 – 60 minutes and TOXSWA completing a 1 year simulation in 15 – 30 minutes depending on the capabilities of the computer. Output from the TOXSWA model will be in the form of peak hourly concentrations in water and sediment plus "time weighted average" concentrations (over a range of intervals) for comparison with acute and chronic eco-toxicity end points respectively.

MANAGING THE SCENARIOS

Because of the complexity of the process of step 3 modelling and the loose coupled nature of the various models, a scenario manager tool (SWASH) was developed to guide the user through scenario selection and which models to be run for which scenarios. To illustrate this further, if tobacco is selected as the target crop then only one scenario needs to be considered (R3) and only one water body (stream), so one PRZM run and one TOXSWA run need to be conducted. However, if winter cereals is chosen as the target crop then 9 scenarios need to be considered (all except R2) with 15 associated TOXSWA runs. The SWASH tool also contains a database of pesticide properties required as input for the MACRO, PRZM and TOXSWA models with the intention that this database interacts with databases in the model shells, thus ensuring that all databases contain the same information and thereby reducing potential errors from data transcription. SWASH also contains a hard coded version of the spray drift calculator and it is intended that the tool should prepare input parameter files containing drift inputs and pesticide properties for the TOXSWA model. Another function of SWASH is to prepare tables of runs to be conducted with unique run identifiers for the various simulations. These tables can be printed and simulations checked off as they are conducted and provide a written record of work done.

Table 1: Broad charateristics for surface water scenarios

Scenario	**Soil**	**Water body**	**Slope %**	**A A Precip^n. mm**	**Av. spring & autumn temp. °C**
D1	Clay	Stream Ditch	Level (0 – 0.5)	600 - 800	<6.6
D2	Clay	Stream Ditch	Gentle (0.5 – 2)	600 - 800	6.6 - 10
D3	Sand	Ditch	Level (0 – 0.5)	600 - 800	6.6 - 10
D4	Loamy	Stream Pond	Gentle (0.5 – 2)	600 - 800	6.6 - 10
D5	Loamy	Stream Pond	Moderate (2 – 4)	600 - 800	10 – 12.5
D6	Heavy loam	Ditch Pond	Level (0 – 0.5)	600 - 800	> 12.5
R1	Silty	Stream Pond	Moderate (2 – 4)	600 - 800	6.6 - 10
R2	Loamy	Stream	Steep (10 – 15)	>1000	10 – 12.5
R3	Heavy loam	Stream	Strong (4 –10)	800 – 1000	10 – 12.5
R4	Loamy	Stream	Strong (4 – 10)	600 - 800	>12.5

Table 2: Broad characteristics of surface water bodies and their associations with the scenarios.

Water body type	**Ditch**	**Pond**	**Stream**
Width (m)	1	30	2
Depth (m)	0.3	1	0.5
Length (m)	100	30	1000
Distance (m) from:			
top of bank to water	0.5	3	1
crop to top of bank	0.5	0.5	0.5
Average residence time (d)	50	50	0.1
Relevant scenarios	D1, D2, D3, D6	D4, D5, D6, R1	D1, D2, D4, D5, R1, R2, R3, R4

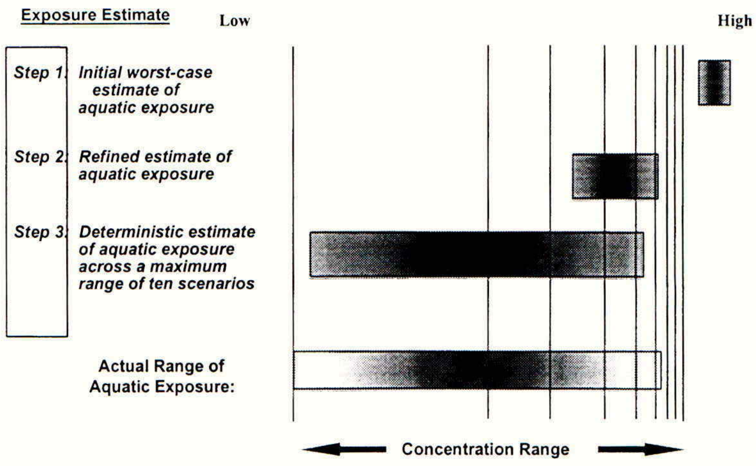

Figure 1. Relationship of predicted exposure concentrations for Steps 1, 2 and 3 calculations.

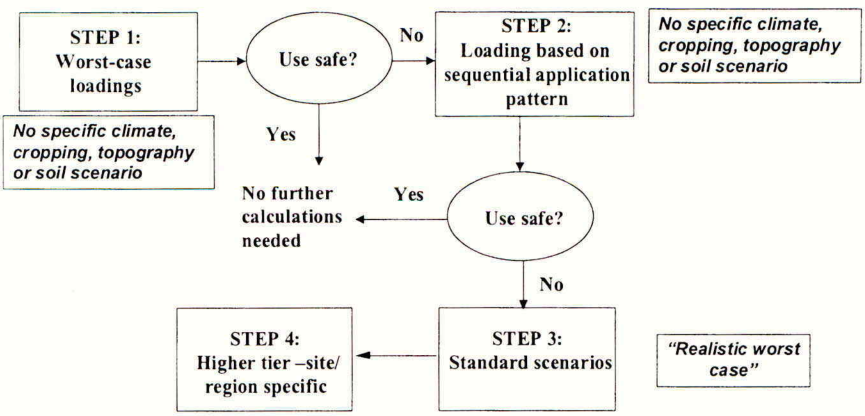

Figure 2. Inter-relationship of the four assessments steps for surface water exposure.

CONCLUSION

The preceding sections have been a quick summary of the current status of the FOCUS Surface water scenarios workgroup activities and condense the activities of four years into a hand full of pages. As of today the final report is in an advanced draft form and beta test versions of the Step 1and 2 calculator, MACRO, PRZM and SWASH models are available and have been tested for some months. An early release version of the new TOXSWA model is also being tested. A joint FOCUS/ECPA project is underway to evaluate steps 1, 2 and 3 with a range of 9 fictitious compounds with different Koc and DT50 values in order to ensure that the relativity of steps 1, 2 and 3 is correct, with step 1 being most conservative. The results of this may be used to adjust losses for run-off/erosion and drainage at steps 1 and 2. The results of this work have also been presented in a separate presentation at this conference. Seven real example compounds are also being tested and the results from these will be compared with monitoring data to ensure reasonableness of the predicted results. Predicted exposure concentrations will also be compared with eco-toxicity end points and risk assessment conducted. Comparisons have also been made between the old surface water exposure model which was based on drift and the new step 1 and 2 calculator and for a limited set of compounds the results are not very different. This work also continues.

The current timetable for the FOCUS surface water scenarios report calls for completion of the report and all models and submission to the Commission by the end of the year. Adoption and final release is then anticipated mid-2002 after member state review and comment.

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The influence of wind speed and spray nozzle geometry on the drift of chlorpyrifos to surface water

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ABSTRACT

Under the Plant Protection Product (PPP) Authorisations Directive (91/414/EEC) the risk of a PPP to off-crop non-target aquatic organisms is assessed in a tiered approach. From the properties and use pattern of the product, the likely routes of entry into surface water are assessed for PPPs applied as sprays. These assessments are based upon a calculated percentage of the active substance being deposited on a static body of water, 30cm deep, related to the distance from the end of the spray boom to the edge of the water body (Ganzelmeier *et al.* 1995). For some PPPs, such as chlorpyrifos, a buffer (no spray zone) may be applied to "in use" situations to reduce drift off-crop. However, there is little data to demonstrate how well drift events with specific chemicals match Ganzelmeier data or the extent to which application factors such as wind speed and spray nozzle affect the degree and amount of drift. Using a large-scale wind tunnel, a series of controlled, replicated studies were carried out to measure the influence of two wind speeds in combination with a conventional and three star (UK) rated reduced drift nozzle on the spray drift of chlorpyrifos, applied as Dursban 4, and its deposition on to an artificial ditch, simulating a static edge of field water body, 30cm deep. Results showed a clear reduction in amounts of chlorpyrifos as distance from the nozzle increased. The combination of 3mph (low) wind speed and low drift nozzle had a significant influence in reducing drift by ca. ten-fold at 2m from the spray nozzle, and five-fold at the mid-ditch position (4.5 or 5m), as measured by polyethylene strings stretched horizontally across the path of the drift. Water concentrations were reduced by ca. half from an average of 1.11μg L^{-1} to 0.45μg L^{-1} The presence of a 50cm artificial bank had no significant influence on the concentration of chlorpyrifos in surface water. Results show that both low wind speed and low drift nozzle can contribute to risk reduction of certain PPPs in surface water.

INTRODUCTION

Environmental (ecological) risk assessment of PPPs is usually based on a tiered approach ranging from conservative assumptions at Tier 1 to more realistic scenarios at higher tiers, reflecting normal use patterns of the product. For PPPs applied as sprays, aquatic risk assessments are based upon a calculated percentage of the active substance being deposited on a static body of water, 30cm deep, related to the distance from the end of the spray boom to the edge of the water body (Ganzelmeier *et al.* 1995).

For regulatory purposes, the 95th percentile worst case figures are currently used to calculate a Predicted Environmental Concentration (PEC) which is used in conjunction with single species toxicity data LC50, EC50 or NOEC to derive a Toxicity Exposure Ratio (TER). If acute or chronic TERs are below 100 or 10, respectively, then higher tier approaches based on either less conservative assumptions or using measured data are applied to refine exposure and, consequently, effects on non-target organisms. For some PPPs, such as chlorpyrifos, a buffer (no spray) zone may be applied to "in use" situations as a risk reduction (mitigation) tool to reduce drift to edge of field water bodies. However, there is little data to demonstrate how well drift events with specific chemicals match Ganzelmeier data or the extent to which application factors, such as wind speed and spray nozzle geometry, might affect the level of drift.

Using a large-scale wind tunnel, a series of controlled, replicated studies were carried out to measure the influence of two wind speeds, in combination with a conventional and three star (UK rated) reduced drift nozzle, on the spray drift of chlorpyrifos, applied as Dursban 4, and its deposition on to an artificial ditch, simulating a static edge of field water body.

MATERIALS AND METHODS

The wind tunnel facility used in this study at Silsoe Research Institute, Silsoe, UK, was designed specifically to enable experiments using active pesticide formulations to be conducted under safe and controlled conditions (Miller 1998). The tunnel used a re-circulating design such that airborne pesticide spray material was not lost from the system during the experiment.

Following each experimental run, air was drawn into the working section of the tunnel, through the fans and airflow straightening sections, before being blown up a discharge stack to atmosphere. The complete tunnel was sited in a sealed pit in which any liquid discharge, waste or spillage drains to a sump from which could be pumped into a treatment plant. The working section of the tunnel was 3m wide and 2m high and 7m wide. Air movements within the tunnel were generated by two 15kw, 1.25m diameter axial flow fans mounted above the working section. Flow through the fans was ducted through an air straightening section, turned through 180° using vanes, into a contraction section and then into the working section. The system was designed to operate with a plug air flow down the tunnel at speeds ranging from 2 to 19mph. Humidity within the tunnel was controlled using an air-conditioning plant.

An artificial ditch, comprising a stainless steel tank 2m long, 1m wide and 35cm deep, containing 30cm deep (600L volume) tap water, was situated within the working section of the tunnel ca. 4.5m from the spray track with the water level ca. 5cm below the level of the floor of the wind tunnel.

In some experimental 'runs' a stainless steel plate, simulating a sloping (45°), 50cm high ditch bank, was fixed to either side of the ditch and the tank lowered so that the bank top was at floor level. (Figure 1). Experiments were conducted at constant relative humidity and temperature and, after each application of chlorpyrifos, the tunnel was purged for 2 minutes to remove any residual chemical from the atmosphere.

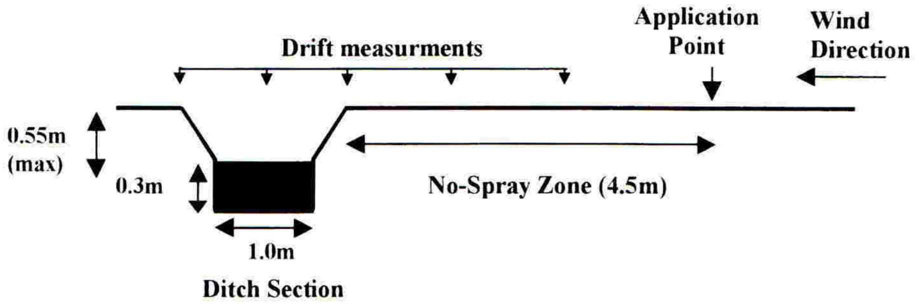

Figure 1. Wind tunnel layout

The formulated product (Dursban 4) was applied from a single spray nozzle at a concentration calculated to represent that arriving at the end of a standard 12m boom under normal use. Spray drift was captured by 1.5m length polyethylene "strings" (diameter 1.98 mm) stretched horizontally across the path of the drift at 2, 3 and 4.5m from the spray nozzle ca. 10cm above the floor surface. Additionally, a string was placed at the centre of the ditch above the water surface at 5.0m distance where no bank was present, or 5.5m with the bank *in situ*.

Following each spray run, chlorpyrifos was removed from each "string" by slowly passing it through a glass U-tube, containing 10ml n-hexane, held in an ultra-sonic bath. Following each spray application the water in the ditch was vigorously stirred for 2 minutes using a stainless steel paddle, in order to mix the chemical, and 3x 250ml samples were collected in acid washed glass bottles. The samples were firstly acidified with pH 4 buffer to prevent hydrolysis of chlorpyrifos and then 50mL n-hexane was added to extract the compound from the water. Non-homogeneity of the formulated product in the water after mixing was evident from the variability in concentrations of chlorpyrifos in some water samples. This was improved by drilling holes in the stainless steel paddle which resulted in better mixing and more even distribution of the chemical. Analysis of chlorpyrifos was carried out by Gas Chromatography – Mass Spectrometry (GC/MS). The organic phase of the extracted sample was separated from the aqueous phase using a sodium sulphate funnel, before reducing under nitrogen and analysis using a Hewlett Packard 6890 Plus GC with Hewlett Packard 5973 mass selective detector and ZB5-MS 30m x 0.25mm x 0.25μm column.

Experimental design

The study comprised of replicated randomised treatments based on a statistical design (three factorial randomised block). The first set of experiments reported here evaluated the influence of either 3mph (low) or 6mph (high) wind speed combined with a conventional or a low drift 3 star (UK rated) nozzle, and also compared the influence of a 50cm deep ditch bank on spray drift.

RESULTS

For each treatment combination (Table 1), chlorpyrifos deposition at each of the monitoring points was calculated from the material extracted from the spray drift targets ("strings") as a proportion of the applied mass. Standard statistical methods were used to determine the significance of observed differences between the treatment combinations.

Table 1 Randomisation plan – phase 1 applications (block 1 of 3)

Application	Block	Treatment 1 Wind speed	Treatment 2 Spray nozzle	Treatment 3 Bank height
A1	1	Low	Low drift	5cm
A2	1	High	Low drift	5cm
A3	1	High	Conventional	5cm
A4	1	High	Conventional	55cm
A5	1	High	Low drift	55cm
A6	1	Low	Low drift	55cm
A7	1	Low	Conventional	55cm
A8	1	Low	Conventional	5cm

Results showed a clear reduction in amounts of chlorpyrifos as distance from the nozzle increased (Figure 2).

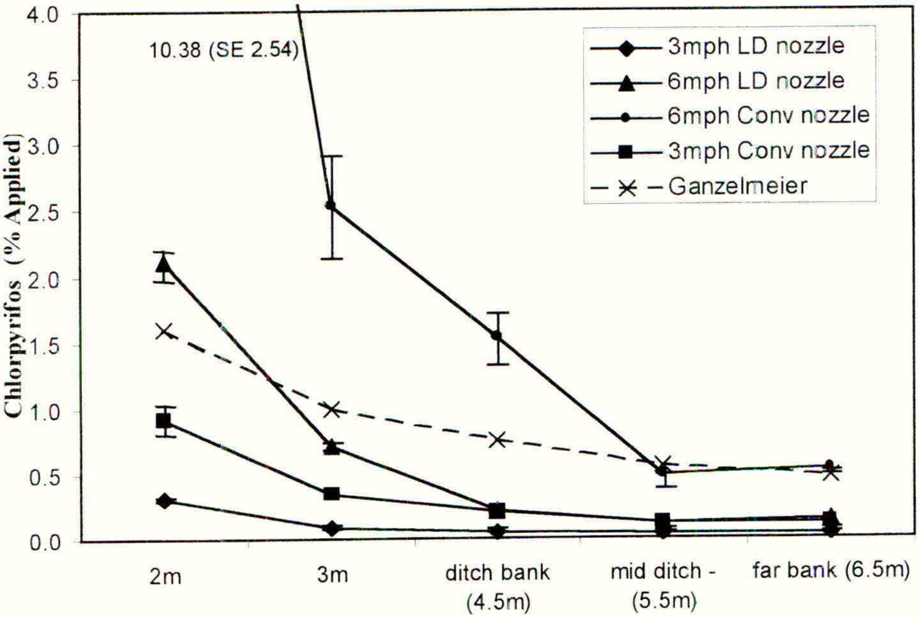

Figure 2. Mean chlorpyrifos deposition at increasing distance from application point (with 50cm deep ditch sides in place)

The high wind speed/conventional nozzle treatment showed the greatest variance with the calculated values given by Ganzelmeier at the 2m position, although the measured and predicted values converged with distance from the application point, and were similar at the mid ditch position (5.5m).

When compared to the high wind speed / conventional nozzle treatment, the combination of 3mph (low) wind speed and low drift nozzle had a significant ($p<0.001$) influence in reducing drift by ca. ten-fold at 2m from the spray nozzle, seven-fold at 3m and five-fold at the mid-ditch position (Figure 2). The addition of a 50cm artificial bank on either side of the ditch had no significant influence on the deposition of chlorpyrifos at drift capture points across the 4.5m no-spray zone to the ditch section (Figure 3).

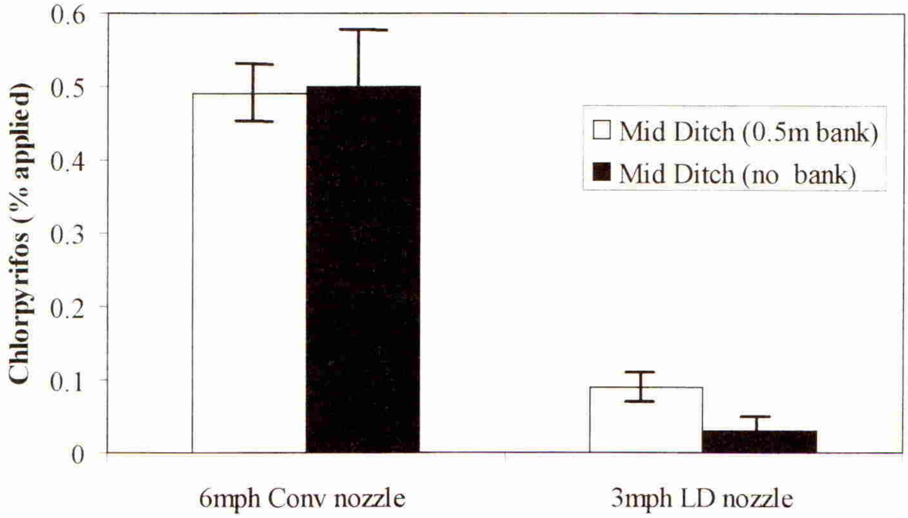

Figure 3. Spray drift deposition (as chlorpyrifos) with and without a 50cm ditch bank

Water concentrations in the initial test runs showed a large amount of variability between replicate samples, which was attributed to insufficient agitation of the ditch water causing non-homogeneous mixing of chlorpyrifos. Re-design of the stainless steel paddle and its use in later tests gave more consistent results. Concentrations were reduced by ca. half from an average of 1.11$\mu g\ L^{-1}$ with the high wind speed / conventional nozzle combination, to 0.45$\mu g\ L^{-1}$ under the low wind speed and low drift nozzle treatment.

DISCUSSION

The initial phase of the work described here demonstrated the value of using a large- scale wind tunnel to conduct spray drift / exposure potential investigations, as opposed to either field based or small scale laboratory experiments. Controlled conditions within the wind tunnel isolated the test system from external influences, and allowed the implementation of a replicated statistical design to test individual spray application parameters and their combinations. In addition, field scale application methods and rates could be utilised while retaining laboratory characteristics of measurement and repeatability.

Results from this first phase showed significant differences in the pattern of spray drift deposition for the combinations of spray nozzle and wind speed tested, when compared with Ganzelmeier data. Differences were most marked within 3m of the spray nozzle. In general, the data suggest that the use of both low wind speed and low drift nozzle can contribute to reductions in the amount of certain PPPs deposited on edge of field surface waters. This has significant potential for reducing initial exposure concentrations in the water body and consequent reductions in effects on susceptible non-target aquatic organisms. The issue of uneven distribution (non-homogeneity) of oily formulations in water arose in this study. It was considered that this could be due the tendency of the emulsifiable concentrate micelles to float to the surface of the water. This phenomenon could influence both the rate of loss of chlorpyrifos from surface water and exposure of organisms in the water body. Further work to investigate this issue was identified and will be reported elsewhere.

ACKNOWLEDGEMENTS

We thank Prof. P Miller and Dr S Parkin of Silsoe Research Institute for their technical assistance in this study, and for the provision of the wind tunnel facilities.

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Prediction of field efficacy from greenhouse data for four auxenic herbicides

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ABSTRACT

The proposed paper will compare greenhouse and field efficacy data in light of concerns for offsite movement of herbicides. A central issue of environmental concern is how well greenhouse or laboratory data collected on a few species can predict injury to a larger, more diverse set of species in the field. A retrospective analysis of four auxenic herbicides shows that most efficacy data was generated to predict, with a high degree of certainty, the application rates required to cause 90% injury. There was little rate response data generated on the same species in both the greenhouse and field sufficient to estimate the 25% or 50% injury that is the environmental endpoint for most regulatory concerns. For those species where direct comparisons could be made, the greenhouse to field injury varied from approximately equal to as much as 20X with large variations between species. For the species with the lowest EC_{25} values, the greenhouse data over predicted the field injury. Alternatively, a species sensitivity distribution uses all available data, and is predictive of injury to plant populations. Initial results suggest that the field and greenhouse data can be adequately modeled as log-normal distributions, were non-parallel, and can be used to predict the maximum application rates that are protective of 95% of species.

INTRODUCTION

Risk analysts, when attempting to judge potential impacts to the environment, have traditionally used deterministic calculations with single point estimates of injury to represent what in reality is a range of exposures and effects. Such risk assessments that use single values, *i.e.*, the most sensitive species tested, loose information about both the extreme values and median responses and require some judgement about what information to exclude from the analysis (Cullen & Frey, 1999). In many instances, the person choosing which data to use has little or no knowledge of the underlying assumptions or range of true values. Currently, US EPA guidelines for pesticide registrations require greenhouse data on ten terrestrial species (USEPA, 1989), while German guidelines require data on six species (Füll *et al.*, 1999) for their ecological risk assessments. In both cases, the assessments are based on the single most sensitive species tested with limited or no consideration of other species or the relative sensitivity between greenhouse and field grown plants.

It is generally accepted that a higher application rate is required to cause injury to field grown plants than greenhouse grown plants because of physical and metabolic differences, dissipation/degradation of the product, plant age and structure, cuticle thickness, and other factors. From a review of published data, Fletcher *et al.* (1990) concluded that the ratios of greenhouse to field EC_{50} values ranged from 0.26 to 3.26. For 30% of the herbicide/species combinations he evaluated, the greenhouse EC_{50} values were lower than the corresponding values in the field. The remaining 70% had field EC_{50} values that were lower than those measured in the greenhouse. In Fletcher's review, it is not clear if the values were calculated from the dose response in individual studies, or from data aggregated across multiple studies. Few dose response studies have made direct comparisons between greenhouse and field grown plants under controlled conditions. In the current investigation using historical data generated during product development, it was found that a limited number of species were tested under both greenhouse and field conditions because of the nature and purpose of discovery screens and field efficacy tests. Direct comparisons of individual species gave variable conclusions. Expressing the data as species sensitivity distributions, however, demonstrated linear relationships between the EC_{25} values and the cumulative percentage of species, and revealed a non-parallel relationship between the greenhouse and field data.

METHODS

Greenhouse and field efficacy data for individual herbicides were retrieved from the archives of Dow AgroSciences LLC and used for comparison between species. Greenhouse data were derived either from studies required to meet product registration requirements or from discovery, efficacy screens. Data on the field response of species were obtained from field development reports or annual data summaries as available. Only those studies with a minimum of three application rates and injury responses that bracketed the appropriate level of injury were included. Estimates of the application rate that caused 25% visual injury (EC_{25}) were made by fitting the data for each study to a four-parameter logistic dose response model. The greenhouse to field ratios were calculated as the average greenhouse EC_{25} divided by the average field EC_{25} across all studies for each species. A species sensitivity distribution for each herbicide was constructed by ranking the EC_{25} values in ascending order and plotted against the cumulative percent of species (Newman *et al*, 2000; Versteeg *et al*, 1999). For example, if there were data on 10 species, each species would represent 10% of all species. Initial results showed that the species EC_{25} values adequately fit a log-normal distribution. A linear relationship was obtained by plotting the common log of the EC_{25} values vs. the percent cumulative species for each product. Estimates of the EC_{25} for the lowest 5% of all species were calculated by least squares linear regression and extrapolation as necessary from the regression equation.

RESULTS AND DISCUSSION

There was very little overlap between the species tested in the greenhouse and field. In this analysis, 104 EC_{25} values were obtained from greenhouse tests and 40 from field tests, that together allowed for direct comparisons between 38 data points. The lack of overlap between species probably stemmed from the different purposes for the two test systems. The greenhouse tests were designed to detect herbicidal activity using a representative set of species based on their economic importance and ability to be grown reproducibly in a greenhouse while field tests were designed to determine with high precision the application rate that caused 90% control under varying conditions. Direct comparisons showed that for 13 of the 38 data points, higher EC_{25} values were measured in the greenhouse than in the field. The greatest differences were for ABUTH and DAOTE with all four herbicides, DATST for pyridyloxy A and pyridyloxy C, and NIOTA for pyridyloxy A (Figure 1). The differences for ABUTH, DATST and NIOTA derive from a single field test and may not be representative. The remaining species had lower EC_{25} values in the greenhouse.

