DRAWING-UP OF PESTICIDE SELECTIVITY LISTS TO BENEFICIAL ARTHROPODS FOR IPM PROGRAMMES IN POTATO

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ABSTRACT

In order to promote IPM programmes in potato, the toxicity of 19 fungicides, 4 herbicides and 11 insecticides commonly used in this crop in Belgium was assessed on three beneficial arthropods. These species were representative of the most important aphid specific natural enemies encountered in potatoes: a parasitic wasp - *Aphidius rhopalosiphi* (De Stefani-Perez) (Hym., Aphidiidae), a ladybird - *Adalia bipunctata* (L.) (Col., Coccinellidae) and a hoverfly - *Episyrphus balteatus* (Dipt., Syrphidae).
In a first time, pesticides were tested on glass plates on *A. rhopalosiphi* adults and *A. bipunctata* and *E. balteatus* larvae. For each insect, products inducing corrected mortality (Mc) lower than 30% were directly classified in a positive list for harmless products (green list). The other compounds were further tested on plants and listed in toxicity classes according to mortalities induced during this extended laboratory test: harmless (Mc<30%), slightly harmful (30%<Mc<60%), moderately harmful (60%<Mc< 80%) and harmful (Mc>80%). A chemical determination of pesticides residues was also performed for each experiment in order to determine the exposure of beneficial arthropods to pesticide residues and to validate the application of chemicals on tested substrates.
On the basis of the results of acute toxicity tests, the period of each pesticide use according to normal agricultural practices and the abundance and importance of the three different groups of aphid natural enemies at different periods of the year, four pesticides lists were built up. Each list corresponded to a different period of pesticides application: Period I - from seedling to beginning of June (based on *A. rhopalosiphi* tests), Period II - beginning to end of June (based on *A. rhopalosiphi* tests), Period III - beginning to end of July (based on *E. balteatus* and *A. bipunctata* tests) and Period IV - August to harvest (no exposure of beneficials).
Results showed that herbicides were not toxic to the three species and can be used according to normal agricultural practices without restrictions. All fungicides can also be used without restrictions at recommended rates. Only the mixture Metalaxyl-M + Fluazinam was slightly harmful to *A. bipunctata* but had no effects on *A. rhopalosiphi* and *E. balteatus*. Results were more contrasted for insecticides and none of them was totally selective for all the 3 beneficial arthropods. Therefore, they can only be used with restrictions at periods II and III, according to the beneficial species that need to be protected.

INTRODUCTION

The use of non selective pesticides towards beneficial arthropods can have serious consequences on the efficiency of biological pest control. Parasites and predators suppression can lead to a pest growth and an increase of the insecticides treatments (Ripper, 1956; Pimentel, 1961; Besemer, 1964; Vickerman & Sunderland, 1977; Shires, 1985; Borgemeister & Poehling, 1989; Croft & Slone, 1998).

Resurgence of pest considered as economically secondary is another frequent consequence of the use of non-selective insecticides, herbicides or fungicides (Adams & Drew, 1965; Nanne & Radcliffe, 1971; Brown, 1978; Sotherton *et al.*, 1987; Sotherton & Moreby, 1988; Lagnaoui & Radcliffe, 1998). As a result, the use of non selective pesticides, its direct consequences on beneficial arthropods and the effect on pests populations lead to a multiplication of pesticides treatments, an increase of production cost and finally a negative impact on health and environment. In the context of sustainable agriculture and implementation of integrated production systems, the use of selective pesticides towards pests natural enemies becomes necessary. Moreover, it's required for agricultural specifications and certification standards as EUREPGAP, PERFECT and GIQF.
In Belgium, on account of the humid weather in summer and the high sensitivity potato varieties to potato blight, plant protection products are often used in potato fields. Fungicide protection of this crop is complex and needs between 7 and 10 fungicides treatments in a rational system, and between 11 and 15 treatments in a non rational system from the beginning of May till the desiccation of plants (Michelante *et al.*, 1998).
Aphids can be important pests in potato and insecticides treatments are sometimes useful. Nevertheless, they are most of the times perfectly regulated, by natural enemies, as aphid parasitoid Aphidiidea and aphidophagous predators, as hoverflies and ladybirds (Jansen, 2000). It has been noticed, on the basis of ten years of field observations, that an insecticide treatment was only required for 1 field out of 6 on average (Jansen, 2002).
Regarding the importance of biological control, the use of non selective chemicals (herbicides, fungicides or insecticides) towards natural enemies can have a negative impact and can unnecessarily increase insecticide treatments.
The aim of this research was to assess toxicity of pesticides currently used in potato towards natural enemies of aphids and to provide information to the farmers with help of selectivity lists. These lists can easily be integrated now to IPM and potato inputs reduction programs. They can bring an additional support to aphids and potato blight advisory systems and allow a potato qualitative integrated production.

