Integrated Pest Management in apple orchards
in the Netherlands: a solution for selective
control of tortricids.

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# Integrated Pest Management in apple orchards in the Netherlands: a solution for selective control of tortricids

Proefschrift
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# STELLINGEN

1. Bij de geïntegreerde bestrijding van plagen in appelboomgaarden in Nederland verdient het gebruik van selectieve bestrijdingsmiddelen en -methoden de voorkeur boven benutting van OP-resistente roofmijten en toepassing van OP-insecticiden.

   *B.A. Croft, 1982. Entomol. exp. appl. 31: 88-110.*
   *C.H. Wearing and W.P. Thomas, 1978. Proc. 31st N.Z. Weed and Pest Control Conf.: 221-228.*
   *Dit proefschrift.*

2. Bij het vaststellen van het bespuitingstijdstip kunnen modellen die de fenologische ontwikkeling van insektenpopulaties beschrijven, een nuttige toepassing vinden, met name voor plagen die in lage dichtheden voorkomen en niet op een eenvoudige wijze nauwkeurig bemonsterd kunnen worden.

   *H. Riedl, 1980. EPPO Bull. 10 (2): 241-252.*
   *Dit proefschrift.*

3. Praktische realisering van geïntegreerde bestrijding vergt niet alleen ondersteunend onderzoek, maar ook een overtuigende acceptatie van deze benadering door planteziektenkundige beleidsinstanties en een konsekwente vertaling hiervan in beleidsmaatregelen.

4. Het gangbare deugdelijkheidsonderzoek voor bestrijdingsmiddelen dient bijgesteld te worden voor bepaalde selectieve bestrijdingsmiddelen en -methoden.

5. De armoede in de derde wereld is niet het gevolg van overbevolking, maar vice versa.

6. Omdat de risico's van de verontreiniging van moedermelk met PCB's niet zijn aan te geven, is het onmogelijk deze te betrekken in een afweging tussen borstvoeding en kunstvoeding.

   *J.J.L. Pieters, 1984. Ned. Tijdschr. Geneesk. 128 (48): 2262-2265.*

7. Dat bepaalde bestrijdingsmiddelen tegen ongedierte alleen beroepsmatig door ter zake deskundigen mogen worden toegepast suggereert een ter zake deskundigheid van de toepasser.

8. Het te verwachten tijdsvoordeel door het gebruik van de computer bij de verwerking van proefgegevens, kan in het niet vallen bij de noodzakelijke voorbereidende activiteiten en de activiteiten achteraf.

9. Het bestrijden van overwinterende lieveheersbeestjes in een klooster dient vanuit theologisch standpunt zondig verklaard te worden.

R.H. de Reede
Integrated Pest Management in apple orchards in the Netherlands: a solution for selective control of tortricids.
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To Jozien,
Edo, Reinout and Jorinde.

## Contents

## General introduction

About 4000 fruit farms exist in the Netherlands, with a total area of 25000 ha. Apples cover the largest area (19000 ha). The main apple varieties grown are Golden Delicious, Belle de Boskoop, Cox's Orange Pippin and James Grieve. Orchards are susceptible to numerous diseases and arthropod pests, many of which lead to injury of the fruit if left uncontrolled. In the sixties orchards were sprayed on average 22 times a year against arthropod pests and diseases (ROOSJE 1967): insecticides were sprayed twice before flowering, once at petal-fall, and three to four times between June and September; acaricides were applied one to three times between May and August (Fig. 1); and fungicides about fifteen times.

As to the time of spraying, the fruit growers were informed by the State Horticultural Advisory Service by telephone or postcard. Routine sprayings were therefore executed at the correct phenological stage, irrespective of the presence of noxious species. In spite of intensive use, however, chemical control in the Netherlands has never evoked side-effects grave enough to force the growers to adopt another form of pest control. In particular, new acaricides reached the market in time to replace chemicals against which resistance developed (BRADER 1977).

An increasing awareness of the risks of injudicious application of pesticides (resistance of pests, side-effects on the environment), the rising prices of the chemicals, and the growing aversion of the public to pesticide use, have stimulated research aimed at reducing the use of pesticides. Emphasis was laid on limiting the use of insecticides and acaricides, mainly because of their toxicity to non-target organisms.

### *Supervised control*

The simplest approach to a reduction of the use of pesticides is supervised control. This consists of pest monitoring, and applying current broad-spectrum pesticides when the pest numbers exceed economic thresholds. Guideliness, describing quick and easy techniques for these assessments and defining action thresholds (thresholds at which control should be performed to prevent economic damage), were developed in several European countries in the late sixties (STEINER and BAGGIOLINI 1968, BAGGIOLINI et al. 1971, VAN FRANKENHUYZEN and GRUYS 1971). GRUYS and MANDERSLOOT (1978) state that "two decades of routine or blanket pest control have reduced the growers' theoretical and field knowledge