The ability to predict field effects from a limited amount of greenhouse data is an important concern in ecological risk assessment. The small number of species with data from both the field and greenhouse limited the comparisons that could be made. A better approach is to examine the trend using all available data instead of single species. Such an approach has been recommended by several groups including the Aquatics Dialog Group of SETAC (SETAC 1994), ECOFRAM (ECOFRAM 1999) and EPPO (EPPO 2000). Species sensitivity distributions for each of the four herbicides are presented in Figures 2 through 5. In each case, the resulting plots were linear but non-parallel between greenhouse and field data with steeper slopes for the field data. The results suggest that a smaller application rate range was required for species in the field than in the greenhouse. From such a distributional approach, it is not possible to predict the response of any given species, but instead indicates the overall population trend. The non-parallel lines suggest that plants grown in the greenhouse vs. the field behave as two separate populations, though they contain the same species. From the regression equations, application rates that would cause 25% visual injury for the lowest 5% of species, i.e. the rate that would be protective of 95% of species, was calculated. The results are given in Table 1. The differences between the field and greenhouse ranged from 3.4X for pyridyloxy D to approximately 13X for pyridyloxy B with the greenhouse values lower than the field. The use of species sensitivity distributions may provide a useful way to summarize disparate data sets and predict field responses of plant populations as part of ecological risk assessments.

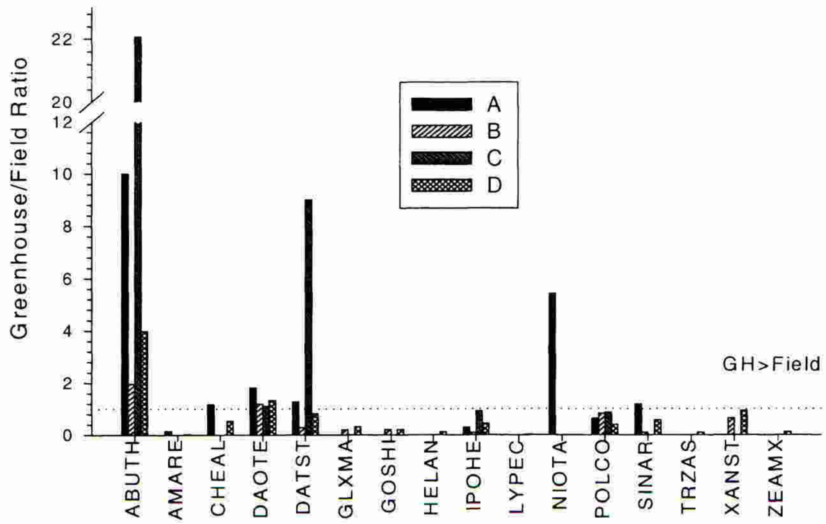

Figure 1. Ratios for the greenhouse EC_{25} to field EC_{25} for four pyridyloxy herbicides (A-D). The dotted line represents a ratio of 1 where the greenhouse equaled the field.

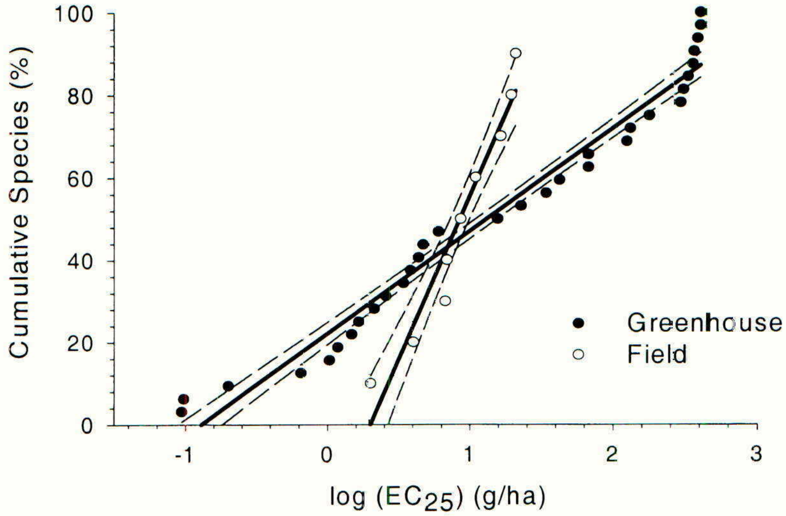

Figure 2. Species sensitivity distributions for pyridyloxy A. The dotted lines are for the 95% confidence interval around the regression lines.

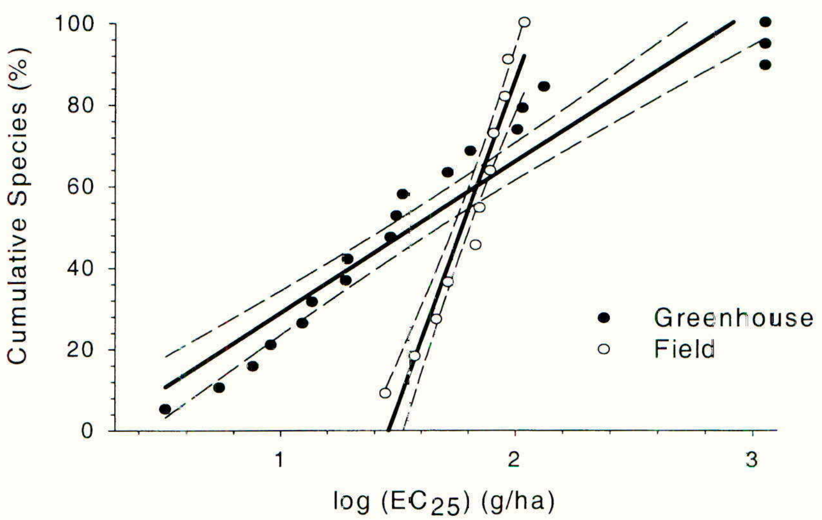

Figure 3. Species sensitivity distributions for pyridyloxy B. The dotted lines are for the 95% confidence interval around the regression lines.

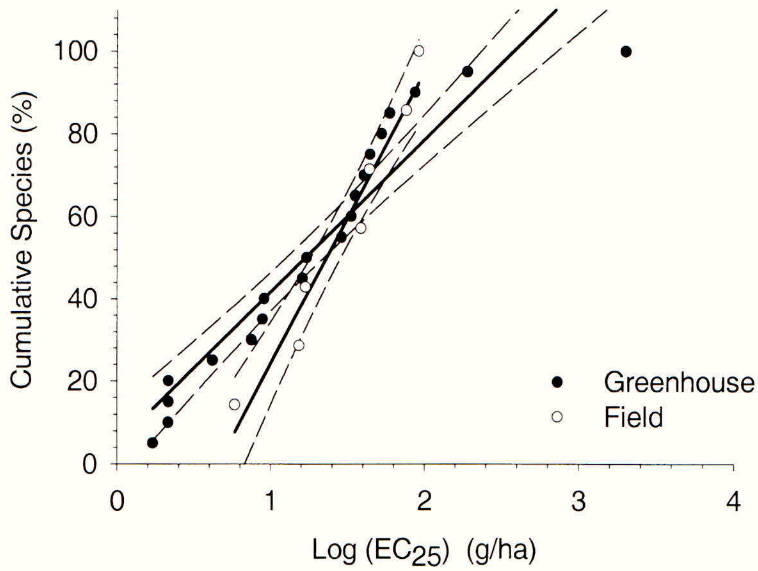

Figure 4. Species sensitivity distributions for pyridyloxy C. The dotted lines are for the 95% confidence interval around the regression lines.

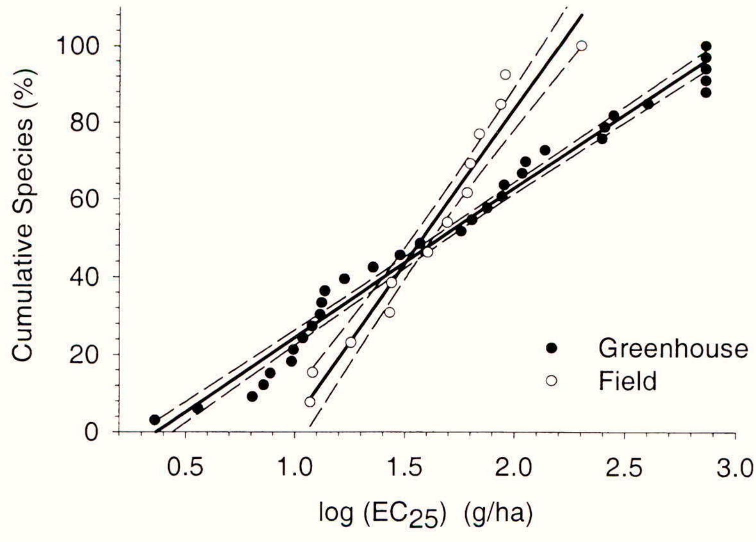

Figure 5. Species sensitivity distributions for pyridyloxy D. The dotted lines are for the 95% confidence interval around the regression lines.

Table 1. Predicted EC_{25} values for the lowest 5% of species, greenhouse vs. field data.

Product	Greenhouse (g/ha)	Field (g/ha)
Pyridyloxy A	0.21	2.3
Pyridyloxy B	2.3	31.0
Pyridyloxy C	1.0	5.3
Pyridyloxy D	3.1	10.6

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SESSION 9C

CRITICAL HERBICIDE USE IN MINOR CROPS

Chairman & Session Organiser:	M A Pearce *Hortichem, Amesbury, UK*
Papers:	9C-1 to 9C-4

Critical herbicide use in minor crops – an agronomist's view

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ABSTRACT

The imminent withdrawal of a considerable number of crop protection products from the market place will have serious consequences for the horticultural industry. It will result in an inability to obtain satisfactory weed control, particularly in vegetable crops. The consequence of a limited range of crop protection products will inevitably result in poorer weed control and over-use of the remaining products. Because of the high cost of toxicology and registration, it seems increasingly unlikely if any of the products being withdrawn will be replaced by new active ingredients.

INTRODUCTION

During the last fifty years, the vegetable industry has been fortunate in being able to use a highly sophisticated range of crop protection products. These products have been invaluable in helping farmers and growers to grow crops that are relatively free from weeds, pests and diseases. Furthermore, it has enabled them to produce food at very competitive prices and of the highest quality.

The introduction of many crop protection products took place in the 1960's and 1970's, and their introduction contributed to the efficiency of vegetable growing in this country. Sadly, over the last decade and for whatever reason, we have started to lose some very important active ingredients, especially herbicides used in vegetable production.

LOSS OF ACTIVE INGREDIENTS FOR VEGETABLE CROPS

One of the first products to go was the mixture of chlorbufam and chloridazon, which was used to control small weeds in salad onions. The 'low dose' technique, which was developed for use early in the life of a crop, was extremely successful and widely used. It meant that cotyledon weeds could be killed when the crop was extremely small and the use of this combination of actives had a high margin of safety. Although a specific off-label approval has been obtained for one of the active ingredients, chloridazon, this material on its own is not as efficient as when it was partnered with chlorbufam. The mixture of chlorbufam and chloridazon was particularly effective in controlling *Viola arvensis* and *Urtica urens*.

In brassicas, we have now lost aziprotryne and desmetryn. The former offered good residual and contact control and was valuable in controlling a wide range of weeds including those of the *Matricaria spp*. Desmetryn was widely used as a post-emergent herbicide for the removal of such difficult weeds as *Chenopodium album* and *Urtica urens*.

However, worse is to come. By 2003 we could lose very many more actives. These include fenuron/CIPC mixtures, sodium monochloroacetate, metoxuron, pentanochlor and prometryn.

With chloridazon/chlorbufam mixtures being withdrawn from the market, fenuron/CIPC mixtures have been useful as a replacement herbicide in controlling small cotyledon weeds very early in the life of the crop of onions and leeks. *Fumaria officinalis, Urtica urens, Polygonum persicaria* and *Solanum nigrum* are all either controlled or suppressed with the fenuron/CIPC mixture. Fenuron/CIPC has also become an essential herbicide combination on spinach. Used in mixtures with lenacil, this fenuron/CIPC combination offers excellent weed control in a crop which is harvested mechanically and must be completely weed free.

This combination of fenuron/CIPC and lenacil is especially useful early or late in the season when the spinach is offering limited competition to the weeds. The addition of fenuron/CIPC mixture to lenacil, greatly improves control of weeds such as *Solanum nigrum* and *Poa annua*, which are either controlled or suppressed by this mixture at the cotyledon stage.

Sodium monochloroacetate is invaluable as a contact herbicide in a wide range of brassicas. It controls *Capsella bursa pastoris, Solanum nigrum, Sinapis arvensis* and many polygonous species which are difficult, and sometimes impossible, to control by any other herbicide. One of the weaknesses of this chemical, however, is that it will not control *Chenopodium album*. The product that we would normally use to control this weed is based on desmetryn – as previously mentioned this has also disappeared. With the disappearance of sodium monochloroacetate I can see *Solanum nigrum* and *Chenopodium album* in particular, becoming uncontrollable in many brassica crops.

Carrot growers will find it very difficult to control volunteer potatoes without the use of metoxuron. Metoxuron has been widely used as a post-emergent herbicide for many years and is particularly good in controlling weeds of the *Matricaria spp*.

Another herbicide that the carrot growers would miss would be prometryn. This herbicide offers excellent control of *Fumaria officinalis*. If the carrot growers will miss prometryn, the loss of this product in leek growing will be disastrous. Prometryn remains one of the few post-emergent herbicides which will deal effectively with *Fumaria officinalis* and *Urtica urens*. Over the last two decades its use in the low-dose technique, in combination with ioxynil, has proved highly successful. It has meant that weeds can be controlled very effectively using very low rates of active ingredients.

Furthermore, we are about to lose monolinuron as a post emergent herbicide in drilled and planted leeks. This loss will make us even more reliant on prometryn/ioxynil mixtures.

During the last couple of years there has been a definite return to the direct drilling of leeks as the cost of planting blocks and modules has risen dramatically. This trend cannot be maintained unless we have an adequate range of effective herbicides to control weeds in - what is after all – a very uncompetitive crop.

Leek growers will lose sodium monochloroacetate, fenuron/CIPC mixtures and prometryn in 2003 if these materials are not supported under the 'essential use provisions.' The loss of these products will make it very difficult to grow the crop economically on a large scale.

Finally herb growers, in particular, will find it difficult to control many post emergent weeds, especially the polygonums species without the use of pentanochlor. This is an extremely safe herbicide on a wide variety of crops and there is nothing in the pipeline which could even come close to replacing this material.

THE ALTERNATIVES

One of the most fundamental changes I have experienced in over thirty years in the vegetable industry is the gradual decline in the availability of suitable field labour. It is more difficult to obtain now than it has ever been. Although we have seen a vast improvement in cultivation machinery, such as brush weeders, these and other mechanical methods of weed control have severe limitations. A brush weeder or front-mounted hoe will not remove a carpet of annual nettles from a field of leeks at the one-leaf stage.

The ability to be able to use a wide variety of crop protection products to control weeds has meant that labour for hand-weeding is only required on an occasional basis. There are, of course, occasions when hand-labour is required to remove perennial weeds or to remove weeds because a herbicide has either not worked as effectively as it should have done, or where there are resistant weeds remaining. If we are to lose so many of our effective herbicides, very much more hand-labour will be required. This hand-labour is simply not available.

We have come a long way from the days when we relied on dilute sulphuric acid to remove weeds from onions and leeks and where the standard carrot herbicide was tractor vaporising oil. However, we are in danger of losing all the technology we have created in the last three decades 'at a stroke'. We will never regain the range of crop protection products that are at our disposal today.

CONCLUSIONS

For the products accepted under the Essential Use provisions, the date up to which they may be used has been suggested as 2007. This is to give time for the development and registration of alternative products. It seems unlikely that any of the products threatened and included in this paper will be able to be registered and replaced by a suitable alternative before 2007.

Growers are used to taking financial risks but it is doubtful whether they will extend this risk to planting a hectare of drilled leeks that will cost over £2000/hectare to establish if there is no suitable product available to remove weeds.

As many of our older actives disappear we will rely even more on existing actives and there is no question that doses will have to be higher and this will undoubtedly lead to an over-use of existing actives. The 'low-dose' technique used on so many crops has resulted in significant reduction in chemical applications. If we no longer have the materials to carry out this technique we will have to use much higher doses of existing herbicides. Furthermore, one of the benefits of having a wide range of actives is that we can rotate herbicides, which will help prevent the build-up of resistant weeds. The over-use of chemicals like atrazine has led to triazine resistant groundsel. Further examples of resistance will follow if we rely too heavily on the few remaining actives.

The current trend in reducing the available number of crop protection products will have serious commercial and financial implications for everybody in the horticultural industry and, in particular, growers in the vegetable sector. We must ensure that we support some of the actives which we consider vital to the industry under the 'essential users' banner.

The future for new actives in the vegetable industry does not look encouraging. Chemical manufacturers will only develop new recommendations for minor crops, as a spin-off from existing products already in use on combinable crops. The cost of toxicology and registration are now so enormous that companies cannot be expected to develop products where there is only a very limited market and when they stand little chance of recouping their costs.

Without funding for research and development to enable new molecules to be developed and registered in the vegetable industry, the future is bleak.

The European Commission review of plant protection products: essential uses

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ABSTRACT

The principles for re-evaluation of existing active substances in the European Union were established via Council Directive 91/414/EEC. This allowed existing products to remain on the market until July 2003 pending European Commission decisions on their acceptability. A total of 834 'existing' active substances were identified as being on the market in July 1993. At the present time it is anticipated that as many as 500 existing active substances could be lost from the market. Many of these active substances are contained in products that are used largely on horticultural or other minor crops. European Commission Regulation 451/200 provides for temporary measures for 'critical uses' for which no efficient plant protection products remain, in order to allow time for alternatives to be developed. In the UK, grower organisations and the Pesticide Safety Directorate have collaborated to identify essential uses and to submit requests for derogation to the European Commission. For both new and existing active substances, Directive 91/414/EEC makes provision for extension of use, by a similar mechanism to the UK 'off-label' scheme. The EC has also developed a draft proposal for a system of Voluntary Mutual Recognition by Member States, whereby uses approved in one Member State could be recognised by other Member States. Close co-operation between European partners and sharing of information is needed if some sectors of the industry are to have access to sufficient plant protection products to remain viable.

INTRODUCTION

Regulatory actions related to pesticides have had considerable impact on the horticulture industry recently. This includes the UK review of acetylcholinesterase-inhibiting active substances and the setting of EU Maximum Residue Limits (MRLs) and their adoption in UK law. In the cases where residues data have not been provided to support uses, then the MRL is set at the limit of detection, which effectively precludes the particular use. This affects both EU and overseas producers (Moorhouse & Hucklesby, 2000) and has made the production of crops of suitable quality difficult to achieve. In addition, a very large number of products will be lost as a result of the EC review of existing active substances because crop protection companies have taken commercial decisions not to generate the necessary data required to support a modern registration dossier.

The first list of 90 active substances for review was published in 1992, (Commission Regulation No. 3600/92) however progress in taking decisions on these active substances has been very slow. This has largely been due to the fact that it has been necessary for Member States and the Commission to develop procedures for the evaluation of active substances and to develop confidence in one another's technical ability across the whole range of data evaluation and risk assessment. Of these 90 active substances, four were not supported at the beginning of the programme, and by July 2001, of the 86 remaining, 23 decisions have been taken, with 11 of these being included in Annex I, the others having been withdrawn from use.

The second review regulation (Commission Regulation No. 451/2000) was published on 1 March 2000 and established a timetable for the consideration of the remaining active substances. The second list included organophosphates, carbamates and some herbicides and of the total 149, only 60 have been supported by notifiers. In the third list, of 402 active substances, 235 were not supported. The role of the German Regulatory Authority (the Render Project) in management of the third list is discussed elsewhere in this session. Where support is declared, dossiers for active substances in the second list must be submitted by April 2002, and for the third list, by 25 May 2003. Unsupported active substances will be withdrawn from the market in the EU on 25 July 2003. A list of active substances in rounds 1, 2 and 3 and the status of support, together with Member States where active substances are registered, are published on the European Commission's website 'www.Europa'. There is also a fourth list of active substances which are considered to be of lower priority for re-evaluation, that contains 193 active substances. Of these, 27 are no longer authorised in any Member State, leaving up to 166 substances to be evaluated in the final phase. It is expected that the EC will introduce further review regulations in early 2002, to establish procedures for dealing with the third and fourth lists.

Table 1 summarises the overall position as it exists in July 2001, in respect of the lists of active substances for re-evaluation. It is likely that as a consequence of the current evaluation of the remaining active substances in the first list, for which decisions have yet to be taken, that some will be withdrawn. Similarly there will be further withdrawals from the other lists. Estimates vary as to how many active substances will be withdrawn in total, but it is expected to be in the region of 500.

Table 1. Status of active substances being re-evaluated in the EU

List	Number of active substances	Under evaluation	To be evaluated	Withdrawn/ To be withdrawn	On Annex I
1st	90	63	-	16	11
2nd	149	-	60	89	-
3rd	402	-	167	235	-
4th	193	-	166	27	-
Total	834	63	393	367	11

In recognition of the fact that the review programme would cause the withdrawal of active substances for which no viable alternatives existed, Commission Regulation No. 451/2000, provided temporary measures for critical uses for which no effective plant protection remains, in order to allow time to develop alternatives. Another paper in this session deals with grower responses elsewhere in Europe. This paper describes the collaboration between UK grower organisations and PSD, as the UK regulatory authority, to identify 'Essential Uses' and to submit requests for derogations to the European Commission and looks at the possible impact of the EU review programme.

LOSSES OF ACTIVE SUBSTANCES FOR MINOR USES

The number of pesticides available for minor uses has always been limited because of the high cost of development and registration, relative to potential sales of the products. Minor uses mainly relate to horticultural crops that are usually grown on small areas, but where produce can have a high market value. The UK figures (provisional) for the calendar year 1999 are £642 million for vegetables, £263.8 million for fruit, £312.3 million for protected vegetables, £709 million for ornamental produce (MAFF, 2000). The fact that these crops tend to be small area, high value, can also add to the potential stewardship costs for approval holders, particularly if there are claims for crop damage. There are also minor uses for crops grown on a large area, such as forestry, and for 'new' developing crops for the UK, for example lupins and soya.

To date, of those active substances registered in the UK, 13 in the second list and 49 in the third list of the EC Review have not been supported. The information is available on the website of the UK Pesticide Safety Directorate: www.pesticides.gov.uk. The decisions of notifiers not to support these active substances were mainly for commercial reasons. These include the high cost of updating the data package required to be submitted, other, higher priorities for registration personnel and research facilities and more important global markets. Manufacture and marketing of some of these products had already ceased or were about to cease (aziprotryne, desmetryn, dikegulac, ethirimol, trietazine); some had only amateur uses and a small number were soon to be superseded by newer alternatives. However the 30 unsupported active substances remaining from the second and third lists, including those organophosphates for which uses had been revoked by the UK regulatory authorities (chlorfenvinphos and disulfoton in brassica crops), were perceived as crucial for production.

The greatest losses will be for broad-leaved weed herbicides, which, for reasons of crop selectivity are more crop specific, thus markets are smaller than for graminicides, fungicides or insecticides. Approximately 40,000 ha of vining peas are grown in the UK for quick-freezing or canning, and 1,000 ha for fresh market and a large proportion are currently treated with pre-emergence herbicides based on terbutryn and fomesafen, none of these products will be available. In addition, cyanazine, will not be supported, which means that the two most widely used post-emergence products will also disappear, so that only bentazone and MCPB and MCPA will remain.

The losses of active substances as a result of the review will not only affect on-label uses, but also the UK Long Term Arrangements for Extension of Use, which allows extrapolation to 62 minor crop species and the Specific Off-label Approvals (SOLAs). Over £1.8 million, funded solely by UK growers, was spent between 1993 and 1999 (Moorhouse & Hucklesby, 2000) on generation of residues data for horticultural crops, and the submission of applications to PSD. SOLAs were granted for over 60 crop species. Now several of these SOLAs will be lost: benazolin for weed control in some brassica crops, pentanochlor and terbacil for weed control in herbs, fomesafen for weed control in soya, prometryn for kohl-rabi, celeriac and herbs and pyrifenox for cobweb control in mushrooms. Under the Long Term Arrangements pesticides registered for peas and beans are permitted for use in lupins, but several pre-emergence pea herbicides will not be supported.

At the time of writing the extent of losses of registered active substances and permitted Extensions of Use in other Member States is not clear, but it is also likely to have a significant economic impact, particularly on the horticulture sector.

ESSENTIAL USE PROVISIONS

As the principle for the establishment of essential uses was only introduced in the 2nd Commission Review Regulation it does not apply to the first round of the review, although some active substances and their uses are regarded as very important, for example, quintozene for control of *Rhizoctonia* in lettuce and brassica crops.

Initially there was no formal guidance from the Commission on criteria for aspects of health and environmental safety, or on any data requirement for evaluation of requests for Essential Uses.

The time period for any temporary derogation has not yet been decided, although it was suggested that an extension of use until 2007 was needed to allow time for development and registration of alternatives. The crop protection industry needed time to adjust production planning where appropriate and therefore a list of Essential Uses was required before the end of 2001. The Commission has specified that Member States should produce their lists of requested derogations by 15 October 2001. Decisions on which derogations will be permitted are unlikely to be made until early in 2002. If a request for derogation is not granted, then the active substance will be withdrawn from the market on 25 July 2003.

The number of exempted uses agreed by the Commission is likely to be limited and estimates range from five to 50. It is worth noting that in the UK the loss of just one active substance could result in the loss of a large number of uses including Specific Off-label Approvals (SOLAs). For example the herbicide pentanochlor is used on 26 crops including apples, foxgloves, celery, conifer seedlings and a SOLA for herbs.

There were also indications that the chance of achieving derogation would be greater where there were similar requests from several Member States. However the registrations for products containing these active substances varies considerably between countries. For example, octhilinone for canker and silver leaf control in top fruit and woody ornamentals is only registered in Ireland and the UK; whilst metoxuron is registered in nine Member States and fenpropathrin in 12. Crops also differ in economic importance between Member States: the area of dwarf French beans has declined to less than 2,000 ha in the UK, but in France the area is around 29,000 ha and fomesafen is vital to production.

There was no official definition by the Commission of an ‘Essential Use’ but it was thought that derogations would only be granted for registered uses for which there was no realistic alternative method of control of a weed, pest or disease which can cause economic loss. Other criteria could include the need for a resistance management tool and current or potential usefulness in an Integrated Pest Management programme.