MATERIAL AND METHODS

The edification of selectivity lists was based on pesticides acute toxicity towards selected natural enemies, on phenology of these beneficial arthropods, and on pesticides application periods. It's therefore possible for each pesticide to know the toxicity towards important beneficial arthropods present in the field when the product is normally applied.

Beneficials phenology

Phenology of beneficials met in potato fields is based on field observations from several Belgian areas between 1994 and 2002. Observations were realised in the framework of advisory systems and populations dynamic was studied by visual inspections (Jansen, 2002).

Pesticides application

19 fungicides, 11 insecticides and 4 herbicides commonly used in potato were tested, in their commercial forms. Insecticides and herbicides were tested at the maximum authorized rate with a single application, while fungicides were tested at 1.5x single application rate to take into account possible multiple applications of the products at short intervals. All the products were applied with a pneumatic atomizer at 200 $l.ha^{-1}$ with a standard deviation percentage lower than 10%.
The rates of application of the different tested products are showed in table 1. To build up the different lists, pesticides applications periods have been established according to good agricultural practices.

Toxicity assessment

Pesticides toxicity towards beneficial arthropods was assessed according to SETAC guidelines (Barrett *et al.*, 1994) and an original methodology developed by Copin *et al.* (2001).
Three beneficial insects were selected for toxicity tests: an aphid parasitoid - *Aphidius rhopalosiphi* De Stefani-Perez (Hym.: Aphidiidae), a ladybird - *Adalia bipunctata* (L.) (Col.: Coccinellidae) and a hoverfly - *Episyrphus balteatus* (De Geer.) (Dipt.: Syrphidae).
The acute toxicity was assessed according to a sequential testing scheme. At the first step, the pesticide toxicity was evaluated on an inert substrate (glass). If the product induced a beneficial arthropod mortality higher than 30%, toxicity assessment was continued on a natural substrate (horse bean for Syrphidae and Coccinellidae, barley for Aphidiidae).
According to the beneficial arthropods corrected mortality (Mc) observed after 48 h (glass tests and parasitoid tests on plants) or after 72 h (predators on plants), agrochemicals were classified in 4 categories:

- Green category, harmless product: Mc<30 % on glass or on plant
- Yellow category, slightly harmful product: 30%<Mc<60% on plant
- Orange category, moderately harmful product: 60 %<Mc<80% on plant
- Red category, harmful product: 60 %<Mc<80% on plant

Chemical determination of residues

For each toxicity test, on glass or on plant, active ingredient on the substrate was measured by chemical analysis at the beginning and at the end of the test. Chemical analysis was carried out to know the accurate pesticide concentration which an insect had been exposed to and to have an idea of the pesticide residue evolution after application (Copin *et al.*, 2001). According to these results, compounds were considered as stable after application if at least 85 % of active ingredient was recovered again on glass after 48h; and instable if less than 85 % the rate was found again.

