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Pesticides selectivity list to beneficial arthropods in four field vegetable crops

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Abstract: Selectivity of pesticides to beneficial arthropods is a key data for the implementation of IPM program. In the context of field vegetable crops, a set of 16 fungicides, 16 herbicides and 13 insecticides commonly used in Belgium were tested on 5 indicator species: the parasitic hymenoptera *Aphidius rhopalosiphi* (De Stefani-Perez) (Hym., Aphidiidae), the aphid foliage dwelling predators *Adalia bipunctata* (L.) (Col., Coccinellidae) and *Episyrphus balteatus* (Dipt., Syrphidae) and the ground-dwelling predators *Aleochara bilineata* (Col., Staphylinidae) and *Bembidion lampros* (Col., Carabidae).

Pesticides were tested according to a testing scheme including a first assessment on inert substrate and, for products that were toxic, a second assessment on natural substrate. The effects of the product were assessed on basis of onion fly pupae parasitism reduction for *A. bilineata* and on basis of corrected mortality for the 4 remaining species. According to the final results obtained at the end of this testing scheme, the products were listed in toxicity classes: green list if effect ≤30%, yellow list 30% < effect ≤ 60% and orange list 60% < effect ≤ 80%. Products with toxicity higher than 80% on plants or on soils, or that reduce parasitism more than 80% on soil were put in the red list and are not recommended for IPM.

Results showed that all fungicides and herbicides were included in the green list except tebuconazole and boscalid + pyraclostrobin that were labeled as yellow for *A. bipunctata*. In opposite, no foliar insecticide was totally selective for all beneficial tested. However some products are in green list for one or several species. Soil insecticides were all very toxic for ground dwelling arthropods and classed in red list.

In conclusion, fungicides and herbicides tested are compatible with IPM programs. For foliar insecticides, some treatments can be used carefully according to the selectivity. But for soil insecticide treatments, their toxicity raise the question of their use in IPM programs in vegetables and the need of new compounds or development of alternative pest control programs.

Key words: *Adalia bipunctata, Aleochara bilineata, Aphidius rhopalosiphi, Bembidion lampros, Episyrphus balteatus*, selectivity list, vegetable

Introduction

In vegetable production in open field, as in other crops, beneficial arthropods are a key factor in the biological control of several pests (Hughes & Salter, 1959; Read, 1962; Coaker & William, 1963; Lövei & Sunderland, 1996). In the context of a sustainable agriculture and IPM implementation, these beneficial arthropods must be preserved from adverse effects, especially from non-selective pesticides. By eliminating pest natural enemies, non selective insecticides can enhance pest outbreak, with population levels that even reach higher levels than those observed without any insecticide treatment (Ripper, 1956; Pimentel, 1961; Besemer, 1964; Vickerman & Sunderland, 1977; Croft & Slone, 1998). Resurgence of pests of secondary importance, simply because their natural enemies have been eliminated is also a consequence of the use of non-selective compounds, even with a simple fungicide or herbicide application (Nanne & Radcliffe, 1971; Sotherton & Moreby, 1988; Lagnaoui & Radcliffe, 1998). Both pest outbreak and pest resurgence multiply pest problems and insecticide use, increase cost production and negative impact of pest control on human health and environment. This situation could be avoided at the beginning, if selective pesticide were available and used instead of non-selective compounds. Actually, there is a trend to try to use selective products, as claimed by certification standard guidelines as EUREPGAP and Chart PERFECT. However, clear information that can directly be used by producers and pesticide users are missing.

In the context of IPM implementation and pesticide users information, the selectivity of pesticides used in Belgium in carrot, onion, pea and bean has been determined according to the methodology previously used for building the selectivity list in potato (Hautier *et al.,* 2006). 16 fungicides, 16 herbicides and 13 insecticides have been tested on 2 to 5 beneficial arthropods species selected as indicator species for these crops. According to the results obtained, products were rated in different toxicity classes and selectivity lists were established.

Material and methods

Products that were taken into consideration are listed in table 1. A first bibliographic survey for products that were well documented was carried out and data were retained when the methods used fulfill the IOBC standard (Hassan, 1994) and were similar or close to those used to build the selectivity list (residual contact toxicity test with inert and/or natural substrate, susceptible life stage, product application and tested rate, exposure time, ...). Only clear results, products that were undoubtedly harmless or harmful at the recommended field rate for Belgium, were retained. All the other products were assessed for toxicity.