The British Crop Protection Council Minor Use Working Group (BCPC MUWG), which acts as a forum for discussion on pesticide issues and for information exchange between groups concerned with minor uses, acted to co-ordinate requests for essential uses. A list of the unsupported active substances was circulated by the Horticultural Development Council (HDC) to grower groups in the horticulture industry, the Home Grown Cereals Authority to cereal and oilseed growers, the Apple and Pear Research Council, the Potato Research Council, the Sugarbeet Industry, Processors and Growers Research Organisation (peas and beans), Forestry Authority and English Nature. In addition many other sectors have been consulted in order to assess which uses were essential and to invite requests for derogation.

Table 2. Provisional UK list of essential uses as of July 2001

Active Ingredient	Essential Uses
2-aminobutane	Fumigant stored seed potatoes (scurf, skin spot, gangrene)
Anthracene oil	Chemical defoliation in hops
Azaconazole	Canker & silver-leaf control in ornamental trees and shrubs
Cyanazine	Weed control in: peas; field beans; oilseed rape; brassicas SOLAs; bulb onions; leeks; bulbs
Fenpropathrin	Pest control in: blackcurrants; top fruit
Fenuron in mixture	Weed control in: spinach; runner beans
Fosamine	Control of woody weeds in forestry, waterside & non-crop areas
Fomesafen	Weed control in: peas; field beans; dwarf French beans; soya
Imazapyr	Weed cntrol in forestry
Oxycarboxin	Rust control in ornamentals
Pentanochlor	Weed control in: carrots & parsnips; ornamentals & bulbs; celery; celeriac; herbs
Prometryn	Weed control in: carrots; drilled & transplanted (including protected) celery; transplanted leeks & SOLA drilled leeks; bulb onions; outdoor & protected herbs SOLAs & parsley
Resmethrin	Sciarid fly control in mushroom
Sodium hypochlorite	Bacterial blotch control in mushroom
Sodium monochloroacetate	Weed control in: vegetable brassicas; bulb onions Removal of basal growth in hops Sucker control in cane fruit
Tar oils	Aphid, scale insects, winter moth control in: bush fruit; cane fruit; plums & cherries
Terbutryn in mixture	Weed control in: lupins (Long Term Arrangements); combining and vining peas; broad and field beans

Information was obtained from crop protection companies regarding intentions to continue manufacture of those products containing active substances which were not supported in the EC review for markets outside Europe. If manufacture would cease in or before 2003, then a derogation request from the UK would not be made. This ruled out 21 active substances from rounds two and three and included benazolin, metoxuron, octhilinone, oxadixyl, pyrifenox, tebutam, bromacil and terbacil, all rated as very important by growers. Companies were also asked to identify any active substances for which support had originally been declared, but that may be withdrawn subsequently, so that growers would have an opportunity to request derogations as soon as the Commission was notified.

UK growers' requests for derogation for 14 active substances were presented to the European Commission by the PSD in April 2001. At that stage the active substances were not reviewed by the UK regulatory authority for acceptability in terms of health and environment, which some Member States may wish to include. Some, but not all, Member States also submitted lists through their national regulatory departments. However, if a company decides at a later date that it no longer wishes to support a particular active substance, then additional essential uses will be requested.

Since April there have been changes and Table 2 shows the status of the list in July 2001, and includes 17 active substances and 43 uses. There may be further changes.

APPLICATION FOR DEROGATION

Each request to the European Commission Health and Consumer Protection Directorate made by national regulatory authorities on behalf of growers for an essential use must be supported by a short submission. At the time of writing the format for this has not been finally agreed.

The UK PSD suggested the type of information that would be required for a formal request for derogation. This included: -

- Significance of pest/importance of use
- Economic impact
- Need for active substance in resistance management / integrated pest management
- Alternative active substances available
- Reasons that alternatives are considered unsuitable
- Planned work to develop suitable alternatives

An example of a response for a machine harvested crop grown for processing and which is heavily dependent on herbicides to achieve yield, harvestability and quality was prepared by PSD for the essential use of a herbicide(fomesafen) in dwarf French beans and made available to authors of requests. The extra cost of cleaning in the factory to remove weedy contaminants and the rejection of crops where the risk of toxic berries and stems from *Solanum nigrum* or potato volunteers pose a risk to the consumer for some vegetables for processing (peas, broad and dwarf French beans). The last is the most difficult section, particularly for those crops known to be intolerant of many herbicides, and where funding for research may not be available. However, it is vital to plan work on alternatives in order to achieve derogation. In this case there are unlikely to be any suitable early post-emergence replacements.

CHANGING SITUATION

A constant watch is needed to assess rapidly changing situations. Recent mergers and take-overs among the large crop protection companies have resulted in rationalisation of product ranges and further decisions are still to be made. Transfer, collation and assessments of dossiers and notification of support within the timescale will be difficult. There could be further losses where: -

- Support for some active substances may still be withdrawn by the notifier as the date for dossier submission approaches
- Decisions change on manufacturing for a global market
- Some supported active substances fail to achieve Annex 1 listing after review
- Approval holders do not reregister minor uses after Annex 1 listing

In addition, at this time we are unable to determine which uses are being supported for each active substance for example, thiabendazole use in potatoes was supported but not a seed treatment for peas. Information on withdrawal of support appears slow to reach the European web site but, where possible, UK growers are continually updated by the BCPC MUWG on all these issues so that additional requests for derogation can be made if necessary.

MUTUAL RECOGNITION

Once an active substance has been included on Annex 1 to Directive 91/414 and products are authorised in a Member State, Mutual Recognition becomes a possibility. This means that a crop protection company can apply for an authorisation in another EU member state on the basis of the fact that the pattern of use of the product, environmental (including climatic) and agricultural conditions are identical.

As the EC review progresses it is inevitable that there will be fewer minor crop approvals on plant protection product labels. The Directive 91/414/EEC makes provision for extensions of use in a similar way to that operated in the UK SOLA scheme and it was implemented into UK law through the Plant Protection Regulations 1995.

In addition to the system for Mutual Recognition allowed for in Directive 91/414/EEC the European Commission has also put forward a draft proposal (9191/VI/97) for a system of so called 'Voluntary Mutual Recognition' for minor uses (Brooijmans, 2000). This system is intended to assist Member States in decision making to determine whether use of active ingredients in products still being evaluated under the EC review programme can be recognized in another Member State in order to avoid duplication of data generation and evaluation. As an extension of use is involved there is a pre-requisite that the product for which extension of use is sought should already have approved use in the recognising country for a different use with a comparable formulation, and that the intended use is 'minor'. The pattern of use, environmental (including climatic) and agricultural conditions should ideally be identical, but extrapolation may be possible. Residues data are necessary for edible crops to establish an acceptable MRL and in situations where these are absent, Voluntary Mutual Recognition will provide no advantage (Brooijmans, 2000). It is proposed that applications to the designated national regulatory authority of the Member State can be made by crop protection companies, grower organisations or growers. However for edible crops, in cases where residues data are needed, provision of GLP-compliant residue studies may be more difficult for the latter. Decisions on mutual recognition are voluntary and will be granted at individual Member State level.

THE FUTURE

The future of development for new plant protection products for minor crops is bleak. Crop protection company priorities are for major crops, which in Europe is limited to winter wheat. Furthermore broad-spectrum herbicides developed for cereal crops are not generally suitable for broad-leaved crops. Development of genetically modified herbicide tolerant minor crops for the EU seems unlikely for commercial reasons and because, for the moment, they are not acceptable to many consumers. Weed control without herbicides for example by, mechanical, hand, flame or steam weeding, has a higher labour requirement than for spray application and with the shortage of labour in the industry, will often not be economically viable. It will thus be difficult to find alternatives. However, opportunities may exist for the crop protection industry to fill gaps.

The many losses of active substances as a result of the review will impose a severe financial burden on the European horticulture industry and there is concern that without solutions to pest, disease and weed problems some production sectors will disappear from Europe. For fruit and vegetables there may also be an impact on the consumer: rising prices, reduced choice, empty shelves and increased "food air miles".

A priority is to identify research needed to develop alternative strategies (chemical or non-chemical) to replace lost active substances. Availability of funding will be a major obstacle.

Many 'Extensions of Use' will be needed and crop protection companies could be encouraged to help by seeking Mutual Recognition. Residue studies will be required so that MRLs can be set. The way forward will be by co-operation between crop sectors across Europe. Retailers source produce from many European countries. Links already exist between European grower organisations (for example herbs, blackcurrants, hops, peas), and between members of the European quick-freezing industry organisation (OEITFL). Other industry sectors must be encouraged to follow their lead.

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The Render Project – third stage of the work programme of Directive 91/414/EEC

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ABSTRACT

Defined by Regulation (EC) No 451/2000, the Render* Project examined notifications for existing active substances to be reviewed in the EU programme of work. A notification procedure was applied for the EU review programme which was fully electronic and highly approved by the notifiers. Of the 419 existing active substances, 60% were not notified at all, i.e. will be excluded from the ongoing work programme and finally, 167 active substances were considered for evaluation, corresponding to 229 notifications. As a result of the Render Project the next steps of the review programme will proceed more effeciently by focussing only on those active substances which will be supported. Furthermore, a big step in respect to the harmonisation of authorisations within the EU is done, because active substances not notified for the third stage will be withdrawn from the market by July 2003 at the latest.

- Review of EU Notifications under Directive 91/414/EEC and Related Regulations

INTRODUCTION

In the view of the high number of existing active substances still to be reviewed, a notification procedure was started in order to identify those substances for which notifiers wish to secure inclusion in Annex I of Directive 91/414/EEC. It was the aim of the Render Project to speed up the review programme by pre-evaluation and to exclude active substances which were not to be supported.

LEGAL BASIS AND PROCESSING

Detailed rules for the implementation of the third stage of the work programme were determined in Regulation (EC) No 451/2000 and came into force on 1 March 2000. As defined in this Regulation, the Render Project was the designated body processing and examining the notifications on behalf of the European Commission. The Regulation determined a time schedule according to which the notification documents were to be submitted and to be evaluated. Furthermore, given deadlines exceeded the duration of the Render Project:

- 31 May 2000: Submission of Section I of notification (brief information)
- 30 November 2000: Submission of Section II of notification (dossier data)
- 30 May 2001: Report on the admissibility of the notifications ("The Render Report")
- 29 June 2001: Consultation of the Render Report at the Standing Committee of Plant Health
- 25 May 2003: Submission of a full data package

- 25 July 2003: Withdrawal of active substances without admissible notification or full data package

The goal of the project was not only to identify the active substances to be reviewed but also to extract those notifications for which submitting a full dossier appeared possible and reliable.

Therefore notifiers had to submit the following information:

- Identification data on the active substance and notifier
- Completeness checks for each point of Annex I and Annex II to the Directive demonstrating the current completeness of the dossier
- List of representative uses
- List of available studies to be submitted to the rapporteur Member State as part of the dossier
- A time plan of further studies still to be performed in order to complete the dossier
- A list of end points as specified in the Regulation

The Regulation also defined the criteria for admissibility of the notifications:

- To be presented within the time limit referred to in Article 10 (2)
- To be introduced by a notifier who is a producer as defined in Article 2 (2) (a) for an active substance as defined by the Directive
- To be presented in the format as provided in Annex IV, Part 2
- It is apparent from the completeness check that the dossier currently available is sufficiently complete or a time plan to complete it is proposed
- The list of end points is sufficiently complete
- A fee as referred to in Article 13 has been paid.

For a clear decision, most of these criteria needed to be specified in more detail, especially those points focussing on the completeness of the dossier and the list of end points. This was done in consultation with the European Commission and Member State experts.

The notification forms provided as MS Word files and a guidance document were made available on the Internet, by e-mail or CD-ROM. After completing the forms the notifiers also submitted the required documents electronically, e.g. by e-mail. These electronic forms ensured a standard format, but were also designed for facilitating completion and data transfer. The vast amount of data required a data base programme for effective evaluation. For this reason, an MS Access data base was developed ("Renderix"), which was integrated in Render's internal network.

Using this database the statistical approach ensured an evaluation with a high degree of transparency and reproducibility. A quick modification of the evaluation strategy was also possible following consultations with Member State experts and the Commission. During this process, certain examination procedures could also be modified, depending on statistical analyses from the notification data. Notifications which appeared incomplete following these statistics were evaluated in more detail, especially by checking the list of studies and the list of end points.

For the first time, a full electronic notification procedure was applied for use in the EU review programme of active substances. In connection with the Internet as an information platform, the electronic notification was an effective tool which met with the high approval of the notifiers, and which also proved to be very compatible within Europe. The common use of standard software (MS Office) and of the internet, even in smaller companies, contributed to the success of this procedure.

RESULTS

Based on the great number of active substances covered by the third stage at the start of the project there was no precise prediction concerning the notifications expected to be evaluated. Finally, 229 main notifications were considered for evaluation, corresponding to 167 active substances. At this early stage of the project, it became clear that about 60% of the remaining existing active substances would be excluded from the ongoing work programme because they were not notified (Figure 1).

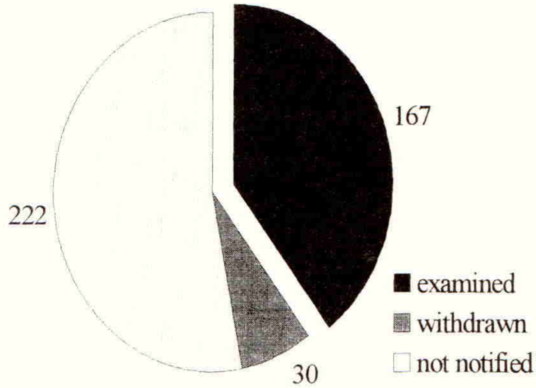

Figure 1: Status of the existing active substances covered by the third stage of the work programme (n=419)

As defined in Regulation (EC) No 451/2000, active substances which were not notified, or for which no admissible notifications were received, will be excluded from the review programme. Furthermore, those active substances would have to be withdrawn from the market by July 2003 at the latest.

Table 1 gives some details listing all herbicides to be withdrawn from the market, but still authorised in at least six Member States.

Table 1: Active substances (herbicides) not notified for the third stage with authorisations in at least six Member States, according to Doc. 3010/VI/91 rev. 18

Active substance	Member States where authorised	Active substance	Member States where authorised
Imazapyr	12	Fenoxaprop	7
Sethoxydim	12	Fluoroglycofene	7
Bromacil	10	Quizalofop	7
Metobromuron	10	Desmetryne	6
Difenzoquat	8	Dimefuron	6
Metoxuron	8	EPTC	6

A total number of 70 notifiers and manufacturers respectively, were involved, however, more than half of them submitted documents for only one active substance. In contrast to this, 5 companies submitted notifications for more than 10 active substances. For a great number of active substances more than 4 notifications were submitted independently of each other (Metamitron, Chlormequat, Diflufenican etc.)
Focussing on the function, the proportion of herbicides which were not notified was slightly higher than that of other functions (Figure 2).

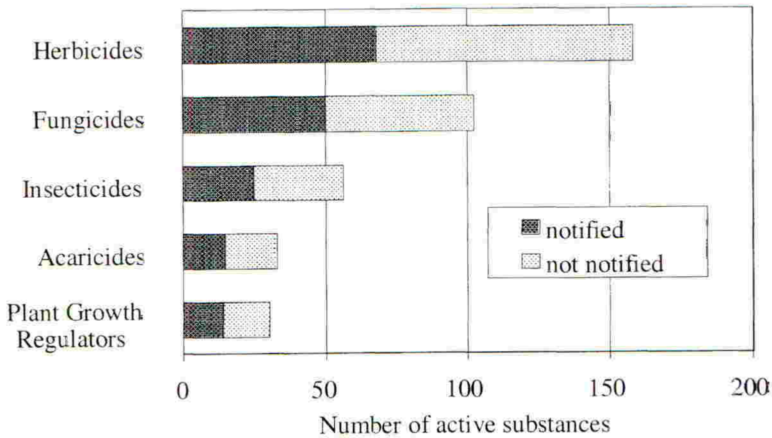

Figure 2: Number and status of active substances relating to the function (note: an active substance may have more than one function)

In the following, the consequences for the Member States of the EU will be discussed: about 50% of the active substances not notified for the third stage are registered in one Member State at the most. However, there are 25 active substances authorised in at least 6 Member States.

By taking a detailed look, it can be seen that Member States with a high number of currently authorised existing active substances are more affected by this reduction compared to those with only a few authorised active substances. Some Member States like Finland, Denmark and Sweden may lose less than 5 active substances, whereas in France, Spain and Italy about 40 herbicides could disappear from the market. Figure 3 shows the current situation within the EU comparing to the expectations for 2003.
However, these data provide only a weak indicator for the future situation as, for example, further existing active substances may be lost because of national restrictions or the final results of the EU review programme. Despite from the harmonisation process intended by the Directive, the availability of active substances in the Member States will still be different. This might be related to the miscellaneous uses, especially fruit and vegetable growing in Mediterranean countries.
The lists of crops and the Member States in which the active substances are authorised are available from the Render notifications. However, information on active substances which were not notified is missing, so that it is difficult to estimate the effect of the loss of active substances.

Furthermore, the status of the notification procedure for a certain active substance gives only little information on the importance of the actual application in a certain country.

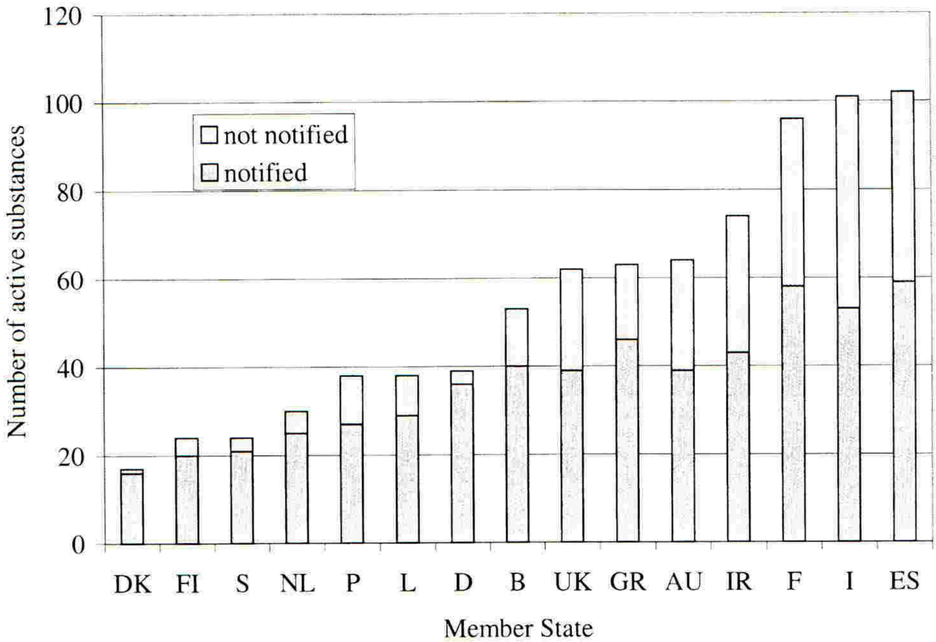

Figure 3: Number of active substances (herbicides) notified for the third stage of the EU work programme compared to those not notified (to be withdrawn from the market by July 2003)

Apart from the decision on the admissibility of the notifications, the submitted documents show clear differences with respect to the completeness of the dossier. The European Commission has meanwhile discussed the recommendations explained in the Render Report with experts of the Member States. The results concerning the admissible active substances as well as their notifiers were published in the document SANCO 2342/2001. Even if a final decision on the remaining active substances has not been made, it seems in the present situation (August 2001) that only one single active substance (sodium dimethylarsinate) covered by the third stage will be excluded.

The following review steps will be described in another regulation which will probably enter into force at the end of 2001. In this regulation the active substances, the notifiers as well as the rapporteur Member States and the deadlines for the submission of the dossiers will be determined. Based on the statistical results, the submitted notification data allow a more intensive evaluation, especially with respect to the completeness of the dossier and the validity of the entries. Therefore, in the course of the preparation of this new regulation, the European Commission will be supported by the Render team, in particular with regard to working out separate lists.

Besides the third stage there are still a great number of existing active substances which are temporarily excluded from the review because of several reasons (e.g. "low-risk products" or overlap with other regulations). Therefore, for this fourth stage no determined procedures nor time schedule are intended at present. This will affect approximately 180 active substances (e. g. commodity substances, plant extracts or repellents), of which some are authorised in almost all Member States (e. g. Bacillus thuriengiensis, bromadiolone, pyrethrins, sulphur). According to the Directive a definite review plan for these active substances has to be established by July 2003 at the latest.

CONCLUSIONS

The fact that a high proportion of active substances has not been supported gives rise to the supposition that in several Member States this could lead to problems in weed control, especially in minor uses.

Problems connected with minor uses will be made even more difficult in the medium term as, besides the active substances already excluded, further active substances will have to be withdrawn from the market for which either no complete dossier has been submitted by May 2003, or the subsequent examination will result in non-inclusion in Annex I of the Directive.

However, Regulation (EC) No 451/2000 offers the possibility to define certain essential uses ("The necessity of re-examination will have to be demonstrated on a case-by-case basis"). The determination of essential uses demands extensive information, e. g. on alternative possibilities of controlling, economical significance of the crop, sale of the active substance, availability of new active substances etc. Therefore, the Member States are making intensive efforts to define their own essential uses, appropriate to the requirements of the country, and to work out solutions (see paper by P J Chapman 9C-2).

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Doc. SANCO/2342/2001 of 21 June 2001; list of active substances and notifiers for which a notification in accordance with Article 10 (2) (b) of Commission Regulation (EC) No 451/2000 has been assessed and appears to be admissible.

All documents and further information on the Render Project are available on http://www.bba.de/english/render/reprojec.htm.

Essential uses: the European farmer's viewpoint

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ABSTRACT

The significance of the Commission's action to "accelerate" the EU review under Regulation 451/2000 has not been realised at individual grower level. The pan-European growers' organisation, COPA, has implemented a substantial consultation programme. The success and validity of this initiative has been hampered by poor communication between Member States and all sectors of the industry, however, the resultant responses from various Member States indicate the enormity of the socio-economic impact the withdrawal of certain active substances will cause.

INTRODUCTION

COPA (Commitė des Organisations Professionelles Agricole) is made up of 29 farming organisations from the 15 members of the European Union. This broad membership allows it to represent both the general and specific needs of farmers and horticultural growers in the Member States and it is now recognised by the Commission and Community Authorities as the spokesperson for the agricultural sector as a whole. Pesticides represent over 8% of European farmers' total input expenditure.

COPA's phytosanitary working group (largely composed of representatives from the larger European Member States) realised the implications of the acceleration of the European review procedure, as outlined by Chapman (2001). Therefore, in January 2001 the Group started to examine the active substances and leading plant production products listed in Regulation EC 451/2000 to determine whether or not they were of essential use in agriculture/horticulture particularly from the perspective of:

1. whether the active substance or related plant protection product(s) is essential if other plant protection measures are currently not available or not available in sufficient quantities;
2. whether the active substance is essential in terms of preventing resistance;
3. whether the active substance is essential to integrated crop production or organic farming;
4. the socio-economic importance of the crop and the use of the plant protection product on the crop in question, and finally
5. production losses or financial impact caused, by not having the active substance available for use.

The Group found that the production of a considerable number of active substances/ plant protection products that were regarded by members as essential would or had been recently discontinued and, therefore, there was little point in considering whether or not they were essential. However, based on an initial screening and taking into account manufacturers' comments regarding future production, Member States' representatives were requested to select those active substances from plant protection products that it regarded absolutely essential to its agriculture.

ESSENTIAL USES

A homologated list from the United Kingdom (UK), Spain (Sp), the Netherlands (NL), Greece (GR), Belgium (B), Denmark (DK), France (F) and Austria (A) is given in Table 1.

Table 1. The 'wish list' of essential uses proposed by COPA members for active substances on EC Review lists 2, 3 and 4.

Active Substance	List	Class	Use	Country
2-aminobutane	3	Fu	potatoes	UK
acifluorfen	3	Hb	soya	F
alloxydim	3	Hb	various	A
anthracene oil	3	PG	hops	UK
athraquinone	4	BR	cereals; maize	B
azaconazole	3	Fu	arboriculture	F, B, A, NL, UK
azaconazole	3	Fu	tomatoes; peppers	B, NL
bendiocarb	2	In	maize & sweetcorn	A
benfuresate	3	In	cotton	Sp
bromopropylate	3	In	arboriculture	F
bromopropylate	3	In	top fruit	B, Sp
bromopropylate	3	In	lemons; tomatoes; grapes	Sp
BT endotoxin	4	In	various	A
butocarboxim	2	In	citrus	Sp
butocarboxim	2	In	ornamental plants	A
(calcium) copper sulphate	3	Fu	fruits, vegetables; olives	Sp
chlorbromuron	3	Hb	carrots	A
chlorfenvinphos	2	In	asparagus	F
chlorfenvinphos	2	In	cress	F
chlorfenvinphos	2	In	swedes & turnips	F
chlorfenvinphos	2	In	radish	F
chlorfenvinphos	2	In	brassicas	Sp, NL
cyanazine	2	Hb	peas; oilseed rape; brassicas; onions; bulbs; forestry	UK
cycloate	3	Hb	spinach	A
dichlofluanid	3	Fu	ornamentals; flowers	F
dikegulac	3	PG	trees; nursery stock	F
dinobuton	3	In	top fruit	Sp
disulfoton	2	In	ornamental plants	F
enthiofencarb	2	In	ornamental plants	A
fenoxaprop - ethyl	3	Hb	legumes	A
fenpropathrin	3	In	apples; blackcurrants	UK, DK
fenuron	3	Hb	spinach; runner beans; leeks	UK

Active Substance	List	Class	Use	Country
flucycloxuron	3	Ac	glasshouse flowers	NL
flumetralin	3	PG	tobacco	Sp
fluridone	3	Hb	aquatic weed control	F
fomesafen	3	Hb	beans; soya	F
fomesafen	3	Hb	peas; beans; soya	UK
fosamine	3	Hb	forestry; non-crop areas	UK, A
furalaxyl	3	Fu	ornamental plants	A
furathiocarb	2	In	leeks	B
glutaraldehyde	3	Bio	mushrooms	B
heptenophos	2	In	n/s	A
hexazinone	3	Hb	lucerne	F
hexazinone	3	Hb	nursery stock	Sp
hydroxy-MCPA	3	PG	tomatoes; egg-plant	Sp
imazapyr	3	Hb	forestry	UK
mepronil	3	Fu	salad vegetables	A
metobromuron	3	Hb	beans; lambs lettuce	B
metobromuron	3	Hb	ornamental plants	Sp
metobromuron	3	Hb	peppers; tomatoes; tobacco	A
metolachlor	2	Hb	sorghum	F
metoxuron	3	Hb	carrots	F, NL
metoxuron	3	Hb	potatoes	B
metribuzin	2	Hb	tomato	Sp
naptalam	3	Hb	melons	F, Sp
omethoate	2	In	ornamentals; lambs lettuce; endive; celery	B, A
orbencarb	3	Hb	lupins	A
oxadixyl	3	Fu	peas	B
oxycarboxin	3	Fu	ornamental plants	Sp, UK
pentanochlor	3	Hb	carrots; ornamentals/bulbs; celery; fennel; celeriac; herbs; parsnips	UK
pyridafenthion	2	In	grapes, grassland; lemons	Sp
prometryn	2	Hb	carrots & parsley; celery; leeks; onions; garlic; kohl-rabi; celeriac; herbs	UK
propachlor	3	Hb	onion; leeks; flowers	NL
propoxur	2	In	top fruit	B
propoxur	2	In	ornamental plants	A
pyrifenox	3	Fu	ornamental plants	Sp
'quat'	4	Bio	mushrooms	B, NL
'quat'	4	Bio	algaecide in glasshouses	NL
resmethrin	3	In	mushrooms	UK
sethoxydim	3	Hb	beans; leeks; brassicas	B
sethoxydim	3	Hb	red beet; flax; etc.	A
silver nitrate		PG	cucurbits; seed treatments	NL
sodium arsenate	3	In	top fruit	F
sodium arsenate	3	In	grapes	Sp, F
sodium hypochlorite	3	Bio	mushrooms	UK, NL
sodium hypochlorite	3	Bio	cutflowers	NL
sodium monochloracetate	3	Hb	brassicas; bulb onions; hops	UK
sodium monochloracetate	3	PG	cane fruit	UK

Active Substance	List	Class	Use	Country
sodium silver thiosulphate	3	Hb	ornamental plants	DK
sodium-p-toluene-sulphonchloramid	3	Bio	cutflowers	NL
sulfotep	2	In	glasshouse crops; tomatoes; cucumbers; beans	A
tar oils	3	In	bush fruit; cane fruit	UK
terbacil	3	Hb	herbs	Sp, GR
terbutryn	2	Hb	lupins; peas; beans	UK
triforine	3	Fu	spinach; blackcurrants	F
triforine	3	Fu	nursery stock; roses; cucumbers	A
triforine	3	Fu	top fruit	DK
vamidothion	2	In	arboriculture	F, B
vamidothion	2	In	top fruit	B, Sp, NL

Fu = fungicide; Hb = herbicide; In = insecticide; PG = plant growth regulator; BR = bird repellent; Bio = bactericide; Ac = acaricide

Austria has provided some notable rationales for retaining the use of certain active substances. Triforine is the only systemic fungicide available to combat bean rust (*Uromyces* spp.) in Austria and for ornamental plants it is the only fungicide still available to counter black rot (*Marsonina* spp.) in roses. It is also a pivotal product in integrated production under Austria's environmental programme.