Table 1. List of tested products, theoretical rate, chemical analysis and stability assessment on inert substrate S = stable ; I = unstable,
* =quantitative determination was not possible.

Group	Active ingredient (a.i.)	Formulation	Theoretical dose (g a.i./ ha)	Percentage of theoretical dose (%)			Percentage of residues after 48 h in compari with initial deposit (%)		
				A. rhopalosiphi	*A. bipunctata*	*E. balteatus*	*A. rhopalosiphi*	*A. bipunctata*	*E. balteatu*
Fungicides	Benalaxyl + Mancozeb	GALBEN M - WP	300 + 2437,5	119 + 96	119 + 96	119 + 96	95 + 81	67 + 81	72 + 78
	Chlorothalonil	CLORTOSIP - SC	2250	93	96	106	97 + 65	96 + 51	99 + 51
	Chlorothalonil + Propamocarbe	TATTOO C - SC	1518,7 + 1518,7	83 + 81	98 + 97	110 + 111	99	95	100
	Cyazofamide+ heptamethyltridiloxane	RANMAN - SC	120 + 190,3	100	100	100	101	101	86
	Cymoxanil + Mancozeb	CURZATE M - WP	135 + 1950	103 + 99	97 + 103	103 + 99	101 + 80	100 + 82	100 + 91
	Cymoxanil + Metiram	AVISO - WG	216 + 2880	101+ 93	101 + 93	101 + 93	99 + 101	98 + 100	98 + 102
	Cymoxanil + Famoxadon	TANOS - WG	225 + 225	112 + 114	112 + 114	112 + 114	100 + 100	101 + 102	99 + 99
	Diméthomorphe + Mancozeb	ACROBAT EXTRA - WG	225 + 2512,5	101 + 103	101 + 103	101 + 100	102 + 89	98 + 92	99 + 91
	Fluazinam	SHIRLAN - SC	300	93	93	93	90	54	65
	Copper hydroxide	KOCIDE - WG	2400	82	90	86	104	99	89
	Mancozeb	DEQUIMAN MZ - WG	4800	101	103	103	86	88	86
	Mancozeb + Zoxamid	UNIKAT PRO - WG	1800,9 + 224	97 + 98	97 + 98	97 + 98	76 + 101	71 + 84	84 + 75
	Maneb	TRICARBAMIX EXTRA - WG	4800	105	94	81	67	78	81
	Metalaxyl-M + Fluazinam	EPOK 600 - EC	150 + 300	100 + 104	100 + 104	100 + 104	105 + 97	78 + 96	88 + 97
	Metalaxyl-M + Mancozeb	RIDOMIL GOLD SPECIAL 68 - WP	150 + 2400	100 + 98	100 + 98	100 + 98	70 + 77	12 + 77	35 + 64
	Copper oxychloride	CUPRAVIT FORTE - WP	3750	108	106	81	89	89	87
	Propineb	ANTRACOL - WP	3150	17	12	10	74	74	75
	Propineb + Copper oxychloride	CUPRO-ANTRACOL - WP	2775 + 1312,5	* + 104	* + 104	* + 104	* + 92	* + 91	* + 83
	Copper sulfate	MACC80 BOUILLIE BORDELAISE - WP	3750	69	69	69	100	92	100
Herbicides	Bentazon	BASAGRAN - SG	1440	104	104	118	96	93	85
	Clethodim	SELECT 240 - EC	120	91	91	91	34	44	20
	Cycloxydim	FOCUS PLUS - EC	600	100	100	100	92	97	98
	Metribuzin	SENCOR - WG	350	100	99	100	103	99	102
Insecticides	Alpha-cypermethrin	FASTAC - EC	12,5	105	105	111	96	102	98
	Carbaryl	CARBISAN - WP	768	90	90	90	53	42	48
	Cypermethrin	CYMTOP 100 - EC	25	110	110	110	96	97	99
	Deltamethrin	DECIS 2,5 - EC	7,5	96	71	93	100	99	101
	Dimethoate	HERMOOTROX - EC	200	106	117	105	66	80	108
	Esfenvalerate	SUMI ALPHA - EC	7,5	96	96	99	98	102	112
	Lambda-cyhalothrin	KARATE ZEON - CS	7,5	113	113	113	93	96	96
	Lambda-cyhalothrin + Pirimicarb	OKAPI - EC	7,5 + 150	98 + 96	99 + 96	103 + 96	103 + 8	98 + 17	96 + 8
	Phosalon	ZOLONE FLO - SC	750	68	70	70	101	100	100
	Pirimicarb	PIRIMOR - WG	200	60	60	56	24	14	56
	Zeta-cypermethrin	FURY 10 - EW	10	101	101	101	98	100	101