Toxicity tests were realized on 2 to 5 different species, according to the use of the product (crop, timing of application and beneficial exposition risk). The tested species were: adult of the parasitic wasp *Aphidius rhopalosiphi* De Stefani-Perez (Hym.; Aphidiidae), larvae of the ladybird *Adalia bipunctata* (L.) (Col.; Coccinellidae) and the hoverfly *Episyrphus balteatus* (De Geer.) (Dipt.; Syrphidae), adults of the carabid beetle *Bembidion lampros* (Herbst.) (Col.; Carabidae) and the rove beetle *Aleochara bilineata* Gyll. (Col.; Staphylinidae).

Toxicity tests fulfilled the SETAC recommendations (Barrett *et al.*, 1994). Details of testing methods for *A. rhopalosiphi*, *A. bipunctata* and *E. balteatus* are available from previous work (Copin et al., 2001; Hautier et al., 2006). Methods used for *B. lampros* were similar as those used for *Poecilus cupreus* (Heimbach et al., 2000), except for insect origin (field collected beetles instead of laboratory rearing) and feeding (*Ephestia kuehniella* sterilized eggs instead of fly pupae, no assessment of feeding capacity). For *A. bilineata*, methods followed were those described by Grimm et al. (2000). Both methods for rove and carabid beetles were validated and used in the context of pesticide registration at European level.

Pesticides were tested at the maximum recommended field rate for one application, on basis of available commercial formulations. Herbicides were only tested on the carabid and rove beetle, as the exposure risk for plant dwelling predator and parasitoid was negligible or inexistent. Insecticides and fungicides were tested on the 5 species. Most products were applied as spray mixtures in water, with rates of 200 l x ha^{-1} ± 10% on glass plates and 400 l x ha^{-1} ± 10% on sand and soil. Thiram was applied as dusting powder and, when required, soil insecticides were incorporated into the soil as granule.

For all products, tests followed a classical IOBC testing scheme (fig 1.) Pesticides were first tested at their maximum field rate on an inert substrate (glass plates or sand). Products that lead to effects (mortality or reduction in parasitism rate with *Aleochara*) higher than 30% were further tested on natural substrate (plants or soils). For the ground-dwelling beneficials, two different soils, one sandy-loamy soil (Soil "A") and one loamy-clayed soil (Soil "B") were used. Soil characteristics are given in table 2. According the results of the tests, products were labeled as harmless and included in a green list (class 1), slightly harmful – yellow list (class 2), moderately harmful – orange list (class 3) and harmful – red list (class 4). The green list includes all selective compounds and the red list all harmful products that must be avoided if possible. Yellow and orange list comprise intermediate products, that have to be used carefully, when no equivalent in the green list exists or for very specific uses, as pest resistance management.

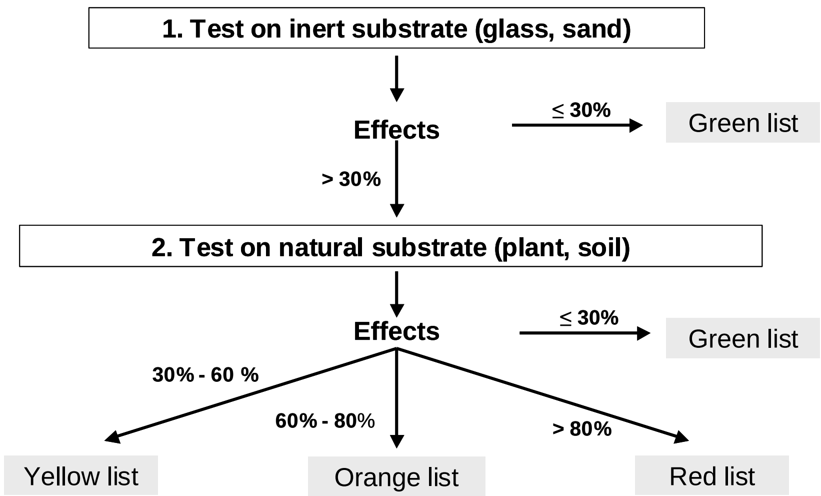

Figure 1. Sequential testing scheme of pesticide selectivity assessment

Results and discussion

Parasitic hymenoptera: Aphidius rhopalosiphi

Results of tests carried out with *A. rhopalosiphi* are listed in table 3. All results were provided by toxicity tests (no bibliographic data). As there was no risk of exposure, the herbicides applied in field vegetables crops were not assessed on this species.

