Nontarget-Plant Risk Assessment for Pesticide Registration

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ABSTRACT / The approach developed by Environment Canada to assess risk to aquatic and terrestrial plants in nontarget habitats potentially exposed to pesticides evaluated for registration is described. An anonymous sample of pesticide submissions is used to illustrate the approach and to examine its merits and limitations in relation to test species, response variability, testing protocols, ecological relevance, and comparability with other regulatory agencies. Future directions are identified, particularly in relation to impending nontarget-plant testing guidelines for pesticide registration in Canada. This approach incorporates some of the latest research and developments in the field of risk assessment for plants. The novelty of this approach also lies in the use of the plant screening data routinely generated by chemical pesticide companies, which is intended to provide a maximum amount of information to evaluators at minimal increment cost to registrants. The proposed approach can serve as a basis for guideline development and modernization for other jurisdictions.

Nontarget-plant risk assessment has become a pressing issue worldwide with the widespread, intense, and increasing use of herbicides and other potentially phytotoxic pesticides (Schwinn 1988, Pimental and others 1991). In Canada, for example, 21.6 million hectares of farmland were treated with herbicides in 1990 (Statistics Canada 1992), representing almost a threefold increase since the early 1970s. Correspondingly, concerns about the potential for adverse impact of phytotoxic chemicals on nontarget organisms have increased (Sheehan and others 1987). In a recent review of the scientific literature, Freemark and Boutin (1994) concluded that wild mammals and birds living in terrestrial farmland habitats are unlikely to be exposed to toxic levels of agricultural herbicides. In contrast, they concluded that herbicide use can have secondary impacts on farmland wildlife, primarily mediated through a variety of toxic effects on plants and changes in habitat composition, heterogeneity, and interspersion.

In Canada, the federal government regulates the registration, classification, and labeling of pesticide products, while provincial governments regulate their actual use through licenses, permits, and related regulatory techniques. At the federal level, the use of pesticides is currently regulated by the Pest Control Products (PCP) Act, which is administered by Agriculture Canada. Environment Canada is responsible for examining all aspects of environmental chemistry, fate, and toxicology for pesticides being considered for new or continuing registration under the PCP Act. Environmental toxicology includes wildlife and wildlife habitat, fish and fish habitat, soil and aquatic invertebrates, pollinators, and microbes. Data requirements for nontarget phytotoxicity are not formally addressed in the guidelines for pesticide registration but are currently under development (Boutin and others 1993, Freemark and others 1990, Swanson and others 1991). Since 1986, Environment Canada has been requesting that registrants submit phytotoxicity data that are routinely generated during product development or have been generated for other regulatory agencies. Additional data have also been requested on a case-by-case basis following preliminary evaluation of the submitted data.

In this paper, we outline the approach currently developed by Environment Canada for assessing risk to aquatic and terrestrial plants in nontarget habitats potentially exposed to herbicides evaluated for registration. We use an anonymous sample of pesticide submissions to illustrate the approach and to examine its merits and limitations. The data are presented anonymously because they are proprietary. Furthermore, our intention is to emphasize the approach for assessing risk rather than the specifics of the data and methodologies used. Lastly, we discuss future direc-

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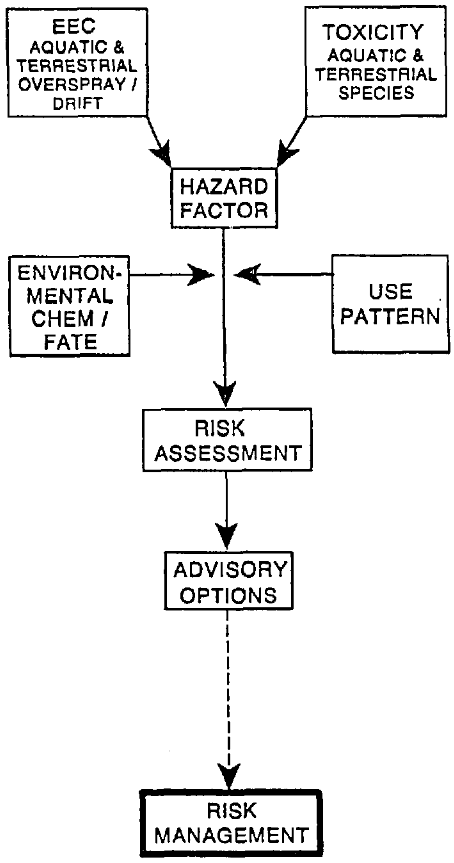

Figure 1. Environment Canada nontarget-plant risk assessment model for pesticides including risk management.

tions, particularly in relation to impending nontarget-plant testing guidelines for pesticide registration in Canada and guideline development and modernization by other jurisdictions.

Nontarget-Plant Risk Assessment Model

The approach currently developed by Environment Canada more closely approximates ecological risk assessment than hazard assessment (Figure 1). Hazard and risk assessment have been variously defined (OECD 1989, Ramamoorthy and Baddaloo 1991). In general, hazard assessment is the process of comparing the toxicological end point of interest to an estimated exposure concentration to determine the probable nature and magnitude of the hazard resulting from the release of the chemical into the environment. Expert judgement is used to apply safety or uncertainty factors based on the amount and quality of toxicological data. Risk assessment extends hazard assessment by estimating the probability or likelihood that undesirable effects will occur, are occurring, or have occurred as a result of exposure to a chemical. Ecological risk assessment deals specifically with adverse effects on the ecosystem which includes plants, animals, and ecosystem properties. Hazard assessment preceded risk assessment and was the approach used in the late 1970s to the mid-1980s (Ramamoorthy and Baddaloo 1991). Ecological risk assessment is still in the early stage of development for toxic chemicals (Bartell and others 1992, Levin and others 1989, OECD 1989, Suter 1993). To date, assessments have been based primarily on expert judgement, although there are recent efforts to develop more quantitative methods (Bartell and others 1992, Suter 1993, van Leeuwen and others 1992).