| RECOMMENDED SPRAYINGS IN ROUTINE SCHEDULES 1960-'70 | | Month | | SPRAYINGS IN SUPERVISED CONTROL | USE OF ACTION THRESHOLDS 1973 | 1983 |
|---|---|---|---|---|---|---|
| APHIDS, CATERPILLARS | → | MAR | | | | |
| APHIDS, CATERPILLARS | → | APR | ← | RUST MITE | -* | - |
| SPIDER MITE | → | | ← | SPIDER MITE | + | + |
| APHIDS, BUG, CATERPILLARS | → | MAY | ← | APHIDS, BUG, CATERPILLARS | +,+,+ | - |
| SPIDER MITE | → | | ← | SPIDER MITE | + | - |
| | | JUN | | | | |
| ADOXOPHYES, CODLING MOTH | → | | ← | ADOXOPHYES, CODLING MOTH | +,+ | - |
| ADOXOPHYES, CODLING MOTH | → | | ← | ADOXOPHYES, CODLING MOTH | +,+ | - |
| | | JUL | | | | |
| SPIDER MITE | → | | ← | SPIDER MITE | + | + |
| ADOXOPHYES, APHIDS | → | AUG | ← | ADOXOPHYES, APHIDS | +,+ | +,+ |
| ADOXOPHYES | → | | | | | |
| | | SEP | | | | |

* OF NO IMPORTANCE

Fig. 1. Sprayings against arthropods, recommended before (routine schedules) and after the introduction of supervised control in Dutch apple orchards.

of pests to virtually nil. When the grower himself is expected to perform the assessments and be responsible for the control decisions- and this position is taken by the authorities in Holland- instruction is a necessary preliminary to practical application of supervised control".

Supervised control was introduced into practice in the early seventies. In order to educate growers on the main arthropod pests, natural enemies, sampling procedures and action thresholds, the State Horticultural Advisory Service organized a series of instruction meetings (one in the winter and 3 or 4 during the growing season) on holdings of the participating growers. The growers could obtain personal help in case of difficulties. The development of supervised control since 1973 (the number of growers taking part in the instruction meetings and applying supervised control) is given in Table 1.

Both plant-protection specialists and field advisors, dealing with all aspects of fruit growing, were involved in the instruction of supervised control. In addition, three additional advisors were appointed solely for the purpose of supervised control. By using this method the number of sprayings against arthropod pests could be roughly halved. Similar results were achieved with supervised control in several

Table 1. Supervised control in practice in the Netherlands 1973-1978.

| Year | Number of groups receiving advice | Number of growers participating | Average number of sprayings | | | insect damage to fruit (%) |
|---|---|---|---|---|---|---|
| | | | insec- ticides | acaricides | total | |
| 1973 | 1 | 8 | 0.6 | 1.3 | 1.9 | 1.9 |
| 1974 | 15 | 175 | 2.4 | 1.0 | 3.4 | 1.4 |
| 1975 | 37 | 400 | 2.2 | 1.4 | 3.6 | 1.0 |
| 1976 | 41 | 400 | 3.5 | 1.5 | 5.0 | 0.9 |
| 1977 | 45 | 600 | 3.4 | 1.4 | 4.8 | 1.8 |
| 1978 | 41 | 700 | 3.0 | 1.0 | 4.0 | 0.4 |

Source: GRUYS et al. 1980.

other West European countries (GRAFFIN 1982). No data on the development of supervised control have been collected since the late seventies, and the interest in supervised control has gradually decreased for several reasons: a) research capacity supporting supervised control was strongly reduced after 1975; b) instruction of growers, particularly on supervised control, is no longer possible because of a reduction of the advisory service since the early eighties; and c) the time required for pest monitoring in supervised control was felt as a disadvantage by many growers and some action thresholds were difficult to establish. Growers tend, therefore, to use only a few of the initially proposed thresholds (Fig. 1). This tendency has been enhanced by the introduction of synthetic pyrethroids, reducing the number of sprayings necessary.

Supervised control has two major short-comings: a) it relies on chemical control with broad-spectrum pesticides - although the amount of pesticides used is reduced compared to the routine schedule of the sixties, the risk that pests will develop resistance remains; b) most pesticides used are highly toxic to useful insects such as the natural enemies of pests, and thus promote the development of secondary pests.

### *Integrated Pest Management*

Integrated Pest Management (IPM) requires an understanding of the whole crop situation, in order to determine those conditions that reduce pest development as much as possible. It relies in the first place on the exploitation of natural mortality factors, in combination with selective agents against those pests which are not kept at an acceptably low level by natural mortality. Additional approaches, such as the use of pest-resistant cultivars (ALSTON 1981) or the modification of cultural practice, are certainly more difficult to develop for orchards than for annual crops and have consequently received less attention (GRUYS 1982).

The natural control of the fruit tree red spider mite (*Panonychus ulmi* KOCH) by phytoseiids has attracted attention for many years. In the Netherlands it was KUENEN (1947) who first observed phytoseiids as common predators of spider mites. The fruit tree red spider mite was almost unknown as a pest before World War II. It became a serious pest when tar oil was introduced as a dormant spray against overwintering insects, and Bordeaux mixture and lime sulphur were increasingly applied against scab and powdery mildew. Natural control of spider mites by phytoseiids appeared to be hampered by the use of these pesticides, and its effectiveness is still limited by many of the current pesticides (GRUYS 1980, HUFFAKER et al. 1970).