Table 1: List of tested products. Commercial name, formulation type, active(s) ingredient(s) and tested dose. (* sowing line applied insecticide= product /m of sowing line)

	Active(s) ingredient(s)	Formu-lation	Commercial name	Tested dose / ha
Insecticides	Alpha-cypermethrin	EC	Fastac	0.25 l
	Bifenthrin	SC	Talstar 8	0.5 l
	Carbofuran	GR	Curater	1.25 g*
	Carbosulfan	GR	Sheriff 1 Gr	6.25 g*
	Chlorpyriphos-ethyl	GR	Dursban 5G	34 g/m²
	Deltamethrin	WG	Décis Micro	200 g
	Diazinon	SC	Disonal	8.5 l
	Dimethoate	EC	Hermootrox	0.5 l
	Lambdacyhalothrin	CS	Karate Zeon	0.1 l
	Methiocarb	SC	Mesurol 500	1.5 l
	Pirimicarb	WG	Pirimor	250 g
	Pirimicarb + lambdacyhalothrin	EC	Okapi	1.5 l
	Pyrethrins (plant extract)	EC	Bio-pyretrex	5 l
Fungicides	Azoxystrobin	SC	Ortiva	1 l
	Boscalid + pyraclostrobin	WG	Signum	750 g
	Chlorothalonil	SC	Bravo	4.5 l
	Difenoconazole	EC	Geyser	0.5 l
	Dimethomorph + mancozeb	WG	Acrobat extra	2500 g
	Dithianon	WG	Ditho	1800 g
	Fluazinam	SC	Shirlan	0.5 l
	Iprodione	WG	Rovral	1000 g
	Mancozeb	WG	Dequiman	3200 g
	Maneb	WG	Tricarbamix extra	6300 g
	Myclobutanil	EC	Systhane 24	0.25 l
	Procymidone	SC	Sumisclex	1 l
	Sulfur	WG	Hermovit	5000 g
	Tebuconazole	EW	Horizon	1 l
	Thiram	DP	Luxan thiram 100	20000 g
	Vinclozolin	SC	Ronilan	1.5 l
Herbicides	Bentazone	SG	Basagram	800 g
	Chlorpropham	EC	Chloor IPC	6 l
	Clomazone	CS	Centium 360	0.25 l
	Cycloxydim	EC	Focus Plus	6 l
	Fluazifop-P-butyl	EC	Fusilade	2 l
	Glufosinate-ammonium	SL	Basta S	3 l
	Glyphosate	SG	Roundup energy	3700 g
	Isoxaben	SC	AZ 500	0.2 l
	Linuron	SC	Linuron 500	1 l
	Metoxuron	WP	Dosanex	4500 g
	Paraquat	SL	Gramoxone	5 l
	Paraquat + diquat	SL	Priglone	5 l
	Pendimethalin	SC	Stomp 400	2.5 l
	Propachlor	SC	Ramrod	10 l
	Quizalofop-ethyl D	EC	Targa Prestige	1.5 l
	Tepraloxydim	EC	Aramo	2 l

Table 2: Textural and physicochemical characteristics of different substrates used.

	Texture (%)			Chemical characteristics		
	Sand	Loam	Clay	organic C (g/kg)	Humus (%)	CEC (meq/100g)
Sand (inert subtstrate)	100	0	0	0	0	0
Sandy loam (soil A)	72.7	18.9	8.3	14.2	2.8	8.22
Loamy-clayed (soil B)	6.6	76.2	17.2	8.9	1.8	13.54

Table 3: Result of toxicity test with *A. rhopalosiphi*, corrected mortality (A=glass plate, B=extended lab) and selectivity class: 1–harmless, 2-slightly harmful, 3-moderately harmful and 4-harmful.