In the approach developed by Environment Canada, herbicides submitted for registration are first evaluated for potential exposure of nontarget plants. Restricted uses such as in closed-system greenhouses, indoors, and swimming pools, do not trigger nontarget plant testing. Each stage of the approach for products that do trigger testing will be described in turn.

Plant Toxicity

A variety of phytotoxicity data for seven products in four herbicide classes were submitted by registrants in response to requests by Environment Canada (Table 1). Product and class names are not given to protect their proprietary nature. Laboratory studies were done with freshwater species of green algae, duckweed, and rooted aquatic vascular plants. For algae, five products were tested with *Selenastrum capricornutum*, (one *Scenedesmus pannonicus*, and one with *Selenastrum capricornutum* and *Scenedesmus subspicatus*). Study designs conformed to the USEPA (1982) or the OECD (1984a). Duckweed studies were submitted for three products; one with *Lemna gibba* and two with *Lemna minor*. Studies that exposed duckweed via the medium conformed to the USEPA (1982) protocol. Studies in which the duckweed was sprayed then removed to fresh media used novel designs since no standard methods are available. The freshwater, rooted, vascular plant species tested with products are not identified for proprietary reasons.

For algal and duckweed species, an EC_{50} (the product concentration causing 50% growth inhibition relative to control plants) is calculated graphically (log-linear plots) or statistically (e.g., probit or regression analysis). The EC_{50} is used because algae and duckweed have short generation times. For rooted aquatic vascular plant species a more conservative value, the EC_{25} (the product concentration causing 25% damage relative to control plants) is used. An EC_{25} is consid-

Table 1. Phytotoxicity data for 7 herbicides evaluated for registation in Canada since 1986

		Laboratory				Greenhouse plant screening (# species/# families)[a]			
			Duckweed			Aquatic		Terrestrial	
						Emergence at application			
Class	Herbicide	Algae (green) (freshwater) # spp.	Medium	Sprayed	Rooted aq. vascular (# spp.)	Pre	Post	Pre	Post
A	#1	1	No	No	—	—	7/3[a]	—	42/15
	#2	1	Yes	Yes	2	—	2/2	—	45/13
	#3	1	Yes	Yes	3	—	16/10	—	—
B	#4	1	No	No	—	—	2/2	—	54/14
	#5	1	Yes	No	—	1/1	2/1	64/16	72/15
C	#6	1	No	No	—	—	7/3	—	46/16
D	#7	2	No	No	—	2/1	2/1	52/14	54/12

[a]Each ratio represents number of species from number of families as in the case indicated (7/3) where seven species have been tested from three families with an early postemergence application.

ered a level of damage sufficient to cause significant adverse effects (USEPA 1982).

Plant-screening data for both aquatic and terrestrial vascular plant species were submitted by registrants for all of the herbicide products included in the sample (Table 1). These data were generated in greenhouse studies that are routinely conducted during product development to evaluate efficacy and crop tolerance. The experimental design used was reported in varying detail but appeared to differ to some extent among different registrants (for a general description of the experimental design see Brown and Farmer 1991 and Marshall and Birnie 1985). A large number of terrestrial species and families were tested with a sufficient number and range of doses to evaluate toxicity. Data were limited for aquatic species. Plants were sprayed either preemergence or early postemergence. Damage to treated plants was rated by visual comparison to control plants, taking into consideration morphological characteristic (chlorosis, epinasty, etiolation, etc.) and differential growth. Visual assessment of damage by herbicide specialists can be as reliable as other, more quantitative measures such as plant dry weight (Brown and Farmer 1991). For statistical analysis, the visual rating was converted to a percent damage score by a linear approximation (Frans and Talbert 1977, Hamill and others 1977). An EC_{25} was estimated by probit analysis for species tested with at least four doses that bracketed the EC_{25} (MacLeod 1993) except for one product (#3), which was tested at high concentrations only.

Estimates of Environmental Concentration

Estimates of environmental concentration (EEC) were calculated based on worst-case scenarios for exposure of nontarget habitats interspersed within or adjacent to proposed use areas. The EEC from an overspray exposure is calculated as 100% of the maximum application rate proposed. This level of exposure could occur during aerial application (Sheehan and others 1987) and/or from multiple swathing during ground application (Maybank and others 1978). In the Canadian prairies, approximately 5%–10% of total farmland is aerially sprayed with herbicides annually (Sheehan and others 1987). The EEC from a spray drift exposure is calculated as 10% of the maximum application rate proposed and is based on the range of values reported in the scientific literature (e.g., Elliott and Wilson 1983, Gohlich 1983, Maybank and others 1978, Norby and Skuterud 1975, Sheehan and others 1987). Concentrations in aquatic environments from overspray or drift exposure are calculated assuming a 15-cm water depth (similar to USEPA 1982). This depth of water could be expected for fish habitat in lotic systems or amphibian habitats in lentic systems. Additional exposure scenarios (e.g., surface runoff) may be used on a case-by-case basis.