RESULTS AND DISCUSSION

Beneficial phenology and pesticides periods application

In potato, aphids parasitoids and predators (ladybirds and syrphids) are the main beneficial insects controlling aphids populations (Jansen, 2000; Jansen, 2002).
The phenology of these beneficial arthropods, based on field observations between 1994 and 2002, is explained in figure 1. Hymenoptera: Aphidiidae were the first active aphids enemies arriving in the field at the same time as the first aphids. The presence of winged parasited aphids at the beginning of the season shows that parasitoids can colonize the crop either at eggs stage or at larvae's stage.
Ladybirds and hoverflies come later. The first eggs were detected around the end of June when aphids populations were sufficient to allow the offspring development (Dixon, 2000). These aphidophagous insects remain in the field until aphids populations decline, from July 15 till the end of the month.
This fast and sudden population decrease results from many factors: the winged aphids mass appearance and its emigration, the efficiency of beneficial insects, and at least, physiological changes within the plant that slow down aphids development (Karley *et al.*, 2003). After this aphids populations decrease, beneficial arthropods emigrate to other fields or ecosystems to find other food resources.

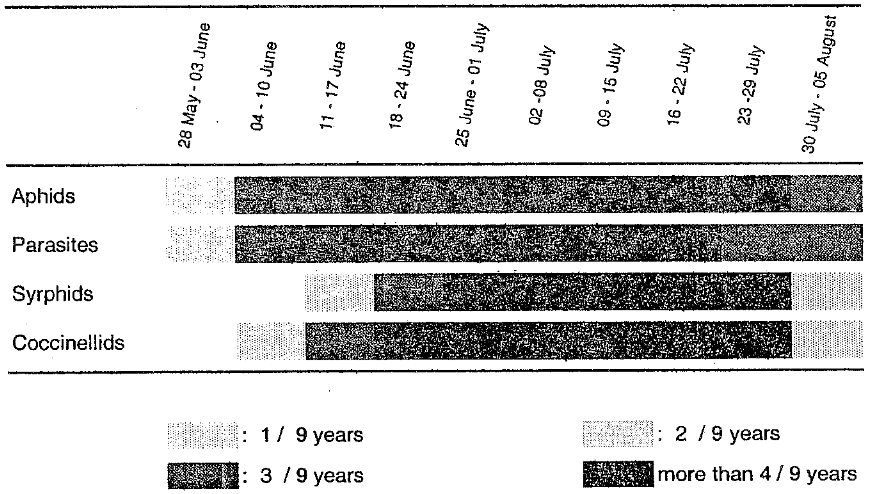

Figure 1. Appearance frequency of aphids and aphidophagous in belgian potato crops between 1994 and 2002.