There are only a few substances that are authorised for use for weed control in forests in Austria. They differ widely in their application but hexazinone is widely used in coniferous forests and natural regeneration stands of spruce, fir and pines where the aim is to keep the trees free of weeds until they are high enough to withstand the competition. A granular formulation can be applied in a more targeted manner to roses or individual trees and the label recommendations have been reduced over the years. Hexazinone has been used in Austria for around 20 years and has proved invaluable even though only 6,000 hectares of land is treated. If authorisation were allowed to lapse forestry workers would be reduced to combating weeds by hand.

The delta-endotoxin of *Bacillus thuringiensis (Bt)* is an organic plant protection product that is used to control Colorado Beetle larvae in organic farming and in integrated crop protection under Austria's environment programme. The only other organic plant protection substance available is azadirachtin of which there is very little practical experience under Austrian growing conditions. As Colorado Beetle is serious potato pest in Austria and in view of the high frequency treatment needed almost every year, Bt products are virtually indispensable for organic and integrated farms.

In Belgium, vamidothion is an essential part of the integrated control of woolly apple aphid on top fruit. There are 60,000 hectares of apples in Belgium of which this pest regularly attacks 75%. The economic losses are of the order of 10-20% for apples but in the worst case scenario - the loss of marketable yield would be absolute.

Azaconazole is the only product approved in Belgium for the control of twig blight, silver blight and wood decay in arboriculture controlling *Botrytis* and *Nectria*. The economic losses if trees are not protected are profound because infected plants are worthless. The product is formulated as an aerosol that permits topical application to the stems. The total area of cultivated trees in Belgium is over 2,500 hectares and up to 60% is at severe risk.

With respect to France, their 'wish' list includes products including glutaraldehyde and 'quat' chemistry, which are currently authorised both as biocides and plant protection products because of their wide spectrum of activity as disinfectants.

SOCIO-ECONOMIC IMPACT

Greece provides an interesting example of economic impact with the use of terbacil on herbs in the *Labiatae* family, eg. mint, to control of broad leaf and grass weeds. It is usually used as a pre-emergence application but it can be used up to 15% crop emergence as it has a harvest interval of 60 days. Table 2 indicates the recent commercial expansion of this minor specialist crop in Greece over the last five years. The table is based on data from farmers contracted by Eucopharm Hellas, a member of the herb organisation EUROPOAM. This is an expanding industry both in terms of farmers and area cultivated.

Table 2. Development of *Labiatae* herb production in Greece

	1997	**1998**	**1999**	**2000**	**2001**
Area (ha)	16	27	83	110	700
No. of growers	10	11	36	40	209
No. of regions	1	1	2	2	7

Table 3 gives an analysis of the financial breakdown of the crop, including a production levy (ELGA). Table 4 indicates the unsustainable reduction in net income that would result from the withdrawal of terbacil use.

Table 3. Production costs (GRD) of *Labiatae* herb production in Greece

	Ist year	**Years 2-7**	**Average**
Crop Establishment	220	0	14.29
Crop maintenance	130	150	147.13
Harvesting	0	50	42.86
ELGA levy, etc.	0	50	42.86
Gross revenue	0	1000	857.14
Net income	-350	750	592.85

Table 4. Production costs (GRD) /year/ha of *Labiatae* herb production in Greece with and without the use of terbacil

	Without terbacil			**With terbacil**		
	Cost	**Yield (kg)**	**value**	**Cost**	**Yield (kg)**	**value**
Crop maintenance	370			150		
Harvesting	40	22	750	50	29	1000
ELGA levy, etc	37.50			50		
Total cost	447.50			250		
Net income		302.50			750	

It has been suggested by COPA to the European Commission that an industry as commercially exposed as herbs, could well exit the EU to third countries with a suitable climate eg. Israel. This would cause significant local infrastructure collapse and social deprivation. The enormity of this, certainly in Italy and Spain, was highlighted in the mid 1990s by the work undertaken by COPA to explore the economic consequences of the withdrawal of methyl bromide as a soil sterilant. In this case, the salad vegetable industry was worried that production would simply move to Algeria and Morocco, where methyl bromide would be still available as these nations have special derogation under the Montreal protocol. There is some small comfort in this instance because the herb production industry in Israel relies upon the availability of terbacil!

PROBLEMS

The resources of growers within Member States are now quite disparate and limited. Many Member States do not have organisations that fulfil the supporting role of the HDC in the UK or the Länders' regional governments in Germany. The industry has come to depend upon locally available products, which often contain a generic active ingredient and has built up relationships with suppliers to fulfil the niche markets. Very often the availability of these products is country-specific and the formulation is not marketed even by another organisation in another Member State. Even with crops as large as carrots and legumes, growers in each Member State have come to rely on different products and this has served to make the drawing up of lists of potential 'essential use' candidates very complex. This is further exacerbated by manufacturing and marketing companies taking a more ruthless view on the financial viability of marketing such products and not declaring their intentions.

Growers have not appreciated the full significance of the truncation of the review procedure and even now growers in many areas fondly believe that the industry will continue to provide them with suitable products. In many instances considerable hope is placed in the mutual recognition regulatory pathways and growers will therefore have the ability to import plant protection products from other Member States. The fact that this will not prove straightforward in practice as is perceived will come as a shock to many grower groups. In addition, the one-year 'wind-down' period post July 2003 (as proposed by the Commission) will lead to significant problems for certain grower groups. COPA has sought primarily to identify those uses where growers are most exposed and has set out to identify the ways in which growers can help themselves.

Nevertheless, this activity relies on identifying those products whose efficacy covers the pests, diseases or weeds in question; where the level of selectivity is acceptable and finally, whether there is sufficient confidence in the longevity of the commercial availability in order to make an investment in residues trials worthwhile. It is well known that at least two seasons are required for residue trials to generate sufficient data for setting Maximum Residue Limits (MRL).

In seeking alternatives, growers have had considerable difficulty in gaining reliable information from manufacturers and marketing companies about whether or not certain formulations will be available even if the active substance is supported. There is a prevalent misunderstanding that just because the product is being supported in the EU review all current uses will automatically be supported. Therefore, in seeking alternatives available in other Member States, grower groups have very much looked at current label recommendations rather than the probable label following the end of the 2003 review process.

The relative conflict between the style of the MRL legislation and the authorisation legislation is making liaison difficult. Undoubtedly the fact that the active ingredients involved in the MRL legislation are not necessarily the same as that in the Authorisations legislative pathways has proved a problem. Considerable hope is placed by growers on the outcome of the Commission's latest 'Simplifying Legislation for the Internal Market' (SLIM) initiative, which is looking to expedite and simplify MRL setting and the subsequent dissemination of information to producer groups and the food retailers regarding their ability to trade treated produce.

NEXT STEPS

In response to sectoral needs, COPA has set up additional *ad hoc* groups, notably for blackcurrants, hops, herbage seed and herbs and spices. They have proved to be most effective, meeting internationally and electronically to monitor and co-ordinate activities. Increasingly the work of these groups requires close liaison with Member States' designated national regulatory authorities.

EUROPOAM, the herb industry's group, has perhaps highlighted one of the most obvious examples of an industry sector dependent on one active ingredient, namely terbacil. The costs of authorising plant protection products are now severe for minor uses. The lack of orchestration by grower groups to undertake extensions of use within the EU has been a subject of papers presented at previous BCPC Conferences. The propensity of grower groups in specific Member States to take a very parochial view still prevails, therefore, the enthusiasm and example set by groups like EUROPOAM is much to be admired.

One of the principle lines of solution in easing the situation lies in the fast and widespread authorisation of newly emerging chemistry. To a degree, the success of this lies very much upon the vision of the scientists in the manufacturers' R & D groups as to whether or not they believe there is a reasonable probability that their active ingredient will control a pest or disease in a minor crop. Manufacturers need to release, under appropriate confidentiality agreements, their lead formulations for evaluation probably much earlier than historically has been the case. In the past manufacturers have first sought authorisations on major crops, adding minor crops over time to expand their product's market. What is now needed is a 'sea change' in attitude whereby manufacturers will release a product early, so when it reaches commercialisation, there is a wide range of minor use authorisations available. COPA members were recently encouraged when Zeneca took this approach with azoxystrobin.

There is also concern amongst growers in Europe that the reduction of near market research resources, as witnessed by the withdrawal of extension services as in the UK and the Netherlands, will lead to problems. Even with extension services it is apparent that the Mediterranean States are floundering.

COPA's working groups have spent considerable time looking at the socio-economic arguments behind some of the consequences of the EU review. It is felt that there is a strong need to alert the Commission to the social impact. In many cases, certainly with herbicides, resorting to mechanical and manual weed control will make the production of certain crops a totally uneconomic option. Consumers have become used to high quality wholesome food at very modest prices and there is a strong indication that they will not countenance higher prices that arise from increased production costs.

The significance in the herb sector, where the European growers are hugely dependent on terbacil, indicates this point very well. There is no possibility that a manufacturer will ever generate data for herbs, the market size is literally too tiny. In addition, generating selectivity data and working out the appropriate regulatory packages for MRLs and taint is a huge problem. Nevertheless the herb industry is prepared to try to tackle this problem although it is desperately short of resources. However, in seeking an alternative to terbacil, the sole manufacturer has now declared that production will cease so the opportunity to 'buy' time by importing terbacil products from third countries will not exist. Manufacturers that have been reticent to indicate whether or not they will continue to invest in the regulatory support needed to sustain an active substance through the review procedure have considerably hampered the identification of an alternative. For example, the notifiers for prometryn and cyanazine, having initially given an indication that these would be supported, have withdrawn support late in the review procedure. This has proved very awkward for growers groups to manage, as they are then required to find an alternative product with only two seasons to go before these products cease to be available.

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SESSION 10A

WEED SENSING TECHNOLOGIES AND TARGETED CONTROL

Chairman & Session Organiser:	Professor P C H Miller *Silsoe Research Institute, Bedford, UK*
Papers:	10A-1 to 10A-4

Sensor systems for automatic weed detection

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ABSTRACT

This paper presents a real-time approach for site-specific weed control in winter barley, sugar beet and maize fields. A digital image analysis system was used to assess weed seedling distribution and plant species composition in the field. The system consists of three CCD-cameras mounted on a spray boom in front of a vehicle. The images of all three cameras were analysed automatically. Weed and crop species were identified using shape analysis. Weed species were grouped according to their competitive ability. A simple decision rule was used to turn on each section of the spray boom separately when a threshold for weed infestation was exceeded. A differential GPS receiver was installed on the vehicle to document the application maps. Site-specific weed control resulted in an average herbicide reduction in winter barley for broad-leaved weeds of 60 % and for grass-weeds of 92 %, in maize for broad-leaved weeds 11 % and for grass-weeds 81 % and in sugar beet for broad-leaved weeds 42 % and for grass-weeds 36 %.

INTRODUCTION

Weed seedling distributions have been found spatially and temporally heterogeneous within agricultural fields. They often occur in aggregated patches of varying size or in stripes along the direction of cultivation (Marshall 1988; Gerhards *et al.*, 1997b; Christensen and Heisel 1998). The variation in weed seedling population has so far been ignored in weed management decisions since techniques to assess the weed seedling distribution in an acceptable time were not available. A few studies were conducted to apply post-emergence herbicides in winter wheat and maize based on geo-referenced maps of the weed seedling distribution (Nordmeyer *et al.*, 1997, Gerhards *et al.*, 1997a, Tian *et al.*, 1999). In winter wheat, an economic threshold model (Gerhards and Kühbauch 1993) linked control decision algorithms with weed maps. Herbicide use with this map-based approach was reduced some 40-50 %.

A basic component of site-specific weed control is a system for automatic and real-time weed detection. Both optoelectronic sensors and digital image analysis systems have been investigated for weed detection and plant species identification. Biller (1998) used optoelectronic sensors to measure the reflectance in the green, red and near-infrared wave bands. Green leaves were characterized by a high reflectance in the green and near-infrared and a low reflectance in the red spectrum compared to the reflectance curve from a bare soil. Felton and McCloy (1992) developed a spot spraying system for non-selective herbicides based on the information of real-time reflectance sensors. The nozzles of the sprayer were turned on automatically when the Normalized Difference Vegetation Index (NDVI) exceeded a set threshold indicating a higher proportion of green vegetation in the field of view of the sensor. Chapron *et al.*, (1999) and Sökefeld *et al.*, (2000) used digital image analysis systems to identify plant species based on characteristic shape-, color- and textural-features. Weed sensors can be used for real-time control of the sprayer or can be taken to create weed distribution and application maps (Mortensen *et al.*, 1998, Sökefeld *et al.*, 2000). Also combinations of real-time sensors and historic weed maps have been investigated (Christensen and Heisel, 1998).

The objective of this study was to develop a real-time patch spraying system for weed control based on multi-spectral and near-infrared images.

METHODS AND MATERIALS

Test site, manual weed mapping and automatic weed detection

The study was conducted from 1996 until 2001 in four fields of between 2.4 ha and 5.6 ha at Dikopshof Research Station in Germany. Winter wheat, winter barley, maize and sugar beet were grown in rotation in each field so that each crop was planted at least once in every year and in every field. Weed control was performed site-specifically in each crop and year. Density of emerged weed seedlings was assessed manually and automatically with a digital camera system prior to and after post-emergence weed control.

For manual weed mapping, a regular 15 m x 7.5 m grid was established in all fields. Weed seedlings were counted in a 0.4 m^2 quadrat frame placed at all grid intersection points. Linear triangulation interpolation was used to estimate weed seedling density at unsampled positions to create a continuous map of weed density (Gerhards *et al.*, 1997a). Interpolated weed maps were reclassified based on weed infestation levels. Infestation levels were defined as weed free (<0.1 seedlings/m^2), low (>0.1-1), medium (>1-5), high (>5-20) and very high (>20 weed seedlings/m^2). Density classes were equal for all species in this study to facilitate the analysis of overlay maps. Weed distribution maps were re-classified based on a weed threshold model to obtain weed treatment maps (Gerhards and Kühbauch 1993). Classes were defined as no, low (60 %), medium (80 %) and high rate (100 %) of post-emergence herbicide.

For automatic weed detection, three digital cameras were mounted in the front of the sprayer. The images of these cameras were analysed automatically and on-line. Weed and crop species were differentiated based on shape parameters. A simple decision algorithm was used to turn on each section of the sprayer separately when a threshold for weed infestation was exceeded. Herbicide was applied at a constant rate. A differential GPS receiver was installed on the vehicle to document the application map.

Real-time image acquisition

The images were taken with three monochrome digital cameras that were mounted on a spray boom in front of a tractor with a distance of 3 m between each camera. Each camera was equipped with a near-infrared band pass filter (780 nm-1150 nm). Under cloudy conditions, the reflectance of green plants in the near-infrared spectrum is higher than the reflectance of the soil (Guyer *et al.*, 1986) (Figure1). The cameras were triggered with an exposure time of 1/4000 s to achieve well focused images at a speed of 7 km/h. Approximately every 2 m, a set of three images was taken and stored on the board computer of the vehicle together with the DGPS coordinates of the picture.

Figure 1. Original image, binary picture and contours of maize and *Chenopodium album* obtained from a monochrome CCD-shutter camera with a near-infrared band pass filter under cloudy conditions and dry soil.

Multispectral image acquisition

It has been found that monochrome near-infrared cameras were not suitable to separate green plants from soil background in digital images when the soil surface is very dry, compacted and under high radiation from the sun. The installation of cover sheets over the cameras is difficult when the cameras are mounted on the spray boom. Therefore, multi-spectral images of the blue, green, red and near-infrared band were overlaid to enhance the contrast between green plants and soil background. The pictures were taken successively with one monochrome camera with a filter-wheel in front of the lens and stored on the hard disc of the computer. The filter-wheel contained the blue, green, red and near-infrared band filter. The motor of the filter-wheel was turned automatically by the computer. For analysis, the images were loaded from the hard disc and the average intensity of the grey level was equalized for all four images. The difference of the near-infrared and the blue image (470-510 nm) was most suitable to enhance the contrast between green vegetation and soil and removed reflecting stones and mulch (Figure 2).

Image analysis

A histogram of the grey level intensity was calculated for all images. A grey level threshold was set automatically between the peak of dark pixels representing the soil and the peak of light pixel representing the plants. In a binary picture, the soil was displayed in black and the plants in white. In the next step, the contours of all white objects in the picture were extracted (Nabout and Nour Eldin, 1993). Objects that were smaller or bigger than plants were automatically removed from the image setting thresholds for the contour length. The contour of plants was then transformed into a chain code of standard vectors from pixel to pixel. Each vector was represented by a number of 0 to 7 indicating the orientation of the vector in relation to the previous pixel. The chain code was already characteristic of the plant species in the image but it was still dependent on size, rotation and position of the plant within the picture. Therefore, the chain code was transformed into a function with a standardized contour length of 2π on the abscissa and the variation of the angle on the ordinate. The result of this transformation was that the contours of the plants were independent of the height of the camera above the ground (zooming invariance). A Fourier transformation was then applied to obtain characteristic parameters of the plant contours that were also independent of rotation and position of the plant within the image. It was found that the amplitudes of the Fourier function was most suitable to describe the shape of weed seedlings (Nabout and Nour Eldin 1993). In addition to the Fourier descriptors, two geometric parameters (compactness and the quotient of minimum Ferrets diameter and maximum Ferrets diameter) and the area of the plants were calculated.

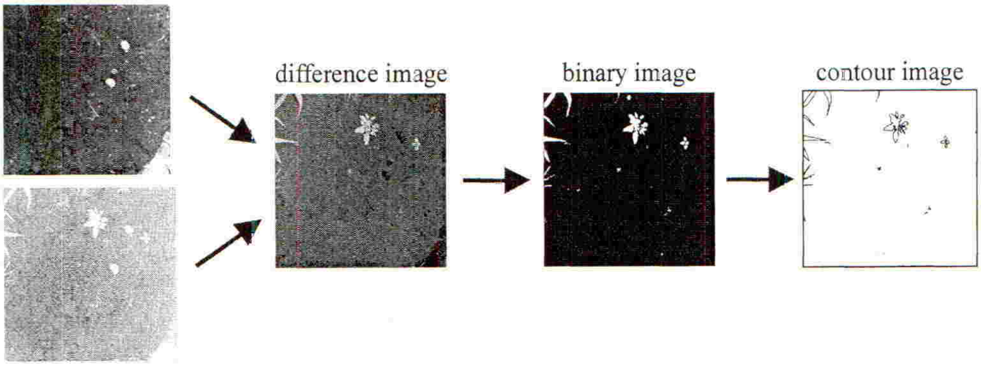

Figure 2. Difference of normalized near-infrared and blue images to enhance the contrast between green plants and soil background, stones and mulch; the images were taken in maize in May 2001 on dry soil under high sun radiation.

All plant features were calculated and stored for single weed and crop species or groups of weeds in a knowledge-base which is the basis for the plant species identification. The extracted plant features of the unknown plants were compared to the knowledge-base and classified as the most similar object in the knowledge-base. Both a minimum distance operator and a fuzzy algorithm were suitable for plant species classification. The time for analysing three camera pictures and creating a decision for turning each boom section on or off was approximately 1 second using a 500 MHz board computer. With a speed of 7 km/h, a set of three images was analysed approximately every 2 m.

RESULTS AND DISCUSSION

Weed distribution and site-specific weed control

The dominant weed species that occurred in the winter wheat and winter barley fields were *Alopecurus myosuroides* Huds., *Veronica hederifolia* L. *Viola arvensis* Murr. and *Galium aparine* L. In maize and sugar beet, the dominant weed species were *Chenopodium album* L., *Solanum nigrum* L. *Polygonum aviculare* L., *Echinochloa crus galli* (L.) Pal. Beauv. and *Galium aparine* L.. The average weed density for those species was high enough that herbicide application was recommended according to the economic threshold model in all four years and crops. However, the spatial distribution of weed seedling populations was very patchy. Often less than 50 % of the total area was actually infested with weed population densities that required chemical weed control (Table 1). Also, weed density and weed species distributions varied significantly between the different years and crops. Grass weed populations and broad-leaved weed populations often occurred at different locations within the fields. Therefore, grass-weed herbicides and broad-leaved weed herbicides were applied in two different treatments. In maize, between 68 % and 98 % of the area remained untreated against grass weeds and between 5 % and 16 % against broad-leaved weeds. In winter barley, average herbicide use was reduced by 60 % for broad-leaved weeds and 92 % for grass-weeds. In winter wheat, an average of 89 % of the total area was not sprayed with herbicides effective against grass-weeds and 62 % remained untreated with herbicides against broad-leaved weed species using site-specific weed control methods. In sugar beet, the herbicide saving was lower than in winter cereals but still 36 % of field 4 remained unsprayed against grass-weeds (Table 1).

Table 1. Savings [%] for grass-weed herbicides and broad-leaved weed herbicides in maize, sugar beet, winter wheat and winter barley from 1997 until 2000 using site-specific weed control strategies

		Herbicide savings [%]						
Crop		Field 1	Field 2	Field 3	Field 4	Field 5	Mean	SD
Maize	Dik.*		16	14	5		11	6
	Gr.**		91	65	98	68	81	16
Winter-barley	Dik.	85	41	54			60	23
	Gr.	97	88	92			92	5
Winter-wheat	Dik.	88	71	72	18		62	31
	Gr.	96	100	92	70		89	13
Sugar beet	Dik.	42					42	
	Gr.				36		36	

* Herbicides against broad-leaved weeds, ** Herbicides against grass weeds

Over the four years of study and with the five fields, a significant reduction of herbicide use was achieved when weed control methods were applied site-specifically. Low density weed populations in the unsprayed areas did not cause an increase of weed density at those locations in the following years. These results correspond with those of Niemann (1986) who found that the application of economic weed thresholds did not cause any problems of higher weed competition in the proceeding years. However, patches with *Alopecurus myosuroides*, *Chenopodium album*, *Galium aparine* and *Poa annua* remained stable in location and density even though effective herbicides were applied in every year and is in agreement with the observations reported by Wilson and Brain (1991) and Walter (1996).

The economic benefit of site-specific weed control mostly resulted from a saving of herbicide costs. So far, these savings have not been high enough to compensate for the costs of manual weed mapping and technology for site-specific herbicide application. However, in combination with sensor systems for automatic and real-time weed detection, site-specific weed control has been calculated to be profitable even for medium farm sizes (Kifferle 1999).

Automatic weed identification and real-time patch spraying

Figure 3 shows the application maps for site-specific weed control of grass-weeds in sugar beet and maize in 2001 and for broad-leaved weeds in winter barley in 2000. In all three fields, larger areas remained unsprayed or were treated with a low (60 %) or medium (80 %) herbicide doseage. Only small parts of the field were sprayed with the full herbicide doseage (100 %).