Hazard Scores

For laboratory data, the hazard score is based on the quotient or ratio method. This method is widely employed in ecological hazard and risk assessment and provides a useful, if somewhat simplistic, approach (OECD 1989). In general, the ratio of the EEC to the toxicological end point of interest is calculated and compared to criterion values that reflect a judgement on the degree of uncertainty in the estimates. Uncertainty arises from several sources, such as differential variability and sensitivity among species, and using a few, single-species tests conducted under laboratory conditions to extrapolate to potential effects on multiple species in the receiving environment. Uncertainty decreases as the number of tests and types of end points used increases. For algal and duckweed species, the ratio of the EEC to the EC_{50} is calculated. For rooted aquatic vascular plant species, the ratio of the EEC to the EC_{25} is calculated. The results of Blanck and others (1984) with algae suggest that ratios greater than 0.01 should be of concern when only a few species are tested. However, because we estimate EECs from worst-case scenarios and because species other than algae were used in the assessment of the phytotoxicity, a criterion value of 0.1 is used.

The ratio method was not used to calculate hazard scores for greenhouse plant screening data because of uncertainties in the experimental design. Instead, the hazard score is calculated as the percent of species or families that have an EC_{25} less than or equal to the EEC. A hazard score is calculated only if sufficient data are submitted—at present, at least seven species from three families. Criterion values of concern are 25% for species and 50% for families arbitrarily based on our experience to date. In the Netherlands, the objective of their risk management strategy for toxic chemicals is to offer protection to 95% of all species in ecosystems, this level having been chosen arbitrarily (van Leeuwen 1990).

According to the Organization for Economic Cooperation and Development (OECD 1989), the use of automatic triggers for further testing is not scientifically or economically justifiable for pesticides given the present state of knowledge. They further contend that there is no substitute for the application of professional judgement in assessing uncertainty in ecological risk assessment (see also Greig-Smith 1992). In contrast, Suter (1993) argues that expert judgement should only be used when quantification of uncertainty is unfeasible, given the inherent subjectivity of expert opinion.

Environmental Chemistry and Fate

Potential for exposure of nontarget plants is related to the behavior and fate of herbicides (and other phytotoxic pesticides) in the environment. Data on environmental chemistry and fate are required for all pesticide products submitted for registration in Canada (Agriculture Canada and others 1987). Phytotoxic products of particular concern are those that are persistent (i.e., half-life in soil or water >1 month) (Goring and others 1975, Rao and Davidson 1980), mobile (water solubility >30 mg/liter) (Cohen and others 1984) or likely to volatilize (vapor pressure $\geq 3.9 \times 10^{-5}$ mm Hg [5.2×10^{-3} Pa]) (Kennedy and Talbert 1977).

Limits of detection in environmental samples may also be of concern for products that are phytotoxic at very low environmental concentrations. It is debatable whether products should be registered if they are toxic below the current detection limits.

Use Pattern

The likelihood that sensitive nontarget plants will be exposed to a herbicide (or another phytotoxic pesticide) submitted for registration is related in large part to the use pattern proposed. **Where** the product will be used determines the type and composition of nontarget habitats which are likely to be exposed. In the prairie pothole region of Canada, for example, sloughs and their associated uplands are interspersed within croplands. In eastern Canada, cropped fields are often bordered by streams, hedgerows (i.e., wooded fencerows), or woodlots. **What** crop(s) the product is to be used on determines the area of farmland that could be treated and thereby the amount of nontarget habitat that could potentially be exposed. **How** the product will be applied (e.g., preplant incorporated, postemergent ground or aerial application) also determines the amount of nontarget habitat that could be exposed. For example, aerial application is expected to expose a greater amount of nontarget habitat and at higher dose levels than ground application. The method of application also affects the likelihood that an EEC will be realized. For example, an overspray exposure is much less likely from ground application than from aerial application. **When** the product is to be used (e.g., season, frequency) determines what species are most likely to be exposed, how often, and at what stage(s) in their life cycle (e.g., seed germination, two to three-leaf stage, flowering, seed set).

Risk Assessment

Phytotoxicity data, estimates of environmental concentration, environmental chemistry and fate and use pattern are combined to evaluate the likelihood that a hazard to nontarget plants will be realized from the use pattern proposed for pesticide products submitted for registration (Figure 1). At the present time, assessments are semiquantitative (e.g., high, medium, low) based on the expert opinion of pesticide evaluators.

Advisory Options

Once a product has been assessed, various advisory options are considered to mitigate the risk to nontarget plants. If data gaps are identified, additional laboratory and/or field studies may have to be submitted

Table 2. Hazard scores (EEC/toxicity end point) for 7 herbicides evaluated for registration in Canada since 1986