On the basis of beneficial insects phenology and the periods of application of plant protection products, the farming year was split in four periods. The first period which ends around 10 June, coincides with the arrival of the first aphids parasitoids. They can be exposed to both fungicides and herbicides

applied respectively to protect plants against potato late blight and for post-emergence treatments.
The second period, from 10 to June 30, is characterized by aphids parasitoids colonisation. These beneficial insects can be affected both by fungicides and insecticides treatments.
During the third period, from 1 to July 30, ladybirds and hoverflies colonize the field and become the most active natural enemies for aphids populations control. They can also be exposed to fungicides and insecticides treatments.
At least, from the beginning of August to harvest (fourth period), aphids populations have decreased drastically and the exposure of beneficial arthropods is very limited.
The lists for periods I and II have been made by taking into account the selectivity of the products (fungicides, herbicides, insecticides) towards aphids parasitoids. For period III, only fungicides and insecticides selectivity on ladybirds and hoverflies (average of 2 results) have been taken into account. During period IV, as beneficial insects have left the crop, there is no specific restriction of pesticides use concerning their negative effects on aphids natural enemies.

Acute toxicity assessment

Tests on Aphidius rhopalosiphi

At the end of the tests on glass and on whole plants in semi-controlled conditions, it can be noticed that all tested fungicides and herbicides were selective towards that aphid parasitoid. Among the 11 insecticides we tested, 6 were harmless (cypermehrin, esfenvalerate, lambda-cyhalothrin, pirimicarb, zetacypermethrin and mixture lambda-cyhalothrin + pirimicarb). The others were either slightly harmful (alpha-cypermethrin, carbaryl and phosalone), moderately harmful (deltamethrin) or harmful (dimethoate).

Tests on Adalia bipunctata

All fungicides were selective towards this ladybird, excepted the mixture of metalaxyl-M + fluazinam which was slightly harmful. For insecticides, only pirimicarb was selective towards *A. bipunctata*; all the others were very toxic with an insects mortality on plant higher than 80 % and often equal to 100%.

Tests on Episyrphus balteatus

All fungicides were selective towards *E. balteatus*. On a total of 11 insecticides, 5 were selective for syrphids. The others were slightly harmful as phosalone, moderately harmful: cypermethrin and deltamethrin, or harmful as dimethoate, pirimicarb and the mixture lambda-cyhalothrin + pirimicarb.
It can be pointed out that no insecticide was selective towards the 3 beneficial insects at the same time. Some insecticides, such as dimethoate or delthametrin, were not recommended in IPM program because of their lack of selectivity. Others were selective towards the aphid parasitoid and toxic to predators as the mixture lambda-cyhalothrin + pirimicarb or cypermethrin.

Finally, no insecticide was selective for both predators: syrphids and coccinellids. Therefore, for a better pesticides use in an IPM programme and to avoid negative impacts on beneficial insects, treatments must be correctly positioned and applied with a plant protection product selective to beneficial insects present in the field.

Pesticides residues stability

Results of quantitative determination of pesticides residues on glass plates after 48h and estimation of stability of tested pesticides are illustrated on table 1. A product was classified as stable, in the conditions of the bio-essay and the chemicals analysis, if 85 % of its active ingredient remained on the support 2 days after its application. Thus, 62 % of all tested pesticides were stable according to this criteria. It can also be observed that the active ingredient's stability of a determined pesticide on glass plates and on plants was similar.

Selectivity lists

The setting-up of the selectivity lists takes into account three elements: the toxicity of plants protection products towards the natural aphids enemies, the phenology of these beneficial insects and pesticides periods of application (Table 2).

Period I – until June 10

All tested fungicides and herbicides can be applied without restriction in accordance with recommended rates because of their lack of acute toxicity on aphid parasitoids. Insecticides treatments were not normally necessary and they are not advisable.

Period II – 10 to June 30

There is no restriction to fungicides application. The situation is more complex concerning the insecticides because some preparations were selective and others not. However, lots of compounds were selective and it is possible to avoid the use of yellow, orange and red products.