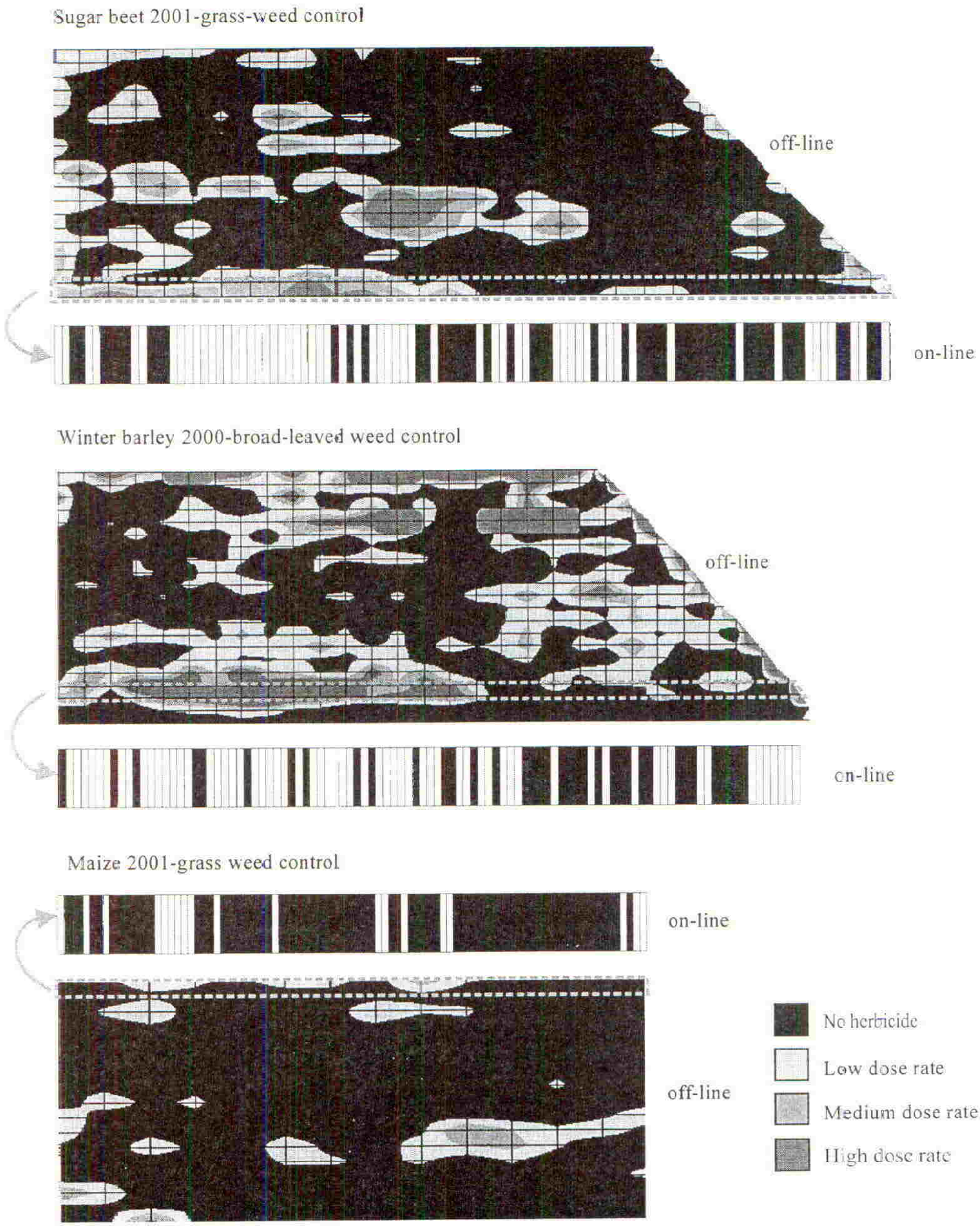

Figure 3. Application maps for site-specific control of grass-weeds and broad-leaved weeds in sugar beet, winter barley and maize; one strip of 15 m was sprayed using a real-time camera system for weed- and crop identification

In one strip of each field (15 m wide) herbicides were applied with a patch sprayer that was controlled by a real-time image analysis system. The imaging system differentiated between weeds and crop and the sprayer was turned on when one or more grass weeds were detected in one image in maize and sugar beet or when more than three broad-leaved weeds were identified in one image in winter-barley. The size of one picture was 0.4 m by 0.4 m. Although the camera system had a much higher resolution than the manually created and interpolated weed maps and the sampling points of both methods were not exactly at the same locations both application maps look similar. Since this was the first attempt for on-line weed control and patch spraying using digital image analysis and plant species discrimination comparisons with other results cannot be made. Earlier investigations under laboratory conditions showed that a discrimination between several weed species is possible even when the weeds were very small (Sökefeld *et al.*, 2000). However, further technical improvements need to be made to overcome the problem of variable illumination conditions in the field and overlapping leaves of different plant species. Currently algorithms have been developed to identify plant species in images with partly occluded leaves (Chapron *et al.*, 1999).

With the described image acquisition system, well focused images with intense contrast between soil and plants were taken at a speed of 7 km/h. However, stones, mulch and reflections of dry soil particles that had a similar size as the plants were not removed from the contour images. These objects were mis-classified as plants. In order to solve this problem, a multispectral imaging system was tested. It was found that the difference of the near-infrared and the blue image (470-510 nm) was most suitable to enhance the contrast between green vegetation and soil and removed reflecting stones and mulch (Figure 2). Similar algorithms with the combination of red and near-infrared and blue, green and red images are described by Chapron *et al.* (1999) and Pérez *et al.* (2000). A dual-band camera is currently constructed that allows real-time acquisition of difference images of two spectral bands.

CONCLUSIONS

Herbicide use was significantly reduced in winter wheat, winter barley, sugar beet and maize when the herbicide sprayer was directed to patches with high weed infestation levels. In order to use this high potential for herbicide reduction, farmers need technologies to automatically detect and map the weed seedling distribution in the field and control the sprayer intermittently. These technologies need to be self-controlling during operation, precise and capable of producing application reports when the work is complete. The results of this study show that automatic weed identification using digital image analysis combined with an on-line patch spraying system has become feasible. However, more tests and adaptations of the image analysis software are needed to improve the weed/crop identification algorithm and to overcome the problem of overlapping leaves and variable illumination conditions.

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The potential of patch weed control in Brazil

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ABSTRACT

Weed control represents a high percentage of the production costs in no-till systems in Brazil, and chemical control using herbicides is by far the most important method used. However, the weeds are not uniformly or randomly distributed but have a patchy distribution such that the broadcast application of herbicides can spray post-emergence herbicides in areas where there are no weeds. Therefore, this work had the objective of demonstrating the potential of saving of herbicides in the no-till production system of the Brazilian agriculture, based on weed seed bank and weed seedling maps. The density of several weeds was mapped using a backpack DGPS and laptop computer. Experiments were conducted in a 17.7 ha field of no-till corn under centre pivot irrigation. Seed bank data was determined from soil cores collected from a depth of 0.05 m in the centre of a 20 m by 20 m grid and emergence assessments in a greenhouse. On the same grid size, weed seedlings were counted in 0.25 m^2 quadrats. Resultant maps showed a high weed density in the seed bank over just 4.67 ha which was only 26% of the field area. The seedling maps demonstrated that grasses and broadleaf weeds had different distributions with broadleaf weeds occupying 12.6% of the field and grasses 87.4%. The targeting of herbicide to weed patches using pre and post emergent herbicides has the potential to reduce herbicide use compared to broadcast application giving both environmental and economic advantages.

INTRODUCTION

Most farmers in Brazil apply production inputs such as fertilisers, herbicides, water and pesticides to their fields based on homogeneity in soil fertility, moisture and weed infestation. However this is often not the case. In many situations these parameters are spatially distributed and may have a spatial dependence that is amenable to analysis using the appropriate geo-statistical tools.

In Brazil, herbicides account for about 25% and 10% of the total input costs for no-till systems for soybean and corn respectively (Agrianual, 2001). This amount of herbicides is already being modified with the development of precision farming tools that have become available in this last 5 years. International machinery companies have used yield mapping techniques in corn and soybean and some types of variable rate technology to apply fertilisers and herbicides. However, more research is needed before such technologies will be widely adopted. This project had the objective of demonstrating the potential for saving herbicides in Brazil based on weed seed bank and weed seedling maps.

MATERIALS AND METHODS

The seed bank and greenhouse emergence studies were conducted at the University of São Paulo - ESALQ campus (22°72`S and 47°61`W) in Piracicaba county with the field study undertaken at the University of São Paulo - FZEA campus (21°46`S and 47°46`W) in Pirassununga county where the predominant soil type is a Typic Hapludox. Both places are located at the Southeast of Sao Paulo state, Brazil. The farm is managed to produce grains for animal nutrition.

The density of several weed seeds and seedlings was mapped using a backpack DGPS and laptop computer with the Field Rover/SST software to collect data in the systematic sampling method. SURFER software was used to construct the weed maps. The whole area was in a 17.7 ha of no-till corn under centre pivot irrigation.

For the seed banks, soil cores were collected to a 0.05 m depth in the centre of a 20 by 20 m grid after harvest corn using a soil probe with 7.5 cm of diameter. Two soil cores were collected to produce one uniform sample of 0.35 kg. For this grid size we had 444 sample points. The soil density used for the calculations of the seed bank was 1.25 g/cm^3 because for three soil measurements at 2 m depth, the density was in a range of 1.2 g/cm^3 to 1.3 g/cm^3. The method used to quantify the weed seed bank was emergence in greenhouse. For this purpose the weed seed bank was counted at 90 days and 100 kg/ha^2 of ammonium nitrate was used to stimulate the weed germination in the last 30 days of the period.

On the same grid size the weed seedlings were counted in a 0.25 m^2 quadrats prior to re-planting corn. The area was managed with the objective to cutoff weed flowering and consequently seed production. After the last cut, weed seedlings were counted to produce weed treatment maps. These maps were used in a desk study to demonstrate the potential of patchy weed control. All the weed density of seedlings and seed bank data were analysed and subjected to exploratory analysis to examine data distribution and to detect the presence of outliers. Before a spatial statistical analysis was conducted, data were $\log_e$ transformed as described previously by Cardina *et al.* (1995). A geo-statistical analysis using the GS + software was used for fitting semi-variograms, and to choose a model that could represent the weed spatial dependence if this could be resolved by this grid size.

RESULTS AND DISCUSSION

Descriptive statistics of the seedlings sample data

The very high infestation was dominated by monocotyledons, mainly by *Panicum maximum* and *Commelina benghalensis*. However, *Panicum maximum* was present in the whole field and the quadrat count would have been very difficult and required a lot of work. A visual assessment was therefore regarded as adequate for the spatial studies and to show the potential of patchy weed control. We used the percentage of soil covered with weed as proposed by Harvey and Wagner (1992) to quantify the weed pressure. The other weeds that were counted in the quadrats and their descriptive statistics are listed in Table 1.

Table 1. Weed seedling data

Species	Mean (plants per quadrat)	Standard deviation	Maximum (plants per quadrat)	Frequency (%)	Infestation (plants.m^{-2})
Commelina benghalensis	3.52	7.67	37	30.18	14.10
Alternanthera tenella	1.43	4.7	30	18.69	5.74
Ageratum conyzoides	0.28	0.8	20	7.20	1.12
Digitaria sanguinalis	0.23	0.48	7	2.25	0.94
Emilia sonchifolia	0.06	0.52	7	1.80	0.24
Brachiaria decumbens	0.04	0.67	10	0.45	0.18
Conyza bonariensis	0.04	0.06	1	0.45	0.18
Chamaesyce hirta	0.01	0.10	1	1.12	0.045
Thythonia speciosa	0.004	0.06	1	0.45	0.018
Acanthospermum hispidum	0.004	0.06	1	0.45	0.018
Ipomoea grandifolia	0.004	0.06	1	0.45	0.018

The seedlings that were counted in the quadrates showed in high patches mainly *Commelina benghalensis, Alternanthera tenella* and *Ageratum conyzoides*, that had the highest infestation level in the time of sampling.

Spatial structure of the seedlings populations

After the exploratory analysis of the seedling data, it was decided to use a simple inverse distance to a power interpolation for the three more abundant weed species because the weeds were found in high density patches at very low frequency. This situation was not good for fit the semivariogram, consequently the kriging method would not have been the best to represent the real weed infestation. Weed density maps constructed by the inverse distance to a power are shown for broadleaf and grass weeds. It is important to know that *Panicum maximum* and *Commelina benghalensis* were the most important weeds to represent the grass class and *Alternanthera tennela* and *Ageratum conyzoides* the broadleaf weeds.

Figure 1. Prescription herbicide maps treatment (A) Grasses, (B) Broadleaf by density count.

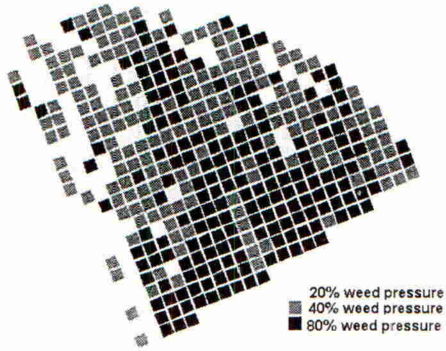

Figure 2. Visual assessment of the distribution of the grass *Panicum maximum*.

The seedling maps demonstrated that grasses and broadleaf seedlings had different sites in the field. In this study the broadleaf weeds occupied 25.7% of the field when a threshold of 4 plants/m^2 was considered. The *Commelina benghalensis* occupied 21.8% of the field when a threshold of 20 grass plant/m^2 was considered. This situation showed the potential to target different types of herbicides to site specific classes of the weeds (grass or broadleaf). The weed cover and pressure is dependent on the threshold level adopted (Table 2).

Table 2. Different threshold level and weed cover of the field for broadleaf and grass weeds (without *Panicum maximum* that was visually evaluated)

	Threshold (seedlings.m^{-2})	Weed cover above threshold (%)
Grasses	**1**	**32.0**
	5	**28.2**
	10	**25.2**
	20	**21.8**
	40	**15.3**
	80	**5.2**
Broadleaves	**1**	**25.7**
	5	**19.8**
	10	**14.9**
	15	**13.3**
	20	**10.8**
	50	**6.3**

The two different classes of weed defined in this experiment could be treated without very sophisticated sprayers that are currently very expensive in Brazil.

Descriptive statistics of the seed bank sample data

All the seed bank data were transformed to seeds/m^2 for an important preliminary analysis but the subsequent spatial analysis was conducted with raw data. Data were $\log_e$ transformed, this procedure is commonly encountered for weed infestation data (Cardina *et al.*, 1995). Almost all the weeds have a log normal distribution. Semivariograms were fitted to these weed data using GS+ software, the semivariograms parameters are listed in Table 4 below. In this grid size of 20 m by 20 m regular grid just these semivariograms could be fitted. Maybe this grid size it is not adequate for these weed seed bank density situation.

Resultant maps using interpolation of inverse distance to a power showed that the total weed seed bank were found in high density patches just in 5.38 ha that was only 30.4% of the whole field using a threshold of 3680 seeds/m^2. The sampling method took 30 min/ha with 3 people, which took approximately 8 h to cover the experimental area.

Based in these two classes treatment maps (grass and broadleaves) the targeting of herbicide to weed seedlings patches using post-emergent herbicides has the potential to led a reduction in herbicide used compared to broadcast application. The same situation is possible when targeting pre-emergent herbicides to weed seed bank considering a threshold level.

The systematic sampling method was time consuming but accurate. The seedling maps change every year because the weed seedling and germination is herbicide and crop (e.g. corn or soybean) dependent. Mapping weed pressure visually may be an important tool to facilitate map generation (e.g. Rew *et al.*, (1996)). Mapping the weed seed bank is more time consuming and needs greenhouse work but these maps have the advantage that they could persist and dispense with mapping every year. The spatial analysis could be better if the experiment had been made for this purpose, maybe a small grid size could be represent the possible spatial dependence of tropical weeds.

Table 3. Statistical characteristics of weed seed bank data

Species	Mean (plants emerged per sample)	Standard deviation	Maximum (plants emerged per sample)	Frequency (%)	Infestation (seeds.m^{-2})
Ageratum conyzoides	5.26	8.58	136	79.72	967.84
Panicum maximum	2.98	4.11	26	64.63	548.32
Phyllanthus niruri	2.17	3.30	36	59.68	399.28
Commelina benghalensis	1.66	2.91	26	48.64	305.44
Alternanthera tenella	0.90	2.48	29	29.27	165.6
Richardia brasiliensis	0.83	1.94	20	37.16	152.72
Leonotis nepetifolia	0.82	2.05	22	33.55	150.88
Gnaphalium spicatum	0.74	1.50	15	35.58	136.16
Digitaria sanguinalis	0.68	1.48	13	31.98	125.12
Chamaesyce hirta	0.27	0.80	7	16.89	49.68
Amaranthus hybridus	0.15	1.07	13	4.72	27.6
Eleusine indica	0.14	0.63	7	8.33	25.76
Ipomoea grandifolia	0.13	0.11	1	1.35	23.92
Nicandra physaloides	0.09	0.50	6	6.08	18.21
Blainvillea rhomboidea	0.08	0.31	3	7.65	14.72
Solanum americanum	0.05	0.30	4	3.60	9.38
Emilia sonchifolia	0.04	0.28	4	4.05	9.01
Bidens pilosa	0.02	0.16	2	2.25	4.41
Cyperus rotundus	0.02	0.17	2	1.57	3.68
Aeschynomene rudis	0.01	0.12	2	0.90	2.02
Sida rombipholia	0.006	0.10	2	0.45	1.10

This weed survey after harvest in no-till crops in Brazil is very important because the subsequently crop or weeds will need to be killed mainly by herbicides to become a good mulch. Normally farmers have two and sometimes three crops per year, for this situation patchy weed control will help to reduce herbicide use with implications for costs and potential environmental damage.

Table 4. Semivariograms parameters of some weed seed banks

Seed bank	Model	Nugget	Sill	Range, m	r^2
Ageratum conyzoides	Exponential	0.1950	0.7080	17.1	0.491
Commelina benghalensis	Exponential	0.2650	0.8574	18.3	0.580
Panicum maximum	Exponential	0.2800	0.8630	27.1	0.669
Plyllanthus niruri	Exponential	0.2790	0.8518	23.5	0.752

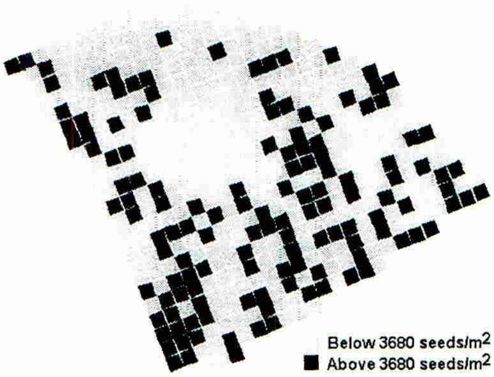

Figure 3. A desk study map of total weed seed bank.

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A map-based system for patch spraying weeds - weed mapping

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ABSTRACT

This paper reports research on the detection of weeds, the first step in the development of spatially selective treatments, using map-based information to control the application of herbicides. The potential of both visual (human) and automatic detection of weeds has been studied. The use of both spectral reflectance and image analysis techniques have not been found to be sufficiently robust to form a basis for weed patch detection in growing cereal crops. It is concluded that for the immediate future spatially selective weed control will need to be based on visual weed mapping. The project has identified at what times of the year it is possible to map important weed species visually and how it can be done from a range of vehicles (tractor, ATV, combine harvester). Alternative methodologies to input the information, using the AGCO Fieldstar touch sensitive screen and voice recognition software, have been explored. Accurate maps of weed distributions have been created which formed the basis of the subsequent spatially selective herbicide application resulting in herbicide reductions of 9-42 %, depending on weed distribution.

INTRODUCTION

The spatial distribution of weeds within fields and the ability to selectively treat them has received increased attention during recent years, and there are now a number of sprayers available which have the potential to apply herbicides at variable rates in a spatially selective way (e.g. Miller *et al.*, 1995; Tian *et al.*, 1999).

The patch treatment of weeds can either use a real-time system, where weeds are detected and sprayed in one pass (Felton, 1995), or a map-based system where a weed distribution map is created for subsequent use in controlling the sprayer (Gerhards *et al.*, 1999; Heisel *et al.*, 1999). A map-based system has been used as this offers the potential for consideration of herbicide choice, the amount needed prior to entering the field, and the ability to include buffers around weed patches prior to treatment (Wheeler *et al.*, 2001). We have targeted weed species that are known to be patchy, controlled with specific rather than general herbicides, and are expensive to treat (i.e. *Avena fatua* (wild-oats), *Alopecurus myosuroides* (black-grass), *Galium aparine* (cleavers), *Cirsium arvense* (creeping thistle), and *Elymus repens* (common couch)).

We have studied the potential for both visual and automated weed detection in narrow row cereal crops. Visual weed detection has taken two forms – grid sampling and continuous recording. Counting weeds on a geo-referenced grid of regularly spaced quadrats is widely used for research purposes (e.g. Gerhards *et al.*, 1997; Häusler *et al.*, 1999; Heisel *et al.*, 1998; Goudy *et al.*, 1999). It provides definitive and quantitative information on weed levels within the field, providing the sampling scale is suitable. However, the time taken to assess each point on a fine grid covering a large area, means that this form of weed mapping is really only suitable for research purposes. Only a relatively small area of the field is sampled in this way, and interpolation methods are needed to estimate the weed cover in unsampled areas. The most commonly used method of interpolation is kriging, though Rew *et al.* (2001) have suggested that this may not be a suitable method for estimating weed densities.

We have used a method to continuously record weed presence/absence by travelling up and down the field on vehicles such as an all terrain vehicle (ATV), tractor or combine harvester fitted with DGPS and a weed recording system, generally following the 'tramlines'.

MATERIALS AND METHODS

Visual weed detection

Two part-fields (1 ha) were marked out on a 5 m x 5 m grid. A 1 m^2 quadrat was positioned at each grid intersection and numbers of the target weeds (*A. myosuroides* and *A. fatua*) occurring within the quadrat were counted several times a year for three years.

Weeds have been mapped whilst driving through the crop at various times of the year on a vehicle fitted with DGPS (ATV in winter / spring, tractor in summer, combine harvester at harvest). Weed presence was recorded in a data file by logging the position using either the AGCO Fieldstar touch sensitive computer screen, or latterly, a notebook computer operating voice recognition software, enabling the operator to speak the name of the weed into a microphone. Weed positional data were stored in a PC for subsequent conversion into a treatment map to control the sprayer (see Wheeler *et al.*, 2001). The width of the area mapped depended on the vehicle used. The ATV was driven at 6 m intervals although the actual area visible to the operator was a strip 1 m wide on either side of the ATV. Mapping from a tractor was restricted to the tramlines, (either 12 m or 24 m), whilst the field of view from the combine was dependent on the width of the header. The areas marked out for grid sampling were also mapped using the continuous sampling method, allowing a comparison between the methods to be made. A number of whole fields have also been mapped using the continuous sampling method. Weed maps were plotted using Surfer (Golden Software, Inc.).

Automated weed detection

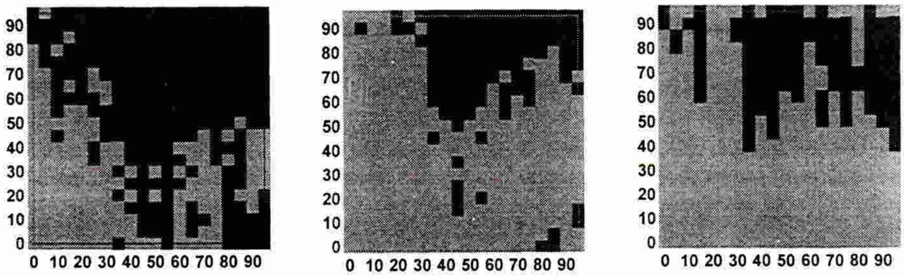
Images were collected using a digital camera mounted both statically and on a tractor with spectral reflectance used as a means to discriminate between crop and weeds. Photographs were taken mainly of *Alopecurus myosuroides* and *Avena fatua* in crops of winter wheat under a range of growing and ambient light conditions. A digital video camera was used for collecting multiple images from which single frames could be extracted for analysis.

RESULTS AND DISCUSSION

Visual weed detection

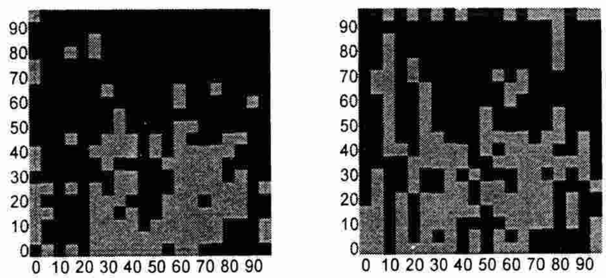
Detailed weed distribution maps have been created using the quadrat grid method to compare with presence/absence continuous mapping. We have found that it is practical to map weeds, recording presence/absence in the crop at different growth stages. Weeds can be mapped by the techniques used at various times of the year. Mapping can be undertaken by a single operator, particularly when using the voice recognition system, and could be combined with another activity whilst travelling the field.

Areas mapped using grid sampling were compared with the same area mapped by continuous sampling methods. Generally maps created from a vehicle were similar to the more detailed maps created using the quadrat grid method. Figure 1 shows an area of a field mapped for *A. myosuroides*. At a quadrat threshold of 5 plants/m^2 there is a correlation of 0.60 between the quadrat grid map (1a) and the ATV map (1c). If the threshold is increased to 20 plants/m^2 (1b), the correlation between the two mapping methods increases to 0.82. From this we conclude that *A. myosuroides* seedlings can be detected using continuous sampling methods at a threshold of 20 plants/m^2. At lower plant densities there is a failure to record all plants. The same field was also mapped for *A. fatua* seedlings (Figure 2). The larger seedlings of *A. fatua* could be seen at a lower density (2 plants/m^2) (correlation between quadrat and ATV map 0.74).



a) b) c)

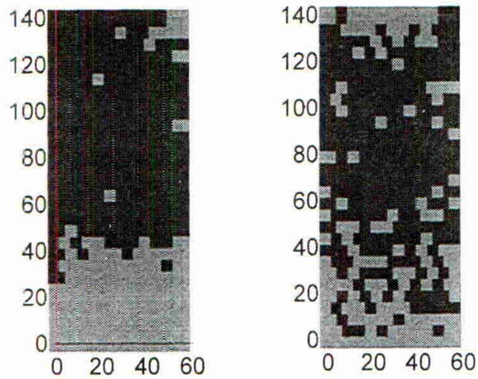
Figure 1. Comparison of *A. myosuroides* distribution mapped with a quadrat on a 5 m x 5 m grid a) threshold 5 plants/m^2 b) threshold 20 plants/m^2 and c) mapped using continuous sampling method from an ATV.



a) b)

Figure 2. Comparison of *A. fatua* distribution mapped with a quadrat on (a) 5 m x 5 m grid - threshold 2 plants/m^2 (b) using continuous sampling method from an ATV.

Care must be taken when mapping weeds, particularly grass weeds from a vehicle. Figure 3 shows two maps of field where the quadrat map (3a) appears to be showing considerable less *A. myosuroides* than the corresponding ATV map (3b). This is because the field also contained a high density of *Poa annua* (annual meadow grass) seedlings, which were not distinguishable from *A. myosuroides* seedlings when travelling across the area on the ATV.



a) b)

Figure 3. Comparison of *A. myosuroides* distribution mapped with (a) quadrat on a 5 m x 5 m grid - threshold 5 plants/m^2 (b) using continuous sampling method from an ATV.