			Laboratory				Greenhouse plant screening (% species/% families)[a]			
							Aquatic		Terrestrial	
				Duckweed			Emergence at application			
Class	Herbicide	EEC	Green algae (freshwater)	Medium	Sprayed	Rooted aq. vascular	Pre	Post	Pre	Post
A	1	Drift	0.0001	—	—	—	—	14/33[a]	—	26[c]/53[c]
		Overspray	0.001	—	—	—	—	14/33	—	50[c]/80[c]
	2	Drift	1[b]	1.5[c]	0.003	1.5[c], 0.3[c]	—	ID[d]	—	44[c]/77[c]
		Overspray	1	15[c]	0.03	15[c], 3[c]	—	ID	—	96[c]/100[c]
	3	Drift	0.007	0.63[c]	0.0006	0.45[c], 0.81[c], 0.83[c]	—	—	—	—
		Overspray	0.07	6.3[c]	0.006	4.5[c], 8.1[c], 8.3[c]	—	81[c]/80[c]	—	—
B	4	Drift	0.32[c]	—	—	—	—	ID	—	1/7
		Overspray	3.2[c]	—	—	—	—	ID	—	26[c]/64[c]
	5	Drift	0.0002	0.66[c]	—	—	ID	ID	53[c]/81[c]	31[c]/67[c]
		Overspray	0.002	6.6[c]	—	—	ID	ID	89[c]/94[c]	90[c]/87[c]
C	6	Drift	0.01	—	—	—	—	0/0	—	35[c]/6
		Overspray	0.1[c]	—	—	—	—	0/0	—	46[c]/31
D	7	Drift	12.7[c], 3.6[c]	—	—	—	ID	ID	40[c]/67[c]	26[c]/58[c]
		Overspray	127[c], 36[c]	—	—	—	ID	ID	77[c]/93[c]	65[c]/100[c]

[a] Each ratio represents percent of species/percent of families as in the case indicated where 14% of the species tested from 33% of families showed 25% inhibition as compared to the control at a dose smaller than the expected environmental concentration (EEC).

[b] Study invalid.

[c] Exceeds hazard criterion value.

[d] Insufficient data.

and evaluated before advice on registration can be provided. In some cases, a conditional registration may be appropriate pending submission of the additional data requested. Restrictions to the registration may be recommended. The region of use may be restricted geographically (e.g., prairies only) or by soil type (e.g., soils pH < 7.5). Limitations may be recommended on the crops to which the product may be applied or on the timing and frequency of use. The method of application may be restricted, for example, to ground application only. Buffer zones around noncrop habitat adjacent to or within use areas may be required. Currently, Environment Canada is recommending a 15-m buffer zone for ground applications. In the UK, Marrs and others (1992) recommend buffer zones of between 6 and 10 m to protect established perennials and 20 m to protect seedlings from drift associated with tractor-mounted sprayers.

Risk Assessment of Herbicide Submissions

The risk assessment approach currently developed by Environment Canada will be illustrated using the sample of herbicide submissions introduced above. As noted previously, the data are presented anonymously to protect their proprietary nature.

Hazard scores for aquatic plant species tested in the laboratory varied substantially among products (Table 2). A hazard score for algae could not be calculated for one product (#2) because the toxicity study was deemed invalid. Of the remaining products, two (#4, #7) exceeded the criterion value (0.1) for algae for both overspray and drift exposures. Another product (#6) exceeded the criterion value for an overspray exposure only. Hazard scores for algae were not necessarily similar for products within the same herbicide class (e.g., #4 vs #5).

All products tested with duckweed exceeded the criterion value (0.1) when plants were exposed via the medium for both overspray and drift exposures (Table 2). All products were less toxic to duckweed when plants were sprayed (then removed to fresh media); no product exceeded the criterion value. Both products tested in the laboratory with an early postemergent exposure via the medium of rooted aquatic vasculars (#2, #3) exceeded the criterion value for all species for both overspray and drift exposures. The toxicity of one product (#3) to rooted aquatic vasculars was also evident in the plant screening data (early postemergence exposure). The other two products (#1, #6) with sufficient plant screening data on rooted aquatic vasculars (exposed early postemergence) showed no potential hazard from either overspray or drift exposures.

Six products had sufficient plant screening data for analysis. Four (#1, #2, #5, #7) exceeded criterion values for species (>25%) and families (>50%) for both overspray and drift exposures (Table 2). Product #4 exceeded criterion values for an overspray but not a drift exposure. Product #6 exceeded the criterion values for both drift and overspray exposures for species but not families.

A risk assessment was conducted for each herbicide product based on its hazard profile, environmental chemistry and fate, and use pattern (Table 3). Since there were no guidelines for conducting risk assessments for nontarget plants and pesticides (or other toxicants), assessment and advice on registration were based on expert judgement and experience accumulated to date. The latter, in particular, resulted in some discrepancies among products. For example, the plant toxicity data for products #1 and #6 were considered sufficient enough at the time to complete the assessment. Restricting application to ground equipment only was recommended for both products to minimize expected hazards from overspray of prairie sloughs and associated upland vegetation in the large extent of cropland potentially treated. In addition, use of a buffer zone was recommended for product #1 because of the potential hazard to terrestrial plants from spray drift. No additional toxicity data were requested for either product. Today, a duckweed study would be requested for both products as part of a minimum data set.

Requests for additional toxicity data were recommended for products #2, #3, and #5. Field studies were considered necessary given the potential hazards evident in the laboratory and greenhouse data, and the persistence, mobility, and the large extent of the proposed use of these products (Table 3). To provide data on terrestrial species for product #3, a field study was deemed preferable to greenhouse testing. A replacement for the invalid algal study submitted for product #2 was not considered necessary at the time the assessment was done because field testing with aquatic vascular plants was requested. Today, it would be requested as part of a minimum data set. Pending evaluation of additional data, restriction to ground application only was recommended for products #2 and #3 given potential hazards from overspray. Use of buffer zones was recommended for all three products to minimize the potential hazards indicated for drift exposure.