Period 3 – 1 to July 30

According to fungicides toxicity results, they can be used during this period because they were selective towards the syrphid and the ladybird. The mixture Metalaxyl-M + fluazinam, which was slightly toxic for ladybirds, had no effects on hoverflies and on aphid parasitoids. Therefore they can be used.
Concerning insecticides, none of them was selective for Syrphidae and Coccinellidae insects tested. Only pirimicarb was safe for Coccinellidae but it remains very toxic for syrphids. For aphicide treatments, the most harmless products were alpha-cypermethrin, esfenvalerate, lambda-cyhalothrin and zeta-cypermethrin. If syrphids were not present, pirimicarb can also be used.

In the case of potato beetle treatments, which are extremely scarce in Belgium, cabaryl can be added to the list of slightly harmful products.
Other products must be avoided during this period because of their lack of selectivity towards beneficial entomofauna. However, they can be used in a specific situation (pesticides resistance strains management , ...).

Periode IV – after August 1

During this period, fungicides sprays can be applied safely in the field because beneficial arthropods are not really exposed. According to normal agricultural practice in ware potato crops, it is not useful to apply insecticides during the month of August.

CONCLUSION

An effective pest management which protects pests predators and parasites in ware potato fields is possible without a specific economic constraint for farmers and a quality decrease in the production.
Concerning weeds and potato late blight control, it is not useful to change the plant protection products and their periods of application because herbicides and fungicides were selective for the beneficial insects. However, it only concerns products disposable on the market in this moment. Therefore the research must be realised with new registered compounds.
The choice of insecticides for field pests control is more complex because they were not selective for both syrphids and ladybirds although lots of products were available. The problem eventually sets up in July when the protection of predators is required for an efficient biological pests control. It is therefore necessary to manage pesticides treatments and to choose the most suitable insecticide. This insecticide should be chosen on basis of it's efficacy, the presence or absence of ladybirds and/or syrphids and on it's selectivity towards these predators. These selectivity lists can help the farmers to choose the product to spray; and they can also complete the information given by potato advisory systems for aphids control.

Table 2. Selectivity list: g (green category) = harmless; y (yellow category) = slightly harmful; o (orange category)= moderately harmful; r (red category) = harmful; - = non justified application of the product.

	Active ingredients	Period			
		1 until June 10	2 10 to June 30	3 1 to July 30	4 after August 1
Fungicides	Benalaxyl + Mancozeb	g	g	g	g
	Chlorothalonil	g	g	g	g
	Chlorothalonil + Propamocarbe	g	g	g	g
	Cyazofamide+ heptamethyltridiloxane	g	g	g	g
	Cymoxanil + Mancozeb	g	g	g	g
	Cymoxanil + Metiram	g	g	g	g
	Cymoxanil + Famoxadon	g	g	g	g
	Diméthomorphe + Mancozeb	g	g	g	g
	Fluazinam	g	g	g	g
	Copper hydroxide	g	g	g	g
	Mancozeb	g	g	g	g
	Mancozeb + Zoxamid	g	g	g	g
	Maneb	g	g	g	g
	Metalaxyl-M + Fluazinam	g	g	g	g
	Metalaxyl-M + Mancozeb	g	g	g	g
	Copper oxychloride	g	g	g	g
	Propineb	g	g	g	g
	Propineb + Copper oxychloride	g	g	g	g
	Copper sulfate	g	g	g	g
Herbicides	Bentazon	g	-	-	-
	Clethodim	g	-	-	-
	Cycloxydim	g	-	-	-
	Metribuzin	g	-	-	-
Insecticides	Alpha-cypermethrin	-	y	y	-
	Carbaryl	-	y	y	-
	Cypermethrin	-	g	r	-
	Deltamethrin	-	o	r	-
	Dimethoate	-	r	r	-
	Esfenvalerate	-	g	y	-
	Lambda-cyhalothrin	-	g	y	-
	Lambda-cyhalothrin + Pirimicarb	-	g	r	-
	Phosalon	-	y	o	-
	Pirimicarb	-	g	y	-
	Zeta-cypermethrin	-	g	y	-

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