		A	B	Class
Insecticides	Alpha-cypermethrin	100%	38%	2
	Bifenthrin	100%	83%	4
	Delthamethrin	100%	75%	3
	Dimethoate	100%	100%	4
	Lambda-cyalothrin	100%	1%	1
	Methiocarb	100%	100%	4
	Pirimicarb	100%	12%	1
	Pirimicarb + lambdacyalothrin	100%	3%	1
	Pyrethrins (plant extract)	100%	97%	4
Fungicides	Azoxystrobin	63%	7%	1
	Boscalid + pyraclostrobin	4%	-	1
	Chlorothalonil	10%	-	1
	Difenoconazole	0%	-	1
	Dimethomorph + mancozeb	2%	-	1
	Dithianon	35%	24%	1
	Fluazinam	8%	-	1
	Iprodione	6%	-	1
	Mancozeb	6%	-	1
	Maneb	0%	-	1
	Myclobutanil	4%	-	1
	Procymidone	11%	-	1
	Sulfur	17%	-	1
	Tebuconazole	92%	5%	1
	Thiram	98%	0%	1
	Vinclozolin	0%	-	1

Ground dwelling predators: Aleochara bilineata and Bembidion lampros

On basis of bibliographic analysis, the insecticides carbofuran, chlorpyriphos-ethyl, diazinon and dimethoate were rated as harmful for carabid and rove beetles according to their high toxicity for these insects (Mowat & Coaker, 1967; Hassan, 1969; Edwards & Thompson, 1975; Finlayson, 1979; Finlayson *et al.,* 1980; Kirknel, 1978; Cockfield & Potter, 1983; Vickerman *et al.,* 1987; Floate et al., 1989; Kegel, 1989; Casteels and De Clerq, 1990; Bale *et* *al.,* 1992; Samsøe-Petersen, 1993; Sivasubramanian & Wratten, 1995). On the opposite, pirimicarb was included in the green list according to its selectivity for these ground dwelling beneficial insects (Unal & Jepson, 1992; Samsøe-Petersen, 1993).

Table 4. Result of toxicity test with *B. lampros* and *A. bilineata,* corrected mortality on sand, and soil A and B. Selectivity class: 1–harmless, 2-slightly harmful, 3-moderately harmful and 4-harmful.

		A. bilineata test				*B. lampos* test			
		Sand	Soil A	Soil B	Class	Sand	Soil A	Soil B	Class
Insecticides	Carbosulfan	100%	100%	100%	4	100%	97%	100%	4
	Deltamethrin	100%	55%	30%	1-2	72%	13%	30%	1
	Lambdacyhalothrin	100%	100%	84%	4	100%	10%	10%	1
	Methiocarb	100%	99%	100%	4	100%	100%	100%	4
	Pirimicarb + lambdacyhal.	100%	99%	100%	4	96%	20%	17%	1
	Pyrethrins (plant extract)	100%	0%	0%	1	100%	80%	43%	2-3
Fungicides	Azoxystrobin	1%	-	-	1	4%	-	-	1
	Boscalid + pyraclostrobin	0%	-	-	1	0%	-	-	1
	Difenoconazole	0%	-	-	1	20%	-	-	1
	Dimethomorph +mancozeb	0%	-	-	1	0%	-	-	1
	Dithianon	0%	-	-	1	0%	-	-	1
	Fluazinam	5%	-	-	1	0%	-	-	1
	Iprodione	0%	-	-	1	0%	-	-	1
	Mancozeb	24%	-	-	1	0%	-	-	1
	Maneb	0%	-	-	1	0%	-	-	1
	Myclobutanil	0%	-	-	1	4%	-	-	1
	Sulfur	0%	-	-	1	0%	-	-	1
	Tebuconazole	-	-	-	1	0%	-	-	1
	Vinclozolin	0%	-	-	1	0%	-	-	1
Herbicides	Bentazone	0%	-	-	1	4%	-	-	1
	Chlorpropham	100%	7%	0%	1	100%	0%	10%	1
	Clomazone	0%	-	-	1	14%	-	-	1
	Cycloxydim	-	-	-	1	0%	-	-	1
	Fluazifop-p-butyl	-	-	-	1	4%	-	-	1
	Glufosinate-ammonium	-	-	-	1	7%	-	-	1
	Glyphosate	-	-	-	1	0%	-	-	1
	Isoxaben	2%	-	-	1	0%	-	-	1
	Linuron	16%	-	-	1	10%	-	-	1
	Metoxuron	2%	-	-	1	3%	-	-	1
	Paraquat	1%	-	-	1	3%	-	-	1
	Paraquat + diquat	18%	-	-	1	3%	-	-	1
	Pendimethalin	29%	-	-	1	0%	-	-	1
	Propachlore	0%	-	-	1	19%	-	-	1
	Quizalofop-ethyl D	2%	-	-	1	30%	-	-	1
	Tepraloxydim	0%	-	-	1	0%	-	-	1