The hazard profiles for products #4 and #7 were the most incomplete of the sample of products evaluated. For product #4, additional laboratory data were recommended for duckweed, rooted, aquatic vascular plants, and other algal species given data gaps, potential hazard evident for algae, and the persistence, mobility, and large extent of proposed use of the product. Pending evaluation of additional data, restriction to ground application only and use of buffer zones were recommended to minimize the potential hazards evident in the data submitted. Field studies were recommended for product #7 to better assess potential hazard to both aquatic and terrestrial vascular plants in the proposed use area given the data gaps, potential hazard from both overspray and drift, and the persistence, potential volatility, and large extent of proposed use of the product. In the interim, use of a buffer zone and restrictions on the crop and season of use were recommended to mitigate risk.

For the sample of products reviewed here, application was restricted to ground equipment only to minimize hazards from overspray of nontarget plants. For aerial application, more specific, supplementary data are generally needed to refine the assessment of plant damage and recovery and to incorporate ecological relevance to the proposed use area.

By and large the data provided encompass the type of tests that will be requested at the tier 1 or 2 level in the proposed Canadian guidelines (Boutin and others 1993), namely: tests with algae, duckweed species, as well as aquatic and terrestrial plant screening data generated by pesticide registrants. Seed germination and root elongation tests with vascular plants are also included in the proposed guidelines, although these data were not submitted or requested for the sample of products reviewed above.

Limitations

Risk to aquatic plants is difficult to assess from the limited data routinely submitted. Interspecific sensitivity can vary substantially among algae and vascular plants (Fletcher 1990, Swanson and others 1991). For illustration, a sample of pesticides evaluated for registration were compared (Table 4). Hazard scores for different classes and species of freshwater algae differed among the products by as much as four orders of magnitude. The least sensitive species also differed among products. Hazard scores for freshwater algae exceeded the criterion value (0.1) for an overspray exposure for 66% of species for the fungicide compared to 0%–33% of species for the herbicides. Hazard scores for the marine alga exceeded the criterion value for the fungicide and one of the three herbicides. Although the comparison is confounded by a

Table 3. Risk assessment and advice for 7 herbicides evaluated for registration in Canada since 1986

	Risk assessment					
	Hazard profile					
Herbicide	Plant type[a]	Potential hazard[b]	Potential hazard exposure[c]	Env. chemistry and fate	Use pattern and nontarget habitat(s) of concern	Advice on data needs and use pattern
1	Algae	No		Not persistent	Large ha	No data
	Duckweed	?		Not mobile	Ground/aerial	Ground only
	AVP lab.	?		Not volatile	Prairie sloughs	Buffer zone
	AVP scr.	No				
	TVP scr.	Yes	D, O			
2	Algae	?		Persistent	Large ha	AVP (field)
	Duckweed	Yes	D, O	Mobile	Ground/aerial	TVP (field)
	AVP lab.	Yes	D, O	Not volatile	Prairie sloughs	Ground only
	AVP scr.	?				Buffer zone
	TVP scr.	Yes	D, O			
3	Algae	No		Persistent	Large ha	AVP (field)
	Duckweed	Yes	D, O	Mobile	Ground/aerial	TVP (field)
	AVP lab.	Yes	D, O	Not volatile	Prairie sloughs	Ground only
	AVP scr.	Yes	O[d]			Buffer zone
	TVP scr.	?				
4	Algae	Yes	D, O	Persistent	Large ha	More algae
	Duckweed	?		Mobile	Ground/aerial	Duckweed
	AVP lab.	?		Not volatile	Prairie sloughs	AVP (lab)
	AVP scr.	?				Ground only
	TVP	Yes	O			Buffer zone
5	Algae	No		Persistent	Large ha	AVP (field)
	Duckweed	Yes	D, O	Mobile	Ground	Buffer zone
	AVP lab.	?		Not volatile	Streams/hedgerows	
	AVP scr.	?				
	TVP	Yes	D, O			
6	Algae	Yes	O	Not persistent	Large ha	No data
	Duckweed	?		Not mobile	Ground/aerial	Ground only
	AVP lab.	?		Volatile	Prairie sloughs	
	AVP scr.	No				
	TVP scr.	Yes[e]	O			
7	Algae	Yes	D, O	Persistent	Large ha	AVP (field)
	Duckweed	?		Not mobile	Ground	TVP (field)
	AVP lab	?		Volatile	Streams/hedgerows	Buffer zone
	AVP scr.	?				Restricted crop
	TVP scr.	Yes	D, O			and season

[a] TVP scr., AVP lab, AVP scr. = terrestrial or rooted aquatic vascular plants tested under laboratory conditions or plant screening data submitted by registrants.

[b] No = no hazard; ? = no data; Yes = hazard expected.

[c] D = drift; O = overspray.

[d] Assessment for drift was not possible with data provided for TVP product #3.

[e] Toxicity to grasses only.

difference in test duration, the formulated fungicide appeared to be an order of magnitude more hazardous to marine algae than the active ingredient. Formulated product is not routinely tested for regulatory purposes (Freemark and others 1990). Hazard scores for duckweed (exposed via the medium) exceeded the criterion value for two of the herbicides only. In both cases, duckweed was at least an order of magnitude more sensitive than algae. Aquatic vascular species, such as duckweed, are not routinely tested for regulatory purposes (Freemark and others 1990). As these data show, pesticides other than herbicides can be phytotoxic.