We believe that continuous recording of presence/absence of weeds can provide an acceptable basis for the spatially selective application of herbicides. Although discrete quadrat sampling is the method that has been most widely used for research purposes, it is laborious, and it may not be the most suitable method of mapping for weed management purposes (Rew & Cousens, 2001). They argue that continuous data would be more useful than quadrat counts for site-specific weed management.

Timing of visual weed mapping

By mapping fields for different species at various time of year, using different vehicles, we have been able to produce guidelines as to the most suitable seasons for mapping particular weed species. These recommendations are given in Table 1.

Table 1. Suitability of different weed species to mapping from a vehicle at different times of year

Species	Winter	Early Spring	Summer	Harvest
A. myosuroides	?	yes	yes	no
G. aparine	?	yes	yes	?
A. fatua	?	?	yes	yes
E. repens	no	no	?	yes

Economics of patch spraying

The potential reductions in herbicide usage from patch spraying depend on the density and distribution of the weed population. Fields that have been mapped and treated for several weeds as part of this project have demonstrated that herbicide reductions of 9-42 % were possible, depending on weed distribution. These reductions in herbicide use achieved reductions of £2-£18/ha in herbicide costs (Table 2). However, reductions in herbicide use have to balanced by the costs of mapping. We calculate this as approximately £1.38/ha (assuming operator labour cost of £6/hr). This cost can be discounted over several years as fields do not have to be mapped every year, and can be further reduced if the person mapping is carrying out another farm operation at the time of mapping. The costs of the additional electronic controls and machinery to enable a conventional sprayer to patch spray are difficult to establish because they depend on the level of precision farming equipment the farmer already has. The cost of all the necessary location and control equipment if the farmer had none initially would be in the region of £7000, but this could also be used for other precision farming activities. The added cost of the sprayer with the equipment to patch spray would be in the range £2,000-6,000 over the cost of a standard sprayer.

Table 2. Potential herbicide savings from patch spraying

Weed	% area infested	Herbicide used	% herbicide saved	Cost saving £/ha
Avena fatua	51	Tralkoxydim	27	£10.00
Galium aparine	27	Fluroxypyr	30	£6.00
Alopecurus myosuroides	65	Clodinafop + trifluralin	9	£2.00
Cirsium arvense		Clopyralid	31	£18.00
Elymus repens	27	Glyphosate	42	£8.50

Automated weed detection

Reliable automated detection of weeds in narrow row crops either with reflectance, or from the analysis of digital images, or from a combination of these approaches has proved extremely difficult because of the similarity between crops and weeds (especially grass weeds in cereals), and variability in lighting conditions. This result is in agreement with the findings reviewed by Zwiggelaar (1998). It was particularly noticeable that the apparent colour differences between the weed and crop were a function of lighting conditions and the orientation of the crop/weed. While in-field calibration may be able to accommodate much of the variation in differences in spectral characteristics due to variety and growing conditions, effects due to changes in ambient lighting and crop orientation due, for example, to the effects of the wind, need further study.

There is strong evidence to indicate that variability in overall vegetation (primarily crop) can be detected by reflectance methods (Stafford and Bolam, 1998). Abnormal increases in vegetation levels, especially at the very early stages of growth, can often be due to the presence of weeds. Thus such maps, coupled with limited field walking to confirm that abnormalities are due to weeds, could form the basis of a weed patch map.

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A map-based system for patch spraying weeds – system control

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ABSTRACT

The use of patch spraying approaches based on weed patch detection at an appropriate time to generate a weed patch map that is then transformed into a treatment map has many advantages. The transformation can account for factors such as the characteristics of the detection system used, the dose response of the herbicide/target weed system to be treated and the accuracy of the in-field location system. This paper considers the processes that are involved in the generation of a treatment map and the ways in which these can be effectively developed. For patch spraying to be fully cost effective, weed patch maps need to be able to be used for more than one season with the minimum of up-dating editing. Results from experiments monitoring the stability of patches of *Avena fatua* and *Galium aparine* showed a patch expansion in the direction of harvesting and cultivation of approximately 3 m over three cropping seasons. Data from this experiment compliments existing information for *Alopecurus myosuroides* and provides a sound basis for input to weed patch to treatment map transforms.

INTRODUCTION

Research and commercial developments have successfully shown that substantial savings in herbicide use can be achieved by selectively targeting weed patches (Miller and Paice, 1998). The use of a map-based control system enables weed patch detection to be undertaken at a time when it can be conducted effectively to give relatively accurate maps both in terms of weed species/density and also position, (Perry *et al.*, 2001). The approach also has advantages associated with the selection of both product/formulation and dose rate and this may be via an interface with a decision support system. Defining those materials that are needed for the treatment of a particular field also limits the loading and transport of herbicides on the application system.

The use of a map-based approach requires (Miller and Paice, 1998):

- a method of location within a field, now commonly achieved using differential satellite navigation (DGPS), for both weed patch detection and sprayer control;
- an appropriate method for weed patch detection (e.g. as described by Perry *et al.*, 2001);

- a computer-based platform for both collecting and transforming weed patch information and delivering a treatment map to the application vehicle;

- a method of controlling the application system with a capability of operating over a wide range of dose rates without compromising the physical delivery of the herbicide, (Paice *et al.*, 1996).

Many of these components are now commercially available particularly relating to the application machinery. Methods of detecting and recording weed patch positions are the subject of continuing research (e.g. Perry *et al.*, 2001) but equipment for recording the results of visual assessments is now readily available. Computer programs have been developed that enable spatial data to be input, manipulated and to write out treatment maps in a range of formats using different transfer media to suite the available hardware. We have used one such program, Patchwork, as the basis of our development work to date. The aim of the work that forms the main part of this paper is to define the components of a weed patch to treatment map transform. The platform under which such a transform is undertaken will need to be easy to manage such that data can be safely and effectively manipulated by a non-specialist computer user.

It is likely that for the foreseeable future, patch treatment of weeds will depend on visually created weed maps, so it is important to minimise the frequency of re-mapping to reduce labour costs. The need to re-map will depend on the stability of the patches. Patch stability will also influence the size of buffers which need to be added to weed maps in their conversion to treatment maps.

MATERIALS AND METHODS

Weed patch map to treatment map transforms

The generation of a treatment map involves the following main steps:

(i) the reading into an appropriate software package of the recorded data relating to weed patch positions - species and/or densities;

(ii) the generation of a weed patch map involving an interpolation of the recorded data to define discrete weed patches and the recognition of outlying weeds away from a defined patch - note that results from previous studies have shown that application strategies based on multiple dose levels are more likely to give reliable control over a number of seasons (Paice and Day, 1997; Lutman *et al.*, 1998) and therefore weeds or small weed patches outside of a main patch are likely to be treated with herbicide but at a lower dose than in the main patch;

(iii) the extension of patch boundaries to account for factors such as weed and seed movement in the period between detection and treatment and uncertainties relating to the performance of the in-field location system;

(iv) the definition of treatments to be applied to the extended patch and intermediate areas in terms of:

- the type(s) of formulation and/or tank mix;
- the dose rate;

(v) the writing of the treatment map to the appropriate output media and in an acceptable format.

Commercially available software systems are currently able to undertake steps (i), (ii) and (v) from the above list. A weed patch map generated for *Alopecurus myosuroides* by visually mapping from the combine at harvest and using the Fieldstar terminal to record the observations has been used as an example of the currently available procedures.

Weed patch stability

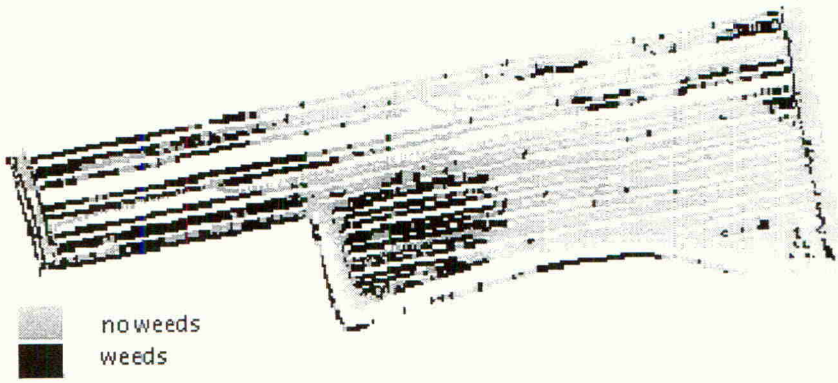
We have been investigating aspects of the stability of patches of *Avena fatua* (wild-oats) and *Galium aparine* (cleavers), to provide evidence to support decision on the frequency of weed re-mapping and the extent of buffer zones that need to be established when converting weed maps to herbicide treatment maps for spatially selective weed control. Patches (3 m x 3 m) of *A. fatua* and *G. aparine* were established in winter wheat crops in 1997 and 1999 respectively. All cultivations and harvesting directions have been kept constant since establishment of the patches. Half of the total number of *A. fatua* patches received an application of clodinafop-propargyl herbicide in spring 2000. Seed production and seed movement has been monitored, together with the shape of the patches, and location of outlying plants.

RESULTS AND DISCUSSION

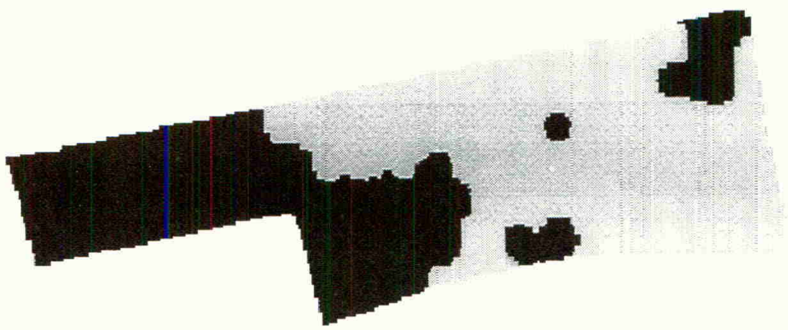
Weed patch map to treatment map transforms

Plots of the recorded weed patch presence/absence, its input into a map-based data management program (Patchwork) as a weed patch map and the output treatment map are shown in Figures 1(a), 1(b) and 1(c) respectively. The raw data plot, Figure 1(a) reproduces the combine track in the field and tags each position as either having weed (black) or no weed (grey). When this is read into the data management package the standard interpolation routine correctly recognises the presence of two main weed patch areas on the left hand side of the map and merges these into a single large weed patch area. Weed patch areas on the right hand side of the map area are less well represented on the interpolated map and there may be scope to adjust the interpolation parameters to improve the fit in this area. Small outlying areas and single weeds have been ignored as expected.

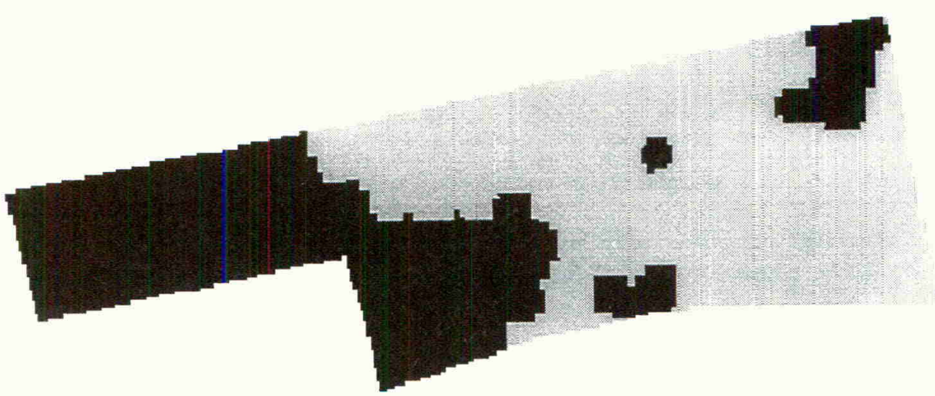
The form of the treatment map closely resembles that of the interpolated weed patch map. This is to be expected since the current packages do not include a specialised weed patch to treatment map algorithm. Work currently in progress is defining methods by which such treatment maps will be generated both in terms of the areas to be treated and the treatments to be applied. Where weed patch mapping is conducted in the season prior to treatment, a buffer zone will be added to account for factors such as weed seed movement and location



(a) Weed patch map as recorded



(b) Weed patch map after initial interpolation



(c) Treatment map

Figure 1. Weed patch map (a) as recorded; (b) when read into a data management package as a weed patch map and (c) as an output treatment map.

errors. There is strong evidence to indicate that the width of such buffers should be greater in the direction of harvesting and cultivation but this leads to additional complexity in the operation of any transform program and may not be justified initially. Weed patch maps are commonly stored in a raster format (Figure 1) whereas the movement of boundaries is more effectively conducted in a vector format. The treatment map generation program is therefore likely to include a raster/vector transform.

The selection of a herbicide or tank mix treatment should consider:

- the dose response characteristics of the herbicide/mixture particularly in relation to the low dose treatment areas;
- the characteristics of the weed patch detection system in terms of threshold densities, reliability and positional accuracy;
- the competitive status of the weed;
- the cost and environmental characteristics of the herbicide/mixture.

Many of these factors may be best included by an appropriate interface with a decision support system.

Weed patch stability

The majority of seeds of both *A. fatua* and *G. aparine* have only moved 1-3 m away from the original patches, though some *A. fatua* seeds have moved up to 30 m away from the source, probably carried by the combine. Patch areas of both species have increased during the course of the study. The front edges of the patches have typically advanced by 3 m in the direction of cultivations and harvesting (Figure 2).

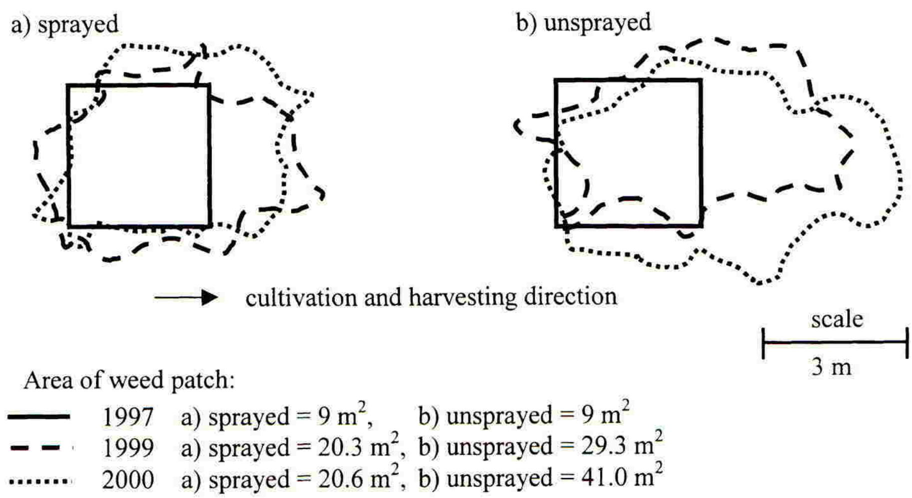


Figure 2. Movement of patches of *Avena fatua* a) treated with clodinafop-propargyl in 2000, b) unsprayed.

The application of clodinafop-propargyl to some of the *A. fatua* patches in 2000 resulted in the patches being held at their 1999 area (Figure 2a), whilst those which were left unsprayed further increased in area (Figure 2b).

Rew *et al.* (1997) recommended that a 4 m buffer strip around the outside of mapped weed patches would be adequate to account for the majority of weed mapping system errors and movement of seeds by agricultural machinery. Our findings for *A. fatua* and *G. aparine* confirm that a 4 m buffer would be suitable for these two species. However, the fact that seeds of *A. fatua* can move up to 30 m from their source means that there is the potential for new patches to form, and *A. fatua* patches are probably relatively unstable compared to patches of *G. aparine*, and would therefore need remapping at more frequent intervals.

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SESSION 10B

HERBICIDES IN THE ENVIRONMENT: EXPOSURE, CONSEQUENCES AND RISK ASSESSMENT – PART 2

Chairman & Session Organisers: D J Arnold
Cambridge Environmental Assessments, Boxworth, UK

and

A Craven
Pesticides Safety Directorate, York, UK

Papers: 10B-1 to 10B-4

Biodiversity, herbicides and non-target plants

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ABSTRACT

Herbicides provide a useful tool for the farmer, grower and vegetation manager. However, they are capable of affecting non-target plants. Non-target plants may be those outside the target area, or those within the target area of conservation concern or whose control has untoward effects on biological diversity. A number of farmland birds, invertebrates and plants have shown population declines in Europe; changes in agriculture, including herbicides, are implicated. Whilst a better understanding of the impacts of weed control on biological diversity is needed, the new challenge is the development of more ecologically sustainable production, incorporating the maintenance of some weed species within crops. The first-generation genetically modified herbicide-tolerant (GMHT) crops seem unlikely to provide the required flexibility of management. For success, greater selectivity of herbicide chemistry is indicated, together with a range of risk avoidance approaches.

INTRODUCTION

Herbicides are an essential part of the farmer and grower's equipment for crop management. In addition, herbicides can play a useful role in vegetation management in a variety of non-crop situations, ranging from industrial areas to amenity sites (Marshall, 1994) and even nature reserves and conservation areas. For example, herbicides may be an essential part of control strategies for alien invasive species, such as giant hogweed (*Heracleum mantegazzianum*). Nevertheless, a range of environmental problems, including residues in water, has focussed attention on the regulatory process and the impact of herbicides in the environment. There have been a number of recent developments in approaches to risk assessment and risk avoidance for non-target effects of herbicides (Breeze *et al.*, 1999). This paper reviews the definition of non-target plants, the use of herbicides and assesses the impacts of herbicides on non-targets and biological diversity. The implications of improved understanding of functional biodiversity and of developments in new technologies are discussed. Finally, a number of requirements for the future approval and use of herbicides are proposed.

DEFINING NON-TARGET PLANTS

The movement of herbicide away from the application area will bring it into contact with plants that are by definition non-targets. This "off-field" movement may be due to droplet drift, vapour movement, leaching and erosion, as well as inappropriate disposal. An extremely wide range of plant species (the national flora) is potentially at risk to such movement. Approaches to risk assessment and risk avoidance in the UK have been reviewed by Marshall *et al.* (2001). Advances in non-target risk assessment have also been made in Europe and North America, aimed at assessing the risks to off-field flora particularly from drift events (Hewitt, 2000).

There are also within-field non-target plants that need consideration. There are two very different scenarios where herbicides are used. In most situations, a herbicide is deployed to control all the plant species present except the single crop species. In the non-crop situation, either all species are targets for total weed control, or there is a single target species and all others present are non-targets. This is a simplification, as herbicide selectivities vary and the target group necessarily may be wider. Likewise, within a crop, there may be a number of unsown plant species present forming a weed assemblage. As many of these species reduce yield, or affect harvesting, storage or crop quality, farmers regard them all as weeds worthy of removal. Nevertheless, amongst these non-crop species, there may be both target and non-target species for weed control. A number of rare weed species, such as broad-leaved cudweed (*Filago pyramidata*), are subject to conservation effort and some are included within UK Biodiversity Action Plans (BAPs), the response to the Rio Convention on Biological Diversity (Anon, 1994). These may be regarded as non-target species. Of greater significance, as they are commoner and often have significant biomass there is a suite of species that might be targets at higher density, but may be non-targets at low population levels for biodiversity reasons. There are a number of species that are almost invariably targets for control, usually because of their competitive ability, such as wild-oat (*Avena fatua*). The consideration of non-target species within the application area brings a number of potential complications to the regulatory process and to practical management. However, against the environmental background of significant declines in farmland wildlife across Western Europe, this is a challenge to be faced.

HERBICIDE IMPACTS AND NON-TARGET EFFECTS

Agricultural and horticultural habitats do not occur in isolation in the landscape. Field systems occur as mosaics of crop and non-crop habitat (Marshall, 1988) and may be refuges for many plant and animal species. Whilst most species associated with non-crop areas do not commonly pose serious threats to adjacent crops (Marshall, 1989), these areas may be important for the conservation of biological diversity in agricultural landscapes, particularly as production methods have intensified. Extensive studies of land use change and their ecological consequences also indicate that botanical diversity is continuing to decline (Haines-Young *et al.*, 2000). Whilst the causal effects are not agreed, they are most likely to be eutrophication and disturbance. Agricultural practices, including fertiliser and herbicide applications, are implicated (Kleijn & Snoeijing, 1997).

Within agricultural systems, there have been significant declines in both population sizes and ranges of common birds in the UK (Fuller *et al.*, 1995). Likewise, there have been significant declines in some taxa of invertebrates found within fields (Aebischer, 1991). The idea that arable fields are "ecological deserts" is ill founded, as there is a range of plant and animal species specifically adapted to the habitat, for example the cornfield flowers.

Individual plant species can be affected directly by a herbicide. As part of a plant community made up of many species, a plant species can also be affected indirectly following herbicide contamination. This can be mediated by competition between species, or by affecting plant recruitment (vegetative or from seed), or by affecting herbivore pressure or symbionts. Determining the effects of herbicides on plant communities is not straightforward (Cousens *et al.*, 1988). Susceptibility of plants to herbicides is not a constant characteristic, as application variables interact with plant variables.

Non-target effects of herbicides may be caused when materials reach situations beyond the target application area and/or reach species not intended to be affected growing within the target area. The direct adverse effects of herbicides can range from outright death of a plant or population, through minor effects, to enhanced growth. The spectrum of direct effects on individuals is matched by a spectrum of indirect effects on associated fauna and flora. Direct effects on plants can appear to be insignificant, for example, reduced flowering. However, such impacts may be of major significance to species where seed production is the key element of the regenerative cycle of the plant. Effects on germination and early recruitment of plant species are believed to be of particular importance at a growth stage that is particularly susceptible to pesticides. Non-target effects may have subtle effects on plant community composition, mediated by plant competition or by effects on the water and chemical environment in the rhizosphere.

It is unclear how important the non-target effects of herbicides are. For example, it is unknown if repeated drift events, or mixtures of herbicides at low doses, can have sub lethal effects on plant recruitment. The "off-field" movements from herbicide application are likely to be the most common cause of non-target effects (Breeze *et al.*, 1999). These can result from droplet drift, mist, solid and vapour movement. Of these drift forms, droplet movement is by far the most important and common form. Following application, pesticides may also undergo secondary redistribution with a risk of non-target effects, if pesticide concentrations are high enough.

BIODIVERSITY AND ECOSYSTEM FUNCTION

The reasons for the conservation of biodiversity are moral, aesthetic, social and economic. We steward other organisms for their intrinsic value and because species may be of benefit to human society and have economic value. A culture that encourages respect for wildlife is preferable to one that does not. Biodiversity can be easily lost but is difficult to regain, particularly if species are driven to extinction. Biodiversity, including genetic diversity, may provide economic benefits. Even at the level of landscape, biodiversity may influence tourism and sense of place. Perhaps of greatest concern is that biodiversity has a role in the function of ecosystems (Tilman *et al.*, 1996). Erosion of diversity may thus ultimately result in damage to ecosystem function.

Plants are key components of terrestrial ecosystems, providing the primary production upon which food chains are built. Different plant parts provide a range of resources for associated fauna (Figure. 1). Leaves and stems may be browsed, while pollen and nectar provide resources for pollinating insects. Fruits and seeds are important food for a large number of organisms. Plants have other functions as well as providing food for herbivores. They provide cover, reproduction sites and structure within habitats. Plants also form a substrate for bacteria, fungi etc., both above ground and in the soil.

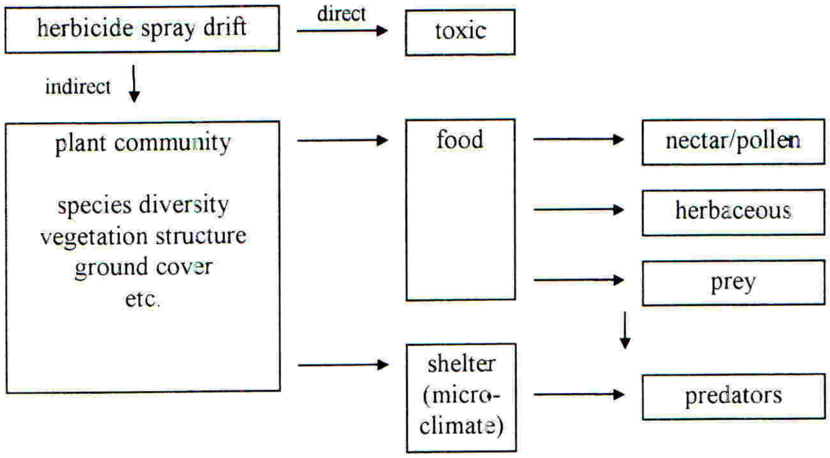

Figure 1. Potential ecological effects of herbicide spray drift on invertebrates – from Breeze *et al.*, (1999)

Even non-crop plants or weeds may play a role in the function of the ecosystem and in supporting many other species. As an example, the grey partridge (*Perdix perdix*) requires insects as chick food during the first ten weeks of rearing. Many of these insects are associated with annual dicotyledonous weeds in cereal crops in the UK. Adult partridges also feed on plants, particularly within arable crops. Management of the crop with pesticides and herbicides is therefore likely to have had a major impact on partridge populations, explaining the major declines in population of this bird species in the twentieth century (Potts, 1991).

Interactions between weed diversity and biodiversity

A comparison of herbicide-treated and untreated plots in the headlands of winter cereal fields in southern England (Moreby & Southway, 1999) has clearly demonstrated that untreated plots had greater weed density and diversity and significantly higher numbers of many invertebrate taxa, notably those that are important in the diet of farmland birds. Studies of the insects associated with soybean in Iowa, USA, indicate that weedier fields have generally higher insect densities. Weed management in herbicide-resistant soybean generally gave fewer insects (Buckelew *et al.*, 2000). The effects were indirect, mediated through the weed flora. Several initiatives, notably for integrated crop management, indicate there are implications for biological diversity within fields from different approaches to weed control. The protection of the farmers' investment and avoidance of risk have been the driving forces for efficient weed control in the past. However, an emerging new paradigm is to match crop production with conservation of biological resources (Paoletti *et al.*, 1992) and the development of more sustainable systems. This may require the maintenance of some weeds within fields.

NEW TECHNOLOGIES FOR WEED MANAGEMENT

Genetically modified herbicide-tolerant (GMHT) crops

The introduction and testing of GMHT crops, whilst widely accepted in North America, has been opposed by many interest groups in Europe. Current work on the field-scale evaluation of the biodiversity impacts of these crops in the UK is examining the likely impact of modified herbicide use within the crop (Firbank *et al.*, 1999). The first generation of GMHT crops are engineered for tolerance to broad-spectrum herbicides, notably glyphosate and glufosinate. These *may* allow greater flexibility in weed management, but there may be effects on biodiversity as a result.