With herbicides and fungicides, Samsøe-Petersen (1995a,b) has concluded that cycloxydim and tebuconazole were not toxic for *A. bilineata*. Fluazifop-p-butyl and glyphosate were also harmless for this rove beetle (Naton, 1989), as glufosinate was (EFSA Scientific Report, 2005). For the other products, no pertinent information was found in the literature and they were tested according to the sequential testing scheme described. All the results are listed in table 4.

Foliage dwelling predators: Adalia bipunctata and Episyrphus balteatus

Results of tests carried out with *A. bipunctata* and *E. balteatus* larvae are listed in table 5. As for *A. rhopalosiphi*, no herbicides were assessed on these insects due to no or little exposure risk.

Table 5. Result of toxicity test with *A. bipunctata* and *E. balteatus,* corrected mortality (A=glass plate, B=extended lab) and selectivity class: 1–harmless, 2-slightly harmful, 3-moderately harmful and 4-harmful.

		A. bipunctata test			*E. balteatus* test		
		A	B	Class	A	B	Class
Insecticides	Alpha-cypermethrin	100%	100%	4	16%	-	1
	Bifenthrin	100%	100%	4	68%	16%	1
	Delthamethrin	100%	100%	4	75%	77%	3
	Dimethoate	100%	100%	4	100%	100%	4
	Lambda-cyalothrin	100%	100%	4	0%	-	1
	Methiocarb	100%	100%	4	100%	100%	4
	Pirimicarb	21%	-	1	80%	94%	4
	Pirimicarb + lambdacyalothrin	100%	100%	4	100%	100%	4
	Pyrethrin (plant extract)	100%	100%	4	100%	70%	3
Fungicide	Azoxystrobin	21%	-	1	14%	-	1
	Boscalid + pyraclostrobin	80%	60%	2	0%	-	1
	Chlorothalonil	0%	-	1	21%	-	1
	Difenoconazole	3%	-	1	21%	-	1
	Dimethomorph + mancozeb	0%	-	1	17%	-	1
	Dithianon	17%	-	1	0%	-	1
	Fluazinam	100%	20%	1	0%	-	1
	Iprodione	30%	-	1	10%	-	1
	Mancozeb	3%	-	1	0%	-	1
	Maneb	0%	-	1	16%	-	1
	Myclobutanil	0%	-	1	0%	-	1
	Procymidone	53%	13%	1	0%	-	1
	Sulfur	45%	11%	1	7%	-	1
	Tebuconazole	96%	32%	2	10%	-	1
	Thiram	61%	7%	1	10%	-	1
	Vinclozolin	13%	-	1	10%	-	1

Discussion

Results obtained from this study (table 6), including bibliographic analysis, showed that most herbicides and fungicides actually registered can be considered as safe for the 5 beneficial species tested. Among 101 tests with herbicides and fungicides, only 2 combinations (boscalid + pyraclostrobin and tebuconazole) were slightly toxic for ladybirds, all the other being finally harmless for all species, even if some of them were first harmful on glass plates. According to the slight effect level observed for the two combinations under extended laboratory conditions, no adverse effects are expected in the field. This very low toxicity is probably the direct consequence of the 91/414 EEC application, harmful fungicides or herbicides being more difficult to register than in the past, when no specific requirements for beneficial arthropods were available.

With insecticides, the situation is not so simple. If some products were harmless for one or more species, no insecticide was harmless for the 5 species tested. The most severe problem occurred for soil applied insecticides and soil dwelling predators. All the products used in this context (carbofuran, carbosulfan, chlorpyriphos-ethyl and diazinon) were harmful to both rove beetle and carabid beetle. These both insects are the only tested that can play a significant role in the control of soil insect pests as the carrot fly, the main pest problem in carrots in Belgium. Consequently, the use of chemical control for this pest together with biological or integrated control are completely impossible. Thus, for these pest, new insecticides that can be used in combination with beneficial insects or alternative control methods are urgently needed to limit pesticide use. This point has been strengthened as these toxic products were not included in the Annex I of the European pesticide list and thus cannot be used in the future.