The sensitivity of aquatic species to pesticides and other toxicants can vary with environmental conditions. For example, a series of papers (Peterson and

Table 4. Hazard scores for aquatic plants tested with one fungicide and three herbicides evaluated for registration in Canada

Plant type	Chemical form tested[a]	Hazard score (test days)			
			Herbicide		
		Fungicide	1	2	3
Freshwater algae					
Class/species					
Green					
Selenastrum capricornutum	a.i.	0.05 (9)[b]	6.0[c] (12)	0.06 (7)	0.09 (5)
Scenedesmus subspicatus	a.i.	—	0.02 (5)	—	—
Diatom					
Navicula seminulum	a.i.	0.89[c] (11)	—	—	—
N. pelliculosa	a.i.	—	0.0002 (14)	0.02 (7)	0.55[c] (5)
Cyanobacteria					
Anabaena flos-aquae	a.i.	5.9[c] (11)	0.06 (14)	0.03 (7)	0.02 (5)
Marine algae					
Class/species					
Green					
Skeletonema costatum	a.i.	3.95[c] (11)	0.0008 (12)	1.06[c] (7)	0.08 (5)
	form.	24.41[c] (5)	—	—	—
Vascular freshwater					
Genus/species					
Duckweed					
Lemna gibba	a.i.	0.009 (14)	94.7[c] (14)	0.02 (14)	5.0[c] (14)

[a] a.i. = active ingredient; form. = formulated.

[b] Test duration indicated within brackets below each score.

[c] Exceeds hazard criterion value for overspray.

others 1984, Peterson and Healey 1985) showed that copper and cadmium were more toxic to *Scenedesmus quadricauda* and *Selenastrum capricornutum* at high (up to 8.5) than at low pH. Peterson (unpublished) has found that diquat was more toxic to *Anabaena* spp. and *Scenedesmus quadricauda* at pH 8 than at pH 6. Tubea and others (1981) showed that the toxicities of fluometron and prometryn to *Chlorella* were similar irrespective of pH, but that dinoseb was more toxic at low pH. Standard methods currently used for regulatory testing recommend one set of test conditions, typically *S. capricornutum* at pH 8.0. In order to customize risk assessments of pesticides for aquatic environments in different regions of Canada (e.g., acidic, neutral, or basic), it is necessary to have data where test conditions such as pH, dissolved organic carbon, and inorganics have been varied.

The utility of plant screening data for assessing risk to nontarget plants is currently limited by uncertainties in experimental design. Details are often not reported on sample size, treatment replication, potting/watering conditions, etc. The reliability of visual rating for measuring treatment effects needs further quantitative validation (such as Brown and Farmer 1991). Variability among different testing facilities also needs to be assessed. Toxicity data for woody plant species are needed to complement the data currently generated only for herbaceous species.

Merits

Compared to laboratory data, plant screening data are better suited for assessing the phytotoxic spectrum of pesticide products, particularly herbicides, because of the large number of crop and, especially, noncrop species from different families (notably herbaceous, terrestrial plants) that are tested during product development (Table 5). Whether greenhouse

Table 5. Taxonomic composition and ecological relevance of herbaceous plant species routinely tested during pesticide development[a]

Plant family		Species (#)	Genera (#)	Genera important as wildlife food (#)
Terrestrial				
Poaceae		40	26	17
Fabaceae		16	11	9
Asteraceae		15	8	5
Brassicaceae		11	9	4
Polygonaceae		7	3	3
Solanaceae		6	4	1
Chenopodiaceae		5	5	2
Malvaceae		5	4	0
Euphorbiaceae		4	1	1
Cucurbitaceae		3	3	2
Caryophyllaceae		3	3	1
Convolvulaceae		3	2	1
Apiaceae		2	2	1
Portulacaceae		2	2	2
Labiatae		2	2	0
Rubiaceae		2	2	0
Scrophulariaceae		2	1	0
Amaranthaceae		1	1	1
Linaceae		1	1	0
Ranunculaceae		1	1	1
Commelinaceae		1	1	1
Cyperaceae		1	1	1
Liliaceae		1	1	0
Violaceae		1	1	1
Asclepiadaceae		1	1	0
Caesalpiniceae		1	1	0
Papaveraceae		1	1	0
Boraginaceae		1	1	1
Total	28	139	99	54
Aquatic				
Cyperaceae		10	4	3
Alismataceae		3	2	1
Poaceae		3	3	1
Hydrocaryaceae		2	2	0
Zosteraceae		2	1	1
Pontederiaceae		1	1	0
Butomeceae		1	1	0
Ariaceae		1	1	0
Salvinaceae		1	1	0
Marsileaceae		1	1	0
Sphenochleaceae		1	1	0
Total	11	26	18	6

[a]The list was compiled from herbicide submissions and information provided by the Crop Protection Institute of Canada (from pesticide companies). Only a sample of these species are tested for any one product. Importance as wildlife food derived from Martin and others (1951).

testing overestimates or underestimates potential hazard in the field is unclear. Garrod (1989) found that less herbicide (sprayed preemergent or early postemergent) was required to obtain 75% control of ten terrestrial species in greenhouse tests compared to field trials. He attributed the reduced effect in the field to environmental factors (e.g., wind and variable temperature and rainfall in the field), plant anatomy (e.g., greater cuticle thickness in the field), and physiological states of the plant (e.g., more active growth in the greenhouse). Supplementary data evaluated for product #2 above showed that 13 species (72%) were more sensitive and five species (28%) were less sensitive in greenhouse tests than in small-plot field trials based on analyses of EC_{25}s for early postemergence spray. On average, Fletcher and others (1990) found less than a twofold difference between plant sensitivity (EC_{50}s) in the greenhouse versus field trials with 13 terrestrial species and 17 herbicides from 11 different classes. In 30% of comparisons, plants treated in the greenhouse were more sensitive, 15% were equal, and 55% showed greater sensitivity of plants in the field.