Watkinson *et al.* (2000) simulated the effects of the introduction of GMHT crops on weed populations and the consequences for seed-eating birds, using fat-hen as the model weed. They predicted that weed populations might be reduced to low levels or practically eradicated, depending on the exact form of management. Consequent effects on the local use of fields by birds might be severe, because such reductions represent a major loss of food resources. Buckelew *et al.* (2000) have shown that herbicide-resistant soybean crops tend to have lower insect population densities, associated with fewer weeds.

Whilst it may be argued that GMHT crops offer the opportunity to delay weed control, some crops, most notably maize, are particularly susceptible to early weed competition. Such crops are likely to be treated with herbicide around the time of crop emergence to eliminate weeds early in the life of the crop. The technology offers reduced risk to the farmer, with opportunities for repeated application, should this become necessary. Environmentally, the technology offers the possibility of clean crops and thus adverse biodiversity effects, as well as the unknown, if low, possibility of gene transfer to wild relatives. Nevertheless, it must be accepted that in the developing world, where weeds are the primary source of crop loss, this first-generation technology may have an important role.

Integrated weed management

Approaches to weed management over recent years have taken an holistic view of the crop rotation as a whole, rather than simply in single crops, as part of integrated crop management (ICM). ICM considers fertiliser use, targeted pesticide use, alternative control techniques, forecasting and modelling, as well as crop rotation (Jordan & Hutcheon, 1995). Economic pressures have also forced farmers and growers to consider the number of herbicide applications made and the dose of active ingredients used. Reduced dose applications have become common. Within ICM, the manipulation of crop architecture, tillage regimes, mechanical weed control, allelopathy, mulching, biological control may all contribute to "integrated weed management".

However, "*devising integrated weed management strategies that address a diversity of weed species with a diversity of life history traits is difficult*" (Mortensen *et al.*, 2000). A sound understanding of species, population and community ecology can contribute to weed management. Advances include population equilibria, density-dependent effects, crop competition models and integration with herbicide dose-response studies.

RISK MANAGEMENT

Risk management needs to address herbicide susceptibility and exposure. Exposure can be most easily manipulated, though susceptibility may be influenced, for example by protectants. The key to risk avoidance must be in targeting only those plant species or populations that require control. This means that precision in chemistry, *i.e.* selectivity of herbicide, and precision of application, *i.e.* only to the target plants, offers the most robust way forward. Aspects of dose, formulation, application timing and application technology may be usefully modified within a sound weed forecasting and decision-support framework. There may nevertheless be opportunities for spatial approaches to biodiversity maintenance. For example, conservation headlands, in which limited pesticide applications are made to the outside 6m or 12m of crop, allow sufficient weeds and invertebrates to survive for grey partridge populations to switch from decline to increase (Rands & Sotherton, 1987).

NEW DIRECTIONS FOR HERBICIDE USE AND WEED BIODIVERSITY

Ecologically, there is a requirement for greater specificity of herbicide action for minimising environmental and non-target effects. This runs against the trend for more broad-spectrum products produced by manufacturers. In order to cover the high costs of product development, manufacturers require products that will sell into global markets. This has resulted in herbicides with wide weed spectra coming to market, with more selective products rarely being commercialised. Greater herbicide selectivity is not without practical and financial difficulties. The inertia of commercial development could only be mobilised by legislative and regulatory requirements, possibly backed up by redirected farm support to growers. In addition, there could be difficulties if there are insufficient product options, e.g. herbicide resistance. Nevertheless, there could be opportunities for specialist market development, if agricultural support is redirected from production to environmental support. Non-crop vegetation management could provide a diversity of niche markets.

Clearly, where selectivity in chemistry is limited, there are opportunities for achieving selectivity by exploiting application technology and spatial methods, as well as manipulating crop phenology and growth characteristics. Further work on the opportunities for arable biodiversity areas, such as conservation headlands, is required.

Under the regulatory regimes for pesticides, there is a need to consider non-target, indirect effects that occur within the target crop area. This will require testing on a wider range of plant species representative of the diverse flora of arable and horticultural fields

Current integrated weed management programmes might be further developed and modified to maintain adequate populations of the most important weed species for biodiversity, while controlling the most damaging. There is some possibility of relaxing weed control either rotationally or in limited areas of fields. Nevertheless, the major constraint is that the most fecund and often the most competitive weed species respond best to reduced control. Therefore, relaxed weed control would need to be managed carefully to allow the less common and less competitive species to increase, while controlling the competitive species. This may indicate a new approach to weed management, with the explicit aim of maintaining specific weed assemblages. These might be more traditional assemblages that were common 100 years ago, or tailored to maintaining beneficial invertebrate species, or for biodiversity more generally. An understanding of the selection pressures applied by management, including the use of herbicides, and their effects on diversity, ranging from genetic to community levels, is needed.

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Terrestrial non-target plant testing and assessment; the conservative nature of the process

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ABSTRACT

Terrestrial non-target plant testing and assessment is an emerging topic in Europe, as it was not previously discussed under the framework of Directive 91/414/EEC in the European Union. Test methods and assessment techniques are under development and an evaluation of the conservative nature of the study design, the exposure assessment and the safety goals need to be carefully considered before implementation. Non-target plants are defined as plants outside of the agricultural unit (i.e., the treatment area, plus a defined area around the treatment area used for agriculture). For non-herbicides, safety can generally be addressed using data generated from plant safety screens and efficacy work done during the development of the product. For herbicides, draft OECD regulatory test methods exist for both soil and foliar exposure assessments. The draft test methods use a suite of domesticated species to indicate the range of response (e.g., two to three orders of magnitude in range, typically) which may be expected for other species not included in the test. This approach makes use of readily available species with well-defined growth characteristics that allow determination of reliable metrics (e.g., visual effects and biomass), and end-points (e.g., EC_{50}). Because the end-points are based on sub-lethal effects and not lethality, and the study design is biased towards a "worst-case" scenario, the approach provides a very conservative estimate of phytotoxicity. These data combined with a conservative estimate of exposure, allow for a very conservative estimate of risk to non-target plants.

INTRODUCTION

Several activities have been ongoing on both the international and national level to address safety to non-target plants. On a national level, Germany has recently included non-target plant risk assessments as part of their National requirements (Füll *et al.*, 1999). And, the European Commission has suggested the addition of terrestrial plant data as part of the dossier package for all crop protection products (CPPs) in their recent Guidance on Terrestrial Ecotoxicology (European Commission, 08.07.2000).

In the area of testing, the Organization for Economic Cooperation and Development (OECD) has been working to revise Technical Guideline 208, for the testing of Terrestrial Plants, Growth Test. The main purpose of the revision is to modify the current guideline to allow for the testing of crop protection products (CPPs) (OECD, 2000).

The European and Mediterranean Plant Protection Organization (EPPO) has developed a proposed risk assessment scheme using the data generated in evaluating product phytotoxicity leading to an estimate of potential risk (EPPO, 2000).

Exposure is predicted using the drift data described by Ganzelmeier *et al.*, (1995).

The purpose of this paper is:

- to briefly review several of these on-going activities,
- to identify those factors in the current glasshouse/laboratory test design which contribute the highest levels of conservatism to the evaluation of plant safety,
- to quantify what contribution each factor may contribute to the conservative nature of the assessment and uncertainty in a determination of the level of safety afforded non-target plants and,
- to demonstrate that current tests are performed in a conservative fashion, such that in combination with a conservative estimate of exposure a very conservative estimate of risk to non-target plants (NTPs) is attained.
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BRIEF REVIEW OF TERRESTRIAL NON-TARGET PLANT TEST METHODS

For non-herbicides, data available from screening and efficacy studies generated by companies to address plant safety are being used to address product safety. Additionally, under Annex III, Section 6.6.1 through 6.6.3 of 91/414/EEC, data are generated to address safety to crops and the subsequent rotational crops for which a product is intended (EU Commission, 27 July 1993). This approach has been used successfully for insecticides and fungicides in general, and for herbicides to address in-field plant safety.

In screening studies, plants are sprayed at the maximum application rate of the product at plant growth stages typical of product use and assessed for visual injury. Since different companies may use different techniques and different rating systems to develop these data, the OECD has proposed guidance (OECD, 2000; Annex III) on what information should be supplied by the registrant and how the data can be normalized to provide uniformity in the hazard assessment.

For herbicides, two regulatory methods are being proposed to assess effects (OECD, 2000). One method assesses effects to seedlings via exposure through the soil, while the other assesses effects to young plants (two to four leave stage) via exposure through the foliage. In most cases, exposure via the foliage produces higher sensitivity, and for regulatory purposes, these data, rather than soil exposure data and seedling emergence, have been primarily used in Germany. There may be exceptions to this general rule, and in cases where the product may show pre-emergence soil activity, tests using soil exposure and seedling emergence may be conducted preferentially.

The test duration is between 14 and 21 days, depending upon the species and growth of the control group. Six species, 2 monocotyledon and 4 dicotyledon species, from the list of species shown in Table 1 (OECD, 2000) are used. The species used in these tests are intended to provide a range of response, similar to other ecotoxicological tests and not to act as taxonomic surrogates. Therefore, several species that are known to be sensitive to the herbicide are tested, as well as a tolerant species. In this fashion, inter-species response may vary as much as a factor of 1000-fold plus, from the most sensitive to the most tolerant species tested.

At the end of the test, the plants are assessed for visual injury (e.g., chlorosis, leaf curling, shoot height, etc.) and biomass (fresh or dry weight). Since a plant species is tested at several concentrations, an EC_{50} and/or EC_{25} are determined. The most sensitive species end-point is then used for the safety assessment.

Table 1. List of species recommended for use in plant tests

Family	Species	Common names
DICOTYLEDONAE		
Chenopodiaceae	*Beta vulgaris*	Sugar beet
Compositae (Asteraceae)	*Lactuca sativa*	Lettuce
Cruciferae (Brassicaceae)	*Brassica alba*	Mustard
Cruciferae (Brassicaceae)	*Brassica campestris* var. *chinensis*	Chinese cabbage
Cruciferae (Brassicaceae)	*Brassica napus*	Oilseed rape
Cruciferae (Brassicaceae)	*Brassica oleracea*	Cabbage
Cruciferae (Brassicaceae)	*Brassica rapa*	Turnip
Cruciferae (Brassicaceae)	*Lepidium sativum*	Garden cress
Cruciferae (Brassicaceae)	*Raphanus sativus*	Radish
Cucurbitaceae	*Cucumis sativa*	Cucumber
Leguminosae (Fabaceae)	*Glycine max (G. soja)*	Soybean
Leguminosae (Fabaceae)	*Phaseolus aureus*	Mung bean
Leguminosae (Fabaceae)	*Pisum sativum*	Pea
Leguminosae (Fabaceae)	*Trifolium ornithopodioides*	Fenugreek/Birdsfoot trefoil
Leguminosae (Fabaceae)	*Trifolium pratense*	Red Clover
Leguminosae (Fabaceae)	*Vicia sativa*	Vetch
Solanaceae	*Lycopersicon esculentum*	Tomato
Umbelliferae (Apiaceae)	*Daucus carota*	Carrot
MONOCOTYLEDONAE		
Gramineae (Poaceae)	*Avena sativa*	Oats
Gramineae (Poaceae)	*Hordeum vulgare*	Barley
Gramineae (Poaceae)	*Lolium perenne*	Perennial ryegrass
Gramineae (Poaceae)	*Oryza sativa*	Rice
Gramineae (Poaceae)	*Secale cereale*	Rye
Gramineae (Poaceae)	*Secale viridis*	Rye
Gramineae (Poaceae)	*Sorghum bicolor*	Grain sorghum
Gramineae (Poaceae)	*Sorghum vulgare*	Shattercane
Gramineae (Poaceae)	*Triticum aestivum*	Wheat
Gramineae (Poaceae)	*Zea mays*	Corn
Liliaceae (Amarylladaceae)	*Allium cepa*	Onion

THE CONSERVATIVE NATURE OF TERRESTRIAL NON-TARGET PLANT EFFECTS TESTING

Key in any assessment, is the reliability of the data and the uncertainty which may exist in extrapolating laboratory data to the environment. In conducting non-target plant tests in the glasshouse/laboratory, there are numerous factors that make this test very conservative in nature and subsequently the assessment as well. The factors to consider and the contribution each factor may contribute to an overly conservative estimation of effects in the environment are as follows (GCPF NTP Work Group, 2001) and are summarized in Table 3. Overall, a 100 to 6000 over estimate of effects is expected based on current test methods.

Exposure (spray drift versus drench application)

Non-target plant testing is conducted to assess the safety of crop protection products (CPP) to plants growing outside the agricultural unit (*i.e.*, the treatment area, plus some small area around the field (EPPO, 2000). However, there is a significant discrepancy between the exposure used in the glasshouse test and potential exposure in the real world via spray drift. In the glasshouse study, plants are treated using some form of sprayer that normally simulates overhead hydraulic spraying as provided by a field tractor spray and utilises normal application spray volumes – approximately 200 L/ha.

Although a range of active ingredient dose rates is tested, no variation in spray volume is used. For example, if the predicted spray drift in the field for ground applications were estimated to be 1% of the application rate, a predicted spray drift of 2L/ha would be expected. It is possible therefore that the greenhouse testing procedure provides for a worse case situation whereby the use of higher spray volumes in the glasshouse results in better spray coverage and therefore an overestimate of activity which may be due to drift. Limited data (GCPF NTP Work Group, 2001) indicate that by using reduced volumes to simulate drift injury can be over estimated using standard high volume techniques by a factor of 2 to 10. More research is needed to develop an understanding of the relationship between plant response from high volume exposures versus drift exposures.

Comparison of lethal and non-lethal effects

While the EC_{25} or EC_{50} may be used to assess plant safety, a 50 or 25% effect does not mean that plant survival will be impacted. Using available regulatory data, a determination of the ratios between an EC_{25}, EC_{50} and EC_{80} was made. The slope was determined and an estimated treatment rate necessary to produce mortality (e.g., LC_{50}) versus a transient effect (EC_{50}) (GCPF NTP Work Group, 2001). This comparison was made for both seedling emergence studies and vegetative vigour studies (Table 2) indicating that the EC_{80}/EC_{25} ratio is between 10 and 20. The EC_{80}/EC_{50} ratio as well as the EC_{50}/EC_{25} ratio for these endpoints is about 3.

These results indicate that if the EC_{80} is representative of a lethal effect, the safety provided between a regulatory evaluation end-point (e.g., EC_{50}) and the lethal effect level can be as large as a factor of 10 to 20.

Table 2. Comparison of EC_{25}, EC_{50} and EC_{80} (lethality estimate) for several products

Seedling Emergence

Endpoint	EC_{80}/EC_{25}	No. of Chem.	EC_{80}/EC_{50}	No. of Chem.	EC_{50}/EC_{25}	No. of Chem.
Survival	31	2	2.2	2	9.9	3
Visual	9.9	4	3.2	4	2.5	4
Emergence	3.9	1	2.1	1	1.9	1
Plant Ht	24	13	5.4	14	3.3	15
Plant Wt	12	14	3.2	14	3.1	14
Mean	16.2		3.2		4.1	

Table 2. Continued

Vegetative Vigour

Endpoint	EC_{80}/EC_{25}		EC_{80}/EC_{50}		EC_{50}/EC_{25}	
Survival	4.6	6	2.2	6	2.1	6
Visual	8	6	2.9	6	2.3	6
Emergence						
Plant Ht	10	18	3.2	18	2.7	18
Plant Wt	9.6	23	3	23	2.7	23
Mean	8.1		2.8		2.5	

Effect of soil pasteurization on non-target plant test results

Soil Pasteurization is sometimes used by researchers, *in lieu* of fungicide seed treatments, to reduce the potential for soil- or water-borne pathogens to cause bacterial, fungal or viral infections of plant seedlings resulting in either mortality or damping-off effects of the test plants. While this may have less of an effect on the results of a vegetative vigour study where test material exposure to the plant is through the foliage, it can have significant effects on plant responses observed in the soil emergence study.

For those test materials which are degraded primarily by microbial or extra-cellular enzyme degradation mechanisms, the observed plant responses can be overly conservative, especially if plant exposure at a given soil concentration must be prolonged to produce the observed effect. Therefore, using un-Pasteurized soil could reduce the level of effect by a factor that is related to the rate of product bio-degradation, but a fungicide may be required to prevent pathogenic effects.

Greenhouse versus field effects

Various studies have shown that greenhouse-grown plants are more susceptible to herbicide injury than plants grown in the field, i.e., a higher application rate is required to cause injury to field grown plants (Fletcher, *et al.*, 1990; De Ruiter *et al.*, 1994; GCPF NTP Work Group 2001). The difference in susceptibility has been attributed to physical and metabolic differences between plants raised in the greenhouse and field, differences in dissipation/degradation characteristics of the product in greenhouse versus field conditions, plant age and structure, cuticle thickness, and other factors. Based on these studies an over estimate can range from 2 to 30 fold (GCPF NTP Work Group, 2001).

Decreasing sensitivity to herbicides based on increasing plant age/size

Regulatory testing requires the use of an early plant growth stage. This, in part, is because smaller plants allow for uniform coverage of the test plants with the spray solution, provide reproducible plant growth stages, allow for rapid production of plants for testing, test a growth stage sensitive to the CPPs and represent the worst-case condition (Brandt, 2000). Several studies (Klingaman *et al.*, 1992; Blackshaw, 1991; Wicks *et al.*, 1997; Rosales-Robles *et al.*, 1999) have shown that differences in plant age compared to very early growth stages can account for a 3- to 5-fold higher sensitivity in younger plants.

Table 3. Summary of factors contributing to the conservative nature of non-target plant tests

Test component	Factor
Exposure (drench in test versus drift in field)	Sophisticated tests to evaluate this are limited, but early indications suggest that a study performed using drift type exposure (patchy exposure of mainly the upper plant parts) exhibits half the level of effect as a study where there is thorough coverage of the complete plant. A factor of 2 or more.
Non-lethal (EC_{25}) versus lethal (EC_{80}) end-point	In going from an EC_{25} to an EC_{80}, an 8- (mean for vegetative vigour tests) to 16-(mean of seedling emergence tests) fold higher rate is needed. However, an EC_{80} is not equivalent to a lethal dose. It's justified to suppose a factor of 10 to 20 for the difference between the observed non-lethal endpoint and a lethal endpoint as used for all other groups of organisms in basic risk assessments for ecotox.
Greenhouse versus field	Between 3- and 30-fold, in order for the same level of effect shown in the greenhouse to be observed in the field.
Plant age	Between 3- and 5-fold less sensitive at later plant growth stages.
Total range of factors	180 to 6000

Inter-species differences

It is generally assumed that an uncertainty factor must be attached in any assessment due to differences in species and the question of whether on not the most sensitive species has been tested. However, based on a review of 11 herbicides, representing 9 different chemistries and 8 modes of action, it was demonstrated that use of the most sensitive crop species from regulatory tests provides an adequate margin of protection for all of the other non-crop species tested with that herbicide (McKelvey, *et al.*, 2001).

As such, the regulatory tests conducted using crop species provides an indication of the range of response that could occur in the field on non-target species. Additionally, using the current approach suggests that an uncertainty factor of 1 can be used to provide an adequate level of protection in performing a risk assessment. A typical case for one product for both pre-emergence and post-emergence tests is shown in Figures 1 and 2.

EXPOSURE

Risk is a function of both hazard and exposure and the more important component of risk assessment is exposure assessment as it can be modified by changes in how the product is used.

Any risk assessment proposal needs to focus on the exposure assessment. For terrestrial plants, there is no currently accepted EU method of exposure estimation, however, the EPPO risk assessment (EPPO, 2001) proposes to use the data generated by Ganzelmeier *et al* (1995) or the data by Rautman (2000) which takes into account drift reduction technology.

As mentioned earlier, consideration of the type of foliar exposure used in the laboratory versus the type of exposure that a plant may encounter (i.e., drift) needs to be considered in higher tiers of a risk assessment. Additionally, it needs to be considered that every application will not necessarily drift off-target and interception by the three dimensional nature of plants will diminish the amount of CPP potentially drifting much faster with distance than is predicted by the Ganzelmeier or Rautman exposure tables. These factors will add to the conservatism of the risk assessment.

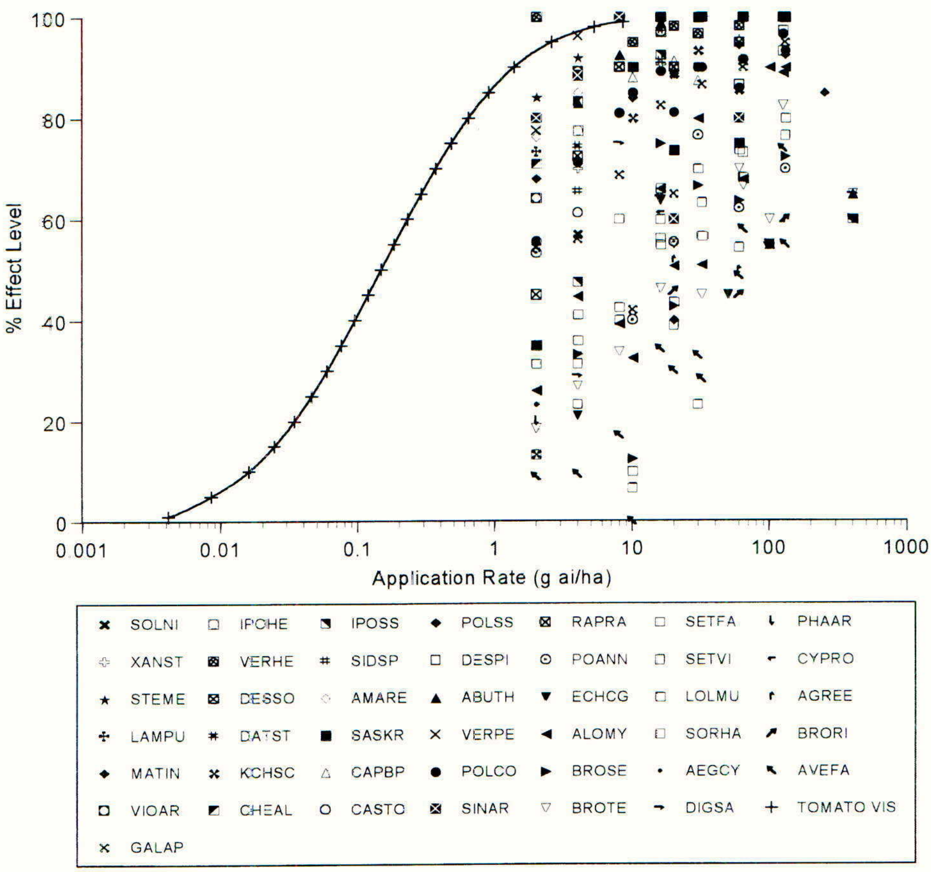

Figure 1. Pre-emergence data comparison for a sulfonylurea herbicide between the response for the most sensitive regulatory species (line) and several non-domesticated plant species (symbols)

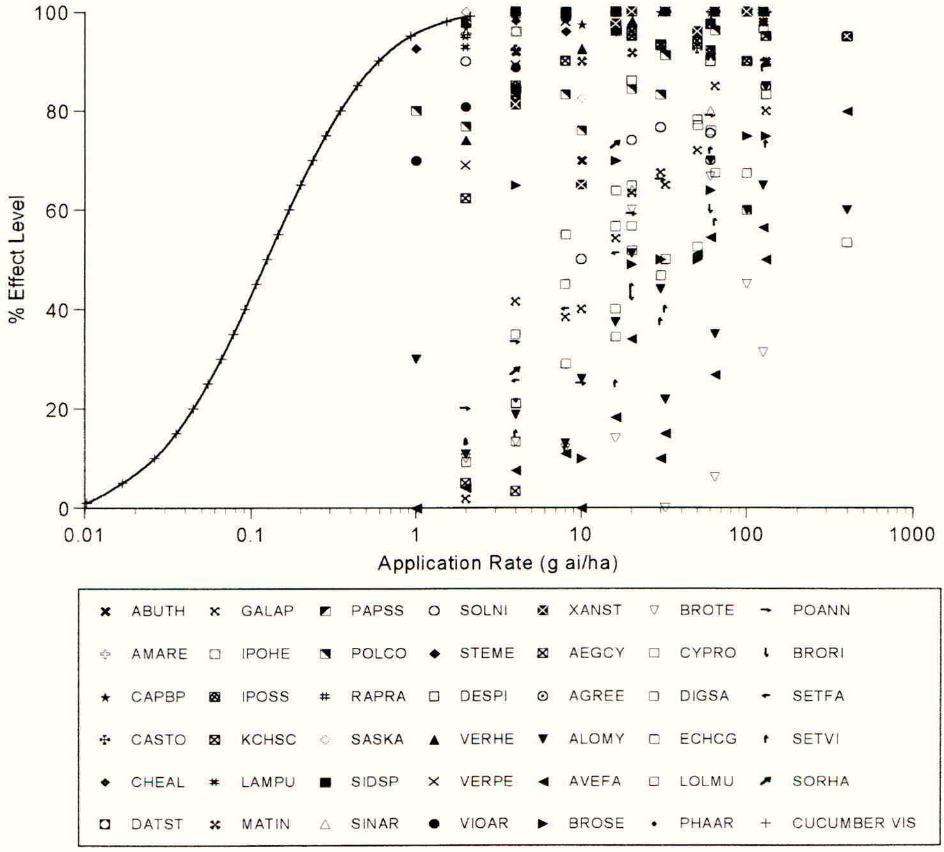

Figure 2. Post-emergence data comparison for a sulfonylurea herbicide between the response for the most sensitive regulatory species (line) and several non-domesticated plant species (symbols)

CONCLUSIONS

Proposed terrestrial non-target plant tests are designed to be conservative in nature, and it is estimated that the effects observed in laboratory tests versus the field will be overly conservative by a factor of 100 to 6000 depending upon the product. A comparison of sensitivities for several typical domesticated species used for proposed regulatory tests to non-domesticated species indicates that the most sensitive regulatory species from those tests is as sensitive as any of the non-domesticated species tested. This comparison plus the conservative test design and the assumptions used in the exposure assessment suggests that an uncertainty factor of one or less should provide adequate protection to non-target plants.

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Recent developments in non-target terrestrial plant test protocols and risk assessment.

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ABSTRACT

The main points of the draft revised OECD 208 Terrestrial (Non–target) Plant Test and the draft EPPO Decision-Making Scheme for Non-target Plants are discussed. The current approach to non-target plant risk assessments is outlined. Some outstanding areas of concern are identified. The potential need to consider indirect effects arising from the removal of plants from the agro-ecosystem and of the 'in-crop' effects is highlighted. Ongoing research to better establish the level of concern is discussed.