With foliar insecticides, the situation can be totally different between products. While insecticides as dimethoate and methiocarb are harmful (class 4) for all beneficial species, other products can be harmless or harmless/slightly harmful for 3 or 4 in 5 species tested. For example, pirimicarb was only toxic for *E. balteatus* and lambdacyhalothrin was toxic for *A. bipunctata* and *A. bilineata* but safe for the three remaining species. Thus, with the availability of several foliar insecticides, the preservation of natural enemies of insect pests and effective chemical control could be compatible by appropriate selection of the product and treatment timing. However, number of selective products is actually quite limited and new products are welcome especially in vegetables. New selective insecticides as pymetrozine or flonicamide used in other crop could be a solution for aphid control, but products with a similar ecotoxicological profile are required for other pests.

Results obtained with natural pyrethrin extracts (Bio-Pyretrex®), an insecticide registered in organic farming, showed that this insecticide has the same impact on natural enemies than synthetic pyrethroids as deltamethrin or bifenthrin. The use of such products in organic farming can be criticized in term of their compatibility with biological control, even if this product is short-lived.

A comparison of the sensitivity of the different species to the same products is indicating that at ground level, *A. bilineata* is probably a little more sensitive than *B. lampros*. For the other beneficials, final toxicity classes were indicating that *A. rhopalosiphi* is not a sensitive species under extended laboratory conditions, with several products more toxic on plants for *A. bipunctata* or *E. balteatus* than for the parasitic wasp. Thus, if this species can be a highly sensitive species on glass plates and therefore selected as an indicative species for beneficial in the context of pesticide registration at European level, the question of the use of extended laboratory study data with this species as an indication of toxicity for larger group species than parasitic hymenoptera can be criticized.

Table 6: Selectivity list of products used in carrots, beans, peas and onions. Class: 1–harmless, 2-slightly harmful, 3-moderately harmful and 4-harmful. Under bracket= bibliographic data, others= toxicity test on inert and on natural substrates in the laboratory.

	Active(s) ingredient(s)	Rove beetle *A. bilineata*	Carabid beetle *B. lampros*	Parasitoid *A. rhopalosiphi*	Hoverfly *E. balteatus*	Ladybird *A. bipunctata*
Insecticides	Alpha-cypermethrin	-	-	2	1	4
	Bifenthrin	-	-	4	1	4
	Carbofuran	(4)	(4)	no risk of exposure (soil insecticide)		
	Carbosulfan	4	4			
	Chlorpyriphos-ethyl	(4)	(4)			
	Deltamethrin	2	1	3	3	4
	Diazinon	(4)	(4)	no risk of exposure (soil insecticide)		
	Dimethoate	(4)	(4)	4	4	4
	Lambda-cyhalothrin	4	1	1	1	4
	Methiocarb	4	4	4	4	4
	Pirimicarb	(1)	(1)	1	4	1
	Pirimicarb + l-cyhalothrin	4	1	1	4	4
	Pyrethrins (plant extract)	1	3	4	3	4
Fungicides	Azoxystrobin	1	1	1	1	1
	Boscalid + pyraclostrobin	1	1	1	1	2
	Chlorothalonil	-	-	1	1	1
	Difenoconazole	1	1	1	1	1
	Dimethomorph + mancozeb	1	1	1	1	1
	Dithianon	1	1	1	1	1
	Fluazinam	1	1	1	1	1
	Iprodione	1	1	1	1	1
	Mancozeb	1	1	1	1	1
	Maneb	1	1	1	1	1
	Myclobutanil	1	1	1	1	1
	Procymidone	-	-	1	1	1
	Sulfur	1	1	1	1	1
	Tebuconazole	1	1	1	1	2
	Thiram	-	-	1	1	1
	Vinclozolin	1	1	1	1	1
Herbicides	Bentazone	1	1	no or low exposure risk		
	Chlorpropham	1	1			
	Clomazone	1	1			
	Cycloxydim	1	1			
	Fluazifop-P-butyl	1	1			
	Glufosinate-ammonium	1	1			
	Glyphosate	1	1			
	Isoxaben	1	1			
	Linuron	1	1			
	Metoxuron	1	1			
	Paraquat	1	1			
	Paraquat + diquat	1	1			
	Pendimethalin	1	1			
	Propachlor	1	1			
	Quizalofop-ethyl D	1	1			
	Tepraloxydim	1	1			

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