Most agencies that currently consider or require phytotoxicity data for chemical registration (including pesticides) use tiered systems based initially on laboratory toxicity tests (Freemark and others 1990). For pesticides, laboratory data are usually generated for a limited number of aquatic and terrestrial species under more rigorous testing conditions than those currently used for plant screening data in order to meet good laboratory practice requirements. Under the Federal Insecticide, Fungicide and Rodenticide Act in the United States, no herbicide phytotoxicity data are required if applied with ground equipment only or if volatility is low ($<1.0 \times 10^{-5}$ mm Hg) or water solubility is low (<10 ppm) (Lewis and Petrie 1991). When testing for vegetative vigor of terrestrial plants is required, ten crop species must be used comprised of six dicots (including soybean and a root crop) from four families, and four monocots (including corn) from two families (USEPA 1982). If the EC_{25} for any species is greater than the EEC (as outlined in Lewis and Petrie 1991), then field testing is required. Using our EEC values and the EPA zero-risk approach (i.e., toxicity to one species triggers further testing regardless of environmental chemistry, fate, and use pattern) for a subsample of the plant screening data reviewed above (comparable to the ten species recommended by EPA), all six of the herbicide products with sufficient data for analysis would have triggered field testing. In contrast, because of the large number and variety of both crop and especially noncrop species and families routinely tested, expert opinion can be used to integrate all of the plant screening data with other factors to assess varying degrees of risk associated with alternative use patterns (which incorporate mitigative measures) for each product. Using this approach, field testing was judged advisable for only four of the six products (assuming application by ground equipment only). A similar comparison can be made with the chemical testing guidelines of the Organisation for Economic Co-operation and Development. For terrestrial plants, OECD (1984b) recommends testing with three species from two or three families. No tier progression criteria are specified. Based on a comparable sample from the plant screening data submitted and our EEC values, all products trigger further testing at the ecosystem level.

About 55% of terrestrial plant genera and 33% of aquatic plant genera routinely screened during product development are ecologically relevant to wildlife as food (Table 5). Among terrestrial plants, many species of the Poaceae, Fabaceae, and Asteraceae families are routinely tested and many genera are important as wildlife food. Among aquatic plants, many species of the Cyperaceae family are tested and most genera are important as wildlife food. Alternative measures of ecological relevance could also be used, such as taxonomic affiliation with endangered species (R. Brown personal communication) or importance as nesting cover for wildlife (Sheehan and others 1987). At present, ecological significance of plant species included in the hazard profile of a pesticide product evaluated for registration in Canada is not routinely incorporated into the risk assessment for nontarget plants.

Discussion and Future Directions

Formal guidelines for testing and evaluating pesticide toxicity to nontarget plants need to be developed and enforced by most regulatory agencies and/or jurisdictions, including Canada. Even for jurisdictions with existing guidelines, nontarget-plant hazard and risk assessment of pesticides is rudimentary at present because of limitations in test requirements, protocols, and hazard and risk assessment methods (as illustrated above; see also Freemark and others 1990, OECD 1989).

Some degree of toxicity testing should be required for all pesticides since products other than herbicides (e.g., fungicides, insecticides) can also be phytotoxic at environmentally relevant concentrations (as illustrated above; see also Swanson and others 1991). In the testing guidelines currently being drafted for Canada (Boutin and others 1993), the general phytotoxic potential of a pesticide is evaluated at a first tier or screening level from toxicity data generated using the active ingredient at the maximum label rate proposed. Data are to be submitted for plant screening tests of terrestrial and rooted aquatic vascular species routinely generated by registrants (minimum ten species from six families but usually around 30 species from ten families for herbicides), and for algal growth inhibition tests conducted with three species of freshwater algae and three species of marine algae from three algal classes (Chlorophyte, Cyanophyte, Diatom, Chrysophyceae, or Bacillariophyceae). Any statistically significant phytotoxic response, or growth inhibition of greater than 25% (plant screening data) or 50% (algae), triggers further testing with the active ingredient and formulated product to generate dose–response data for different types of plants for which protocols are available.

A standard test protocol has recently been developed for freshwater and marine algal species from a variety of taxonomic classes (ASTM 1991a). However, species sensitivity under different test conditions (e.g., pH, dissolved organic carbon, nutrient source, nutrient limitation) still needs to be examined to better predict potential effects under different use patterns (Swanson and others 1991).

Test protocols for emergent and submerged rooted aquatic vascular plants need to be developed and standardized. A seed germination/root elongation test is currently being developed for aquatic vascular plants (APHA/AWWA/WEF 1992). A standard protocol for conducting static toxicity tests with *Lemna gibba* has recently been published by the American Society for Testing and Materials (ASTM 1991b). Further methods development may be required to address concerns about differential sensitivity among different routes of exposure (Lockhart and others 1989).

The comparability of plant screening data submitted by different registrants needs to be evaluated. More rigor may be required in the experimental design(s) currently used (Brown and Farmer 1991). The validity of the EC_{25} as an adverse-effect level for calculating hazard scores for both aquatic and terrestrial vascular plants needs to be ascertained. The ecological relevance of test species (particularly those used in plant screening) needs to be more fully assessed. Testing with woody plant species, currently available for forestry products only, is needed for all products to complement the data currently generated for herbaceous species. Information on the mode of action of phytotoxic pesticides could be useful for customizing test requirements, interpreting test results, and conducting risk assessments.