INTRODUCTION

Within the EU the risk to the main areas of wildlife from the commercial use of plant protection products (hereafter referred to as pesticides) is assessed under Directive 91/414/EEC. For non-target plants, Section 8.6, Annex II of the Directive lays down the following requirement for applicants:

"A summary of the available data from preliminary tests used to assess the biological activity and dose range finding, whether positive or negative, which may provide information with respect to possible impacts on other non-target species, both flora and fauna, must be provided, together with a critical assessment as to its relevance to potential impact on non-target species."

Due to the variation in the methods used in preliminary plant toxicity testing and the lack of a clear reason as to why they should be done, risk assessments for flora have lacked the detailed consideration given to other areas. Within the EU the term 'flora' is generally interpreted as meaning terrestrial non-crop species (either mono- or di-cotyledons). For pesticides the risks to crop plants and aquatic plants are considered separately in the EU and are excluded from further consideration in this paper.

Within the UK there is increasing concern over the possibility of indirect effects arising from the removal of non-crop plant species from arable areas (i.e. Campbell *et al.* 1997), and over the wider issue of biodiversity and sustainability of modern agriculture. A joint proposal between the US Environmental Protection Agency and the Canadian Pest Management Regulatory Agency to harmonise non-target plant toxicity testing under NAFTA was considered by the Scientific Advisory Panel (SAP) in June 2001. The SAP agreed that the non-target plant testing scheme needed to be improved, but could not reach consensus on a number of key issues (The Weekly Report of the US EPA Office of Pesticides Programs (for week ending 13 July)).

Thus the need to develop standardised test protocols and risk assessment schemes to allow a more refined assessment of the risk to non-target plants posed by the use of pesticides is now greater than ever. This paper sets out some recent developments in these areas.

REVISION OF OECD GUIDELINE 208 (Terrestrial (Non-target plant test)

The need to globally harmonise plant toxicity testing and for revision of the Guideline 208 (1984) has been acknowledged by OECD. Following meetings in 1997 and 1999, a draft version of the revised guideline was produced in July 2000. The Guideline serves for general chemicals as well as pesticides. Hence the use to which the results will be put needs to be fully understood before testing is undertaken. The main points of the revised Guideline are highlighted below.

Guideline 208 now consists of two protocols:

- Part A, a seedling emergence and growth test in which the test compound is incorporated into the growing medium, and

- Part B, a vegetative growth test in which young plants are oversprayed with the test compound.

The vegetative growth test was developed primarily for pesticides as spray drift is considered to be a major route of exposure for foliar applied compounds.

The issues of number and type of species tested were major and prolonged areas of discussion. Testing of up to 10 species is proposed. Annex 2 of OECD 208 provides a list of recommended test species; these are all crop species. Traditionally screening studies for herbicidal activity have used representatives of the main crop types.

Concern has been expressed as to the representativeness of these species for non-crop species. Boutin & Rogers (2000) in their analysis of two Canadian and US EPA data sets conclude that there is no consistent pattern in the available data. In separate studies using 5 common herbicides and 15 test species (8 dicots + 7 monocots), 'selectivity factors' >44,000 have been estimated based on ED50 values (Pestemer 1999). Thus, given the current knowledge base, the likelihood of selecting representative species suitable for all pesticides seems low. OECD 208 does make the important statement "The list may be extended to include non-crop species if a suitable seed source is provided...". [As part of the OECD discussion Boutin (Environment Canada) produced a list of 35 non-crop species which have been tested and for which suitable seed sources are known.]

The two new OECD 208 guidelines will not address all potential concerns. For example, they do not address the issue of potential effects on reproduction or of repeat applications. Without modification they are not suitable for testing compounds whose main activity is via the vapour phase.

DRAFT EPPO DECISION-MAKING SCHEME FOR THE ENVIRONMENTAL RISK ASSESSMENT OF PLANT PROTECTION PRODUCTS (Chapter 13. Non-target plants)

Following several years of discussion and changes in panel membership, a draft scheme has recently been produced (October 2000). The key points of the draft scheme are highlighted below:

Definition of "non-target" area

The scheme is concerned with the assessment of the risk in the "off-crop" area. Field margins of 1 m and 3 m are assumed for arable and orchard crops respectively. Initial risk categorisation is based on predicted environmental concentrations (PEC) at these distances.

Selection of toxicity endpoint

A number of potential endpoints exist for plants; seedling germination, biomass (fresh or dry weight shoot weight or shoot height) and visual stress (chlorosis, mortality, developmental abnormalities). For risk assessment it is proposed that the toxicity endpoint used should be the most sensitive one measured for each species. It is also proposed that the 50% effect value (EC50) should be used in the initial risk assessment.

The main reason for this is that it will be based on the most sensitive of the sub-lethal effects obtained from glasshouse studies (*i.e.* OECD 208), which are assumed to overestimate toxicity compared to naturally exposed field grown plants of the same species. Furthermore, the natural variability in responses of plants, particularly if non-crop species are tested, is considered too large to justify using lower effect values such as NOECs or EC5s.

Selection of species

Estimations of the number of species for which testing is required to establish a reliable estimation of the range of sensitivity vary, but figures in excess of 30 species have been quoted (Breeze *et al.* 1999). Given the number of species potentially exposed this is not surprising, but if data for such numbers of plants species were required then it would be disproportionately higher than for other areas (i.e. aquatics, birds). For herbicides, which it is reasonable to assume pose the highest risk to non-target plants, there is often other valuable information, which can be taken into account. For such products specific label claims of activity are made; in some countries (*i.e.* UK) these claims must be supported by efficacy field data. Thus there exists a body of evidence, which identifies some of the more sensitive non-crop species. This information can be used to focus a more detailed laboratory dose response testing regime on these or closely related species. This principle underpins the draft EPPO scheme. Results from tests on such species can then form the basis of a risk assessment. For herbicidally active compounds dose response testing for at least 6 species is proposed.

Calculation of toxicity endpoint for use in decision making

Where acceptable EC50 values for 6 species are available a statistical approach based on the distribution of the EC50 values derived from the OECD tests is proposed in order to determine a calculated toxicity value (*i.e.* HD5). Thus the scheme differs from classical deterministic risk assessments, where an uncertainty factor (typically 10 or 100) is applied to the lowest observed endpoint. However, for plants there is currently no substantive body of data to support this approach. Validation of this step is likely to be required before the scheme can be accepted.

Routes of exposure

The calculated toxicity value is then compared with the appropriate exposure estimate to derive an Exposure:Toxicity Ratio. The routes of exposure considered are spray drift, run-off and gaseous transport. Aerial drift of herbicides is known to cause impacts on plants in areas close to the point of application. This route of exposure is considered to represent the main route of exposure for plants outside of the treated area. The predicted exposure level for each route of exposure is to be obtained from the relevant EPPO Chapter. For spray drift, the exposure value will come from the EPPO Air Scheme (this is likely to be taken from the published BBA spray drift data set (www.bba.de)). For gaseous transport, it is unlikely that the EPPO Air Scheme will be able to produce a value in the short term, hence for compounds which are expected to pose a risk via volatilisation non standard tests/scenarios will be required. The EPPO soil scheme should provide a run-off PEC. All exposure scenarios in the scheme may be defined as "off-crop".

Refinement of risk

The susceptibility of plants to pesticides may be affected by many variables (Marshall 2001 this publication). The scheme acknowledges this and suggests some possible refinement options including; more detailed consideration of the dose response data, more realistic exposure scenarios, testing of less sensitive growth stages (if appropriate to the intended use), consideration of importance of seedbank for sensitive species and use of higher tier studies (**i.e**. semi-field studies). Experience in the conduct and evaluation of semi-field studies is however very limited and such studies should only be conducted once the overall object has been clearly identified.

FUTURE DEVELOPMENTS

The proposed EPPO Decision-making scheme provides a basis for categorising the risk to non-target plants ('Negligible', 'Low', 'Medium' or 'High'). As such it does not attempt to define the 'acceptability' of the risk identified; the final decision on which will, in the foreseeable future, rest with individual countries. In defining 'acceptability' regulators must address the challenge of clearly defining the overall protection goal; this has yet to be done.

Currently risk assessments for non-target plants are limited to the 'off crop' area and tend to be rather qualitative. This situation has arisen because of the general belief that all non-crop plants within the cropped area have the potential to significantly reduce yield and/or cause contamination of seed lots. A reflection of this can be seen in the current UK approach, which for highly active compounds (*i.e.* some sulfonylurea herbicides), consists of the use of advisory label warnings such as

"Take extreme care to avoid drift onto nearby plants"

In contrast to the restrictions which can be applied to the use of certain pesticides near surface waters, there are no specific non-target terrestrial plant buffer zones in the UK. Where data are available to indicate phytotoxicity to non-target plants at distance from the point of application, authorisation has been refused in the UK.

The well publicised reductions in populations of some arable bird species, the demise of certain arable plants and the potential introduction of crops tolerant to broad spectrum herbicides has meant that the view that the cropped area should be free of all non-crop plants is being increasingly challenged (Marshall 2001 this publication). In response to such concerns over the sustainability of modern agriculture, the UK has begun to ask the questions which species of non-target plants are present, and what role do they play, in the agro-ecosystem?

A MAFF commissioned desk study by Breeze *et al.* 1999, identified a number of the more common non-crop plant species associated with agricultural systems. This study also identified some possible associations between these species and some invertebrates and birds. This work has recently been updated by Marshall *et al.* 2001. Existing evidence indicates that certain species *i.e.* blackgrass (*Alopecurus myosuroides*), winter wild oat (*Avena fatua*) and common cleavers (*Galium aparine*) are of such high competitive ability that there is limited opportunity to reduce the high levels of control currently used. However, for other species of far lower competitive ability, the need for consistently high levels of control is more questionable.

The limited available evidence suggests that some plant species which may be important for invertebrates and birds are those which pose less of a threat to agricultural production. Further research is underway to establish whether for some species a balance between weed control and biodiversity can be found (P Lutman BBSRC Rothamsted *pers comm*).

Evidence of the extent to which the use of herbicides *per se* may have impacted on the long-term diversity of non-crop plant species in arable areas is contradictory. Surveys in West Sussex (England) appear to show limited effects of herbicide usage on arable weed populations in cereal fields over the period 1970 to 1995 (Ewald 1999). For the following reasons these results are questionable; surveys conducted at approximately the same time of year, assessed presence/absence only, started after herbicide usage was already well established.

In contrast, claims of increases in plant diversity in organic compared to conventional production fields have been made in Germany, Denmark and Sweden, although again the impact of herbicides cannot be accurately judged. There are a number of other factors, which are considered to play an important role in the diversity of arable weeds. Several authors conclude that the current floristic composition of arable areas is dominated by a relatively small number of species better suited to high nutrient levels. Removal or restrictions on herbicide usage may thus result in the increased dominance of a small number of the more competitive species and not achieve any significant increase in biodiversity. Cropping regime is also considered to be another important factor. The potential scale of changing cropping practice is highlighted by the major reduction in the area of spring barley from 44.7% to 10% of total arable area which occurred in the UK between 1974 and 1998 (based on published MAFF Pesticide Usage Survey Data).

Whilst the evidence that the use of herbicides *per se* is adversely affecting the long term diversity of plants in arable areas is not conclusive, the use of such compounds is likely to have a major impact on their short term abundance (Breeze *et al.* 1999). For associated species *i.e.* phytophagous insects and insectivorous/seed eating birds this potential short-term loss of habitat/food supply may have important implications.

Thus the potential for indirect effects of herbicides is an area which requires further detailed consideration. The Department for Environment, Food and Rural Affairs (DEFRA) has taken over from MAFF the responsibility for a major 5 year research project 'Assessing the indirect effects of pesticides on birds.' (Commission No PN0925). This project will produce a framework for the assessment of the indirect effects of pesticides on birds reflecting the causal chain of pesticide effects on resources, the effects of resources of bird performance and the effects of performance on bird populations. The framework will be tested by expanding ongoing studies on 11 farmland bird species and large-scale replicated field experiments. The study will provide a basis for the decision as to whether indirect effects are substantial enough to warrant regulatory action and an assessment of the extent to which current risk assessment methods provide protection against potential indirect effects.

If future research does identify certain plants with important ecological roles then a potential refinement of the EPPO approach to species selection could be to require specific testing on such species, or their close relatives. It is acknowledged that if several countries were to adopt such an approach it could result in the need to supply and evaluate data on numerous different species. This situation would place a heavy burden on both agrochemical companies and regulators alike and, if possible it should be avoided.

However, this serves to highlight one of the main problems with non-target plant risk assessments i.e. the lack of a robust toxicity database on which to make a judgement as to the representativeness of different species. Indeed, Boutin & Rogers (2000) considered this aspect so important as to conclude, "an improved database on phytotoxicity is a pre-requisite to refine the risk assessment of pesticide effects on non-target plants." Taken in isolation this is a valid statement. However, it is unlikely in the short term that such a comprehensive data set of sufficient quality will be available. The proposed EPPO scheme therefore represents a pragmatic compromise between the increasing pressure to address the issue and the current lack of detailed knowledge.

The recognition of ecologically important plant species currently considered as being 'weeds' would require some consideration of the 'in-crop' risk. Such a development would require a new approach to risk assessment and risk management techniques. If this scenario does arise, then the challenge of protecting/encouraging such species, whilst not unduly compromising the ability to control pernicious weeds, is one which will require the combined efforts of researchers, agrochemical companies, pesticide regulators, environmental policy makers and field based advisory services.

CONCLUSION

The proposed revision of OECD Guideline 208 provides protocols suitable for testing the phytotoxicity of the majority of pesticides. Such harmonisation of testing lays the foundation for the proposed EPPO decision-making scheme. Current risk assessments for non-target plants are focused on the potential for effects in the 'off-crop' area. Concern over the sustainability of some modern intensive agricultural practices is currently challenging the basis of this. If it is deemed necessary to assess the risk to non-crop plants in the 'in-crop' area, a whole new approach to risk assessment and risk mitigation will be required and a clear overall protection goal for non-target plants will need to be defined. The pesticide regulatory process provides a potential route via which appropriate phytotoxicity data can be demanded. However, potential risk management options for non-target plants will need careful consideration and a multi-disciplined approach if the desired objectives are to be achieved.

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Assessing the potential risks of herbicides to non-target aquatic plants

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ABSTRACT

The current preliminary risk assessment scheme for non-target aquatic plants in the EU is described. Reviews of laboratory and field data have demonstrated that under most circumstances, the current study requirements and risk assessment procedures for herbicides should afford reasonable protection for non-target aquatic plants (and other non-target aquatic organisms) in the field. However, where concerns are identified (either through triggering or because of regulatory concerns about inadequacies of standard studies for certain modes of action), higher-tier studies and risk assessment procedures are needed. The approaches described by the HARAP workshop provide a suitable framework for developing higher-tier studies, and some examples of potential approaches for aquatic plants are reviewed. Effective implementation of higher-tier aquatic non-target plant risk assessment will require the development of clear protection goals. Ideally, these goals should be based on ecological information about the aquatic plant assemblages that are associated with agro-ecosystems. A number of initiatives are underway that may enable such risk assessment procedures to be developed in the future.

INTRODUCTION

Assessing the impacts of herbicides on aquatic plants can be a complex matter. On the one hand, they may be a target organism. On the other hand, protection of certain aquatic plants may be a key goal, for example rare, threatened or endangered species. Among lists of threatened and endangered plant species, aquatic and wetland plants are often well-represented, possibly due to habitat declines and land/water management practices. Furthermore, it is important to attend to the functional role of aquatic plants in aquatic ecosystems. Plants are of key importance for their role in primary production and community metabolism. Less obviously, but perhaps of equal importance, they also provide substrates and habitat or micronutrients for other organisms. What is more (but less commonly considered), the presence of aquatic plants may have a profound influence on the fate and distribution of pesticides in the aquatic ecosystem. For these reasons, aquatic plants are beginning to receive more attention in pesticide regulation.

The preliminary risk assessment process for aquatic plants is well-established and generally appears to be effective at identifying low risk compounds. However, for compounds which fail the preliminary assessment, whilst there are a range of options available for higher-tier studies, methodologies are far from standardised and implementation of such data into risk assessment is still under discussion. In this paper, current risk assessment procedures in the EU are discussed, and potential higher-tier approaches are described.

PRELIMINARY RISK ASSESSMENT FOR AQUATIC PLANTS

In the EU risk assessment scheme under 91/414/EEC, all active ingredients must be tested for effects on the growth of a green alga (usually *Pseudokirchneriella subcapitata* previously known as *Selenastrum capricornutum*). For herbicides, an additional algal species is required (the blue-green *Anabaena flos-aquae* is suggested), as well as studies on the floating pond weed *Lemna* sp. (usually the species used are *L. gibba* or *L. minor*). In some cases, where regulatory authorities are concerned that the specific mode of action of the compound is not covered (e.g. if the mode of action is specific to dicotyledonous plants, considering that *Lemna* is a monocot) other studies may be needed. In such cases, the draft EU Guidance Document on Aquatic Ecotoxicology recommends that data from terrestrial plant studies may also be useful for evaluating selectivity. Such data are also relevant for assessing potential risks to emergent (also called semi-aquatic) plants. In some cases, tests with other species (e.g., *Myriophyllum* or *Glyceria* sp.) have been requested by certain authorities, although as yet there are no harmonised guidelines for such studies (see below). This is usually only required if it is anticipated that the standard test species will not be sensitive to the mode of action of the compound. The effect concentrations from these studies (usually 72 or 96 h EC50s for algae, and 7-14 d EC50 for *Lemna*) are then compared to the relevant exposure concentrations, and if the resulting toxicity exposure ratio is less than 10, higher-tier assessments are required.

VALIDITY OF THE PRELIMINARY RISK ASSESSMENT SCHEME

A number of authors (e.g. Fairchild *et al.*, 1998; Peterson *et al.*, 1994) have suggested that testing schemes for aquatic plants may need to be extended because comparison of toxicity endpoints for various herbicides with different algal and macrophyte species do not show consistent results (*i.e.*, no one species is consistently the most sensitive). Selecting 'sensitive' species for toxicity testing is a long-recognised problem (Cairns, 1986). A counter-balancing consideration, though, is that for routine regulatory testing purposes it is essential that test methods involve organisms which can be readily cultured in the laboratory, are reproducible, and are cost-effective. At present, such methodologies for a much broader range of species are limited.

Whilst the conclusion that no one species can ever be the most sensitive is incontrovertible, it also perhaps misses the key point of species selection for risk assessment. This is that species are selected for risk assessment purposes as indicator organisms, not as surrogates. The principle aim of preliminary risk assessment scheme is to identify compounds which present low risks to aquatic plants. So the fundamental question should not be whether the species tested are always the most sensitive, but whether the risk assessment process using the standard species affords adequate protection. What we really need to know is whether the toxicity data that are generated, in combination with an uncertainty factor, are protective of effects seen under field conditions (additionally of course there is the consideration of the likelihood of the exposure concentration that is used in the risk assessment actually occurring from normal uses).

It has generally been assumed in the EU that the lower tiers are conservative, because of the combination of the worst-case nature of the exposure estimates and the sensitivity of the toxicity test endpoints used, combined with the use of a safety factor. For the EU risk assessment scheme, a recent comprehensive review of the latter two assumptions has been made by Brock *et al.* (2000) using laboratory and field studies published in the literature. For herbicides, studies were reviewed on compounds with a wide range of modes of action (photosynthesis inhibition, auxin simulating, and 'other' growth inhibition mechanisms). Generally, they found that the EU risk assessment criteria (based on laboratory toxicity data) were protective of the effects observed in the field. The one exception to this was auxin simulating herbicides, which were not particularly toxic to algae or *Lemna*, but did have some effects on other macrophyte species in the field. The conclusions of the study are encouraging and suggest that in most cases, the proposed scheme will be effective at identifying safe compounds.

OPTIONS FOR HIGHER-TIER STUDIES

If a compound fails the preliminary risk assessment, there are two options for further refinement. Firstly, it may be appropriate to refine the exposure concentrations. Previously in Europe, there have not been many options to do this, but under the new FOCUS surface water scheme, a series of steps will be available with which to refine exposure estimates. Alternatively, it may be appropriate to refine effect concentrations by performing further ecotoxicological studies. Guidance on the conduct of higher-tier aquatic studies was developed at the HARAP workshop (Campbell *et al.*, 1999). In this guidance, there are a number of options for assessing higher-tier risks, and these fall in to several categories:

- Interrogation of core data,
- Additional species testing,
- Modified exposure studies,
- Indoor and/or outdoor micro- and mesocosm studies.

Each of these study areas has potential application for higher-tier assessments of aquatic plants, and are discussed further below.

Interrogation of core data

If higher-tier assessments are triggered, the first point to establish is what is known about mode of action and therefore likely species affected. Valuable information on this can be gathered from reviewing data from terrestrial plant studies (where a range of monocots and dicots are studied) or from data from herbicide efficacy screens. These data may then also be used to refine the risk assessment, particularly if the major route of entry for the herbicide is determined to be spray drift.

A second consideration is what the critical endpoint of the studies are that have triggered the concern. It is important to consider what the likely environmental consequences of the measured effects will be. For example, in algal studies, compound may be algistatic (*i.e.* they limit growth but do not kill algal cells) or algitoxic (resulting in cell death) at concentrations relevant to the predicted environmental concentration. The former has potential consequences for recovery, and aids the design of any necessary higher-tier studies.

Additional species testing

There is a wide range of algal species which can be used to evaluate relative sensitivity (see Lewis (1995) for a review of methods and relative sensitivity data). Reviews of published methods for testing aquatic macrophytes have been produced by Freemark & Boutin (1994) and Lewis (1995). Until recently, the use of submerged plant species in toxicity tests has been limited by the difficulty of generating algae-free cultures. Work by Roshon has led to production of a draft American Society of Testing and Materials guidance for *Myriophyllum sibiricum*. Additionally, there are few cited laboratory methods for emergent species (Davies *et al.*, 1999). However, none of these proposed tests have been validated under a regulatory testing framework. Whilst development of standard, harmonised methods for macrophytes is a clear need for the future, validation of any new test is critical before it can be implemented as a regulatory requirement. Furthermore, there will need to be a clear understanding of how data so developed will be used in the risk assessment process (e.g., the ecological relevance of the various endpoints measured).

At present, comparatively little is known about the relative sensitivity of macrophyte species. Although much data have been published on effects of herbicides on aquatic plants, studies have often been conducted with a view to controlling nuisance species, where aquatic plants are the target species. Consequently, data are difficult to compare due to the use of different methods. A few authors have attempted to make comparisons in species sensitivity, (Davies *et al.*, 1999; Fairchild *et al.*, 1998), but clearly relative sensitivity will depend on the mode-of-action of the compound and the route of exposure of the pesticide.

Many endpoints have been proposed including root and shoot dry weight, root and shoot height, side shoot production, chlorophyll content, photosynthetic rates and enzyme activities such as peroxidase. Measurements of dry weight and biomass are more easily interpreted while measurements of chlorophyll content, photosynthetic rates and enzyme activities are more prone to sampling variation and low-dose enhancement. Thus data can be very difficult to interpret in terms of detrimental effects on a population. In particular, photosynthetic inhibitors like isoproturon have been reported to stimulate chlorophyll content while having no visible effect on biomass (J Davies, unpublished data). Further studies are needed to establish the link between effects at the sub-organism level to effects at the individual level, with linkages of these to effects at the population and community level being a necessary longer-term goal.

Modified exposure and recovery studies

One option for refining effects concentrations is to modify the exposure conditions in the toxicity test. Two approaches to this have been developed. The first is where the exposure concentration in the test vessel can be modified using a variable dosing system e.g., for algae (Grade *et al.*, 2000). Flow-through methods are mentioned for *Lemna* in OECD draft guideline and have also been published for other rooted macrophytes (Steinberg & Coonrod, 1994). Alternatively, it is possible to modify the exposure by adding sediment to the test system, where it is anticipated that the test compound will be dissipated more rapidly in the presence of sediment e.g. for algae (Shillabeer *et al.*, 2000). Similar approaches would be also possible for macrophytes.

Micro- and mesocosm studies

Algae and aquatic macrophyte have been studied extensively in micro- and mesocosm studies. There have been a number of review of such studies, and the reader is again referred to the reviews of Lewis (1995) and Brock *et al.* (2000). The considerations that apply to micro- and mesocosm studies on aquatic fauna also translate in most part to studies on flora, and recommendations for conduct and interpretation can be found in the HARAP (Campbell *et al.*, 1999) and CLASSIC (Heger *et al.*, in press) workshop proceedings. Indeed, even in small microcosms, it is possible to study assemblages of macrophytes that are reasonably representative of natural systems. Williams *et al.* (in press) have found for example that in 1 m^3 outdoor microcosms, the assemblage composition of submerged macrophytes was similar to that found in natural ponds.

FURTHER CONSIDERATIONS FOR HIGHER-TIER RISK ASSESSMENT

The paper so far has focused mostly on the methods that are available for higher-tier aquatic plant assessment. In relation to developing a higher-tier risk assessment scheme, this comes at the problem from the wrong direction. The key need for further development of aquatic plant risk assessment is a fundamental review of risk assessment goals for aquatic plants. As in other areas of ecological risk assessment, a frequently unanswered question is "what are we trying to protect?" This is a particularly difficult question to answer for most pesticides, because they are designed to kill organisms (or at least their close relatives) that under other circumstances we may want to protect. However, in order to produce a rational and cost-effective risk assessment procedure, it is a question that must be tackled. This also leads on to the perennial question of "what is an unacceptable impact?"

Perhaps one of the first steps in trying to answer this difficult question is to know which species of aquatic plants are associated with the water bodies in agroecosystems, and to understand their life-history (e.g., when and how quickly they grow, their reproductive rate, etc.). This information would help in formulating appropriate experiments to assess for potential impacts, and also enable the development of suitable risk assessment paradigms. A number of projects are underway at the moment which may offer potential in this direction in the future. For example, the UK Pesticide Safety Directorate is currently funding a project which will develop scenarios for aquatic ecosystems in the UK agricultural landscape. Information on the floral assemblages associated with these ecosystems will be gathered. In addition, the Freshwater Biological Association in collaboration with the Ponds Conservation Trust have initiated a project called Freshwater Life (www.freshwaterlife.org) which will gather together information on the life-history and taxonomy of aquatic flora and fauna. Furthermore, the National Biodiversity Network in the UK will be collating distribution maps for British macrophyte species (www.nbn.org.uk). Similar intiatives are also underway in other EU countries, so the potential for better informed risk assessment procedures in the future is increasing.

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