More realistic estimates of the EEC are needed to improve the calculation of hazard scores. Regulatory task groups in both Canada and the United States are currently addressing this need, particularly in relation to drift. The calculation of hazard scores is currently limited by the small quantity and variable quality of toxicity data and the rudimentary nature of the EEC estimates available. The criterion values currently used to interpret hazard factors need to be validated, particularly for plant species other than algae. The composition and/or ecological importance of species showing a toxic response needs to be incorporated into the interpretation of hazard factors (particularly for vascular plants). Cases where the EC_{25} is less than the environmental detection limit should be of particular concern.

The spatial patterning of habitats in agricultural landscapes in different areas needs to be quantified to improve exposure scenarios used to estimate risk to nontarget plants. More detailed information on the composition and ecological importance of plant species within farmland habitats is also needed.

More quantitative methods for estimating risk to nontarget plants from proposed or continuing use of pesticides need to be developed. Phytotoxic impacts in the field need to be identified and quantified in order to improve risk assessments (cf. OECD 1989, Freemark and others 1990) and any additional field tests that may be advised.

Although field testing has been recommended, clear, cost-efficient field tests are difficult to design at present because of the limited standardized physicochemical and ecotoxicological data available, and the paucity of information on risks associated with specific use patterns. Although attractive from a regulatory perspective, standardization of field tests (or harmonization among different regulatory jurisdictions) is unrealistic because the type of field study to be done depends on the question(s) to be answered, and this is likely to differ from product to product, from use pattern to use pattern, and from region to region. In addition, we agree with van Leeuwen (1990) that the need for standardization would impose an unreasonable loss of ecological and environmental reality. However, guidelines (i.e., steps that need to be followed to develop a suitable protocol) can be provided and, in our experience, should include the following: a clear articulation of the problem(s), use of multiple doses to differentiate a dose–response relationship from inherent environmental variability, selection of appropriate response variables (e.g., individual species vs species assemblage level), selection of appropriate end points (e.g., growth, reproduction, cover, species number and/or abundance), a priori specification of an adverse effect, selection of appropriate sampling design and statistical analyses (e.g., sample size, replication, parametric vs nonparametric statistics, univariate vs multivariate analyses), site selection, quality assurance, quality control, and reporting requirements. van Leeuwen (1990) suggests that ecosystem-level field studies should not be attempted until toxicity studies at the population level under more or less realistic conditions have been done because it is difficult to explain toxicological effects on ecosystems in terms of causal relationships until the physicochemical behaviour of chemicals and the dynamics of at least a number of key species and processes is understood.

Measures currently being advised to mitigate risk to nontarget plants (e.g., 15 m buffer zones) need to be critically evaluated by computer-modeling and field studies in North America. Alternate measures, such as pesticide exclusion strips or conservation headlands (Hald and Elmegaard 1988, Sotherton 1991) need to be evaluated in North America.

An additional component that is just now being incorporated into the Environment Canada approach is risk management (Figure 1). Risk management initiatives are intended to complement the advice provided to regulatory agencies to prevent and/or mitigate exposure of and adverse effects on nontarget plants from the use of pesticides. Options that have been pursued by Environment Canada include: product monitoring and evaluation during conditional registration, critical reviews of registered pesticides known to be or suspected of being phytotoxic, and education of farmers and pesticide control officers (among other users) through seminars and pamphlets.

Ecological risk assessment and management for toxic chemicals is in an early stage of development, particularly for terrestrial ecosystems (Bartell and others 1992, Levin and others 1989, OECD 1989, Suter 1993). Much work is needed before plant concerns can be incorporated effectively into decision making for pesticides (and other toxicants). This task will be even more challenging in future with the trend in risk assessment away from "end-of-pipe" control towards assessing the aggregate of stresses (some natural, some anthropogenic) at the level of ecosystems or landscapes (Costanza and others 1992, Cairns 1993a,b, Fahrig and Freemark 1993, Levin and others 1989). Compared to current approaches, an ecosystem-level or landscape-level perspective will require much more integration and a wider diversity of information including plants.

Conclusions

Since 1986, Environment Canada has been developing an approach for assessing potential risk to nontarget plants from pesticides submitted for registration. We have described and illustrated our approach in this paper in an attempt to stimulate discussion among all sectors interested in the environmentally responsible registration and use of pesticides, and in the hope that regulatory agencies in other countries and/or jurisdictions can benefit from our experience.

Plant guidelines currently used in other countries (OECD 1981, 1984a,b, USEPA 1982) do not incorporate the considerable amount of research completed in the last decade. The results of our efforts have been useful for developing formal up-to-date guidelines for plant risk assessment for registering pesticides. Marked improvement to current procedures is noteworthy in several areas. First, the use of the plant screening data for assessing vegetative growth and vigor (despite its limitation) is a major contribution since these data, routinely generated by registrants, represent the general spectrum of activity of a given herbicide for terrestrial vascular species and some aquatic species, at low expense for registrants. The consideration of the relationship between toxicological effects, environmental chemistry and fate characteristics, application rates and methods, and requested use patterns is an added refinement not considered in the past for the establishment of advisory options and risk management. Our efforts are concomitant with the increasing interest in plant toxicity testing and risk assessment in the research community (Bartell and others 1992, Gorsuch and others 1991, Suter 1993, Wang and others 1990), professional organizations (e.g., Society for Environmental Testing), and regulatory agencies (e.g., Organisation for Economic Co-operation and Development, European and Mediterranean Plant Protection Organization) in North America and Europe.

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