Internationally, two approaches are being explored in using phytoseiids for natural control of the fruit tree red spider mite. In one approach (used in, e.g., the Netherlands) the predacious phytoseiid mite is preserved by using selective pesticides. The lack of resistance of *Typhlodromus pyri* SCHEUTEN to synthetic pyrethroids and organophosphorous insecticides, such as azinphos-methyl, precludes the use of these compounds in dutch IPM apple orchards (GRUYS 1980). In the second approach which is followed in other countries, advantage is taken of the presence or development of organophosphorus- and carbamate resistant phytoseiids. In this case, other pests can be controlled continually with organophosphorus insecticides. It is anticipated that certain other beneficial arthropods will also become resistant in time, provided the use of pesticides is managed properly. Organophosphorus-resistant phytoseiids are succesfully used in the USA and show promise for use in New Zealand, Australia, England and Switzerland (BAILLOD and GUIGNARD 1984, COLLYER 1980, CROFT 1982, READSHAW 1981, SOLOMON et al. 1984).

Field trials to determine a coherent system of apple IPM were started in the Netherlands in 1967, when a 12 ha apple orchard "De Schuilenburg" at Kesteren became available for experiments in this field. In 1972, preliminary tests of IPM were initiated on plots of 0.5 to 2 ha in commercial holdings, and from 1978 onwards trials were carried out in a small number of entire orchards. The IPM program available in 1978 is given in Table 2. Before 1975, only *Ryania* and *Bacillus thuringiensis* were used against caterpillars, and damage by larvae of the codling moth, winter moth, noctuids and leafrollers was high (Table 3). When diflubenzuron (a chitin synthesis inhibitor) became available in 1975, it became possible to reduce caterpillar damage (Fig. 2, Table 3). Difficulties with leafrollers remained, however, because some species were only slightly susceptible to diflubenzuron. From 1978 onwards, Insect Growth Regulators with juvenile-hormone activity (i.e. initially epofenonane and later fenoxycarb) were tested against leafrollers in our experiments.

*Leafrollers in IPM*

Amongst leafrollers, *Adoxophyes orana* (F.v.R.) is the major species in top fruit growing in the Netherlands. This species was therefore accorded the most attention in the research on IPM. Six methods were tested.

Table 2. Control measures in the integrated program for orchards in the Netherlands, in 1978.

| | |
|---|---|
| Acari | |
| *Panonychus ulmi* | typhlodromids release! white oil, benzoximate, fenbutatinoxide |
| Lepidoptera | |
| *Operophtera brumata* | |
| *Orthosia* spp. | Dimilin (diflubenzuron) |
| *Adoxophyes orana* | parasites, incl. *Colpoclypeus florus*; epofenonane, Dipel (*Bacillus thuringiensis*) |
| other tortricids | Dimilin (not effective against all species), epofenonane |
| *Laspeyresia pomonella* *Pammene rhediella* | Dimilin |
| *Stigmella malella* | *Chrysocharis prodice* release! Dimilin |
| Homoptera | |
| *Eriosoma lanigerum* | endosulfan, in early spring; pirimicarb, in growing season; *Aphelinus mali* |
| aphids | pirimicarb |
| Hemiptera | |
| *Lygus pabulinus* | suppress dicotyledonous weeds by frequent mowing; white oil at bud burst |
| Hymenoptera | |
| *Hoplocampa testudinea* | Dimilin (suppresses next generation); thiophanate-methyl |
| Coleoptera | |
| *Anthonomus pomorum* | Dimilin, in early spring |
| *Phyllobius oblongus* | Dimilin: strong suppressive effect on next generation |
| Diptera | |
| *Dasineura mali* | endosulfan: spray at low temperature |
| Fungi | |
| *Venturia inaequalis* | dodine, captan; do not use Mn-containing fungicides! |
| *Podosphaera leucotricha* | bupirimate, triadimefon, nitrothal-diisopropyl; do not use sulphur nor dinocap |
| *Pezicula* spp. | captan, thiophanate-methyl |
| Fruit thinning | naphthalene acetamide |

Source: GRUYS 1980b.

Table 3. Fruit injury by Lepidopterous pests in the apple harvest of IPM-orchards in 1972-1977.

| Year | No. of orchards | Total area (ha) | Fruit injury (%) | | |
|---|---|---|---|---|---|
| | | | winter moth, noctuids | codling moth | leafrollers |
| 1972 | 7 | 9.2 | 2.4 | 1.9 | 0.4 |
| 1973 | 6 | 7.8 | 1.8 | 4.9 | 1.3 |
| 1974 | 7 | 9.6 | 4.7 | 2.1 | 1.3 |
| 1975 | 15 | 17.4 | 0.9 | <0.1 | 1.1 |
| 1976 | 16 | 16.1 | 0.6 | 0.4 | 1.4 |
| 1977 | 14 | 12.5 | 0.5 | <0.1 | 1.9 |

Source: DE REEDE and ALKEMA 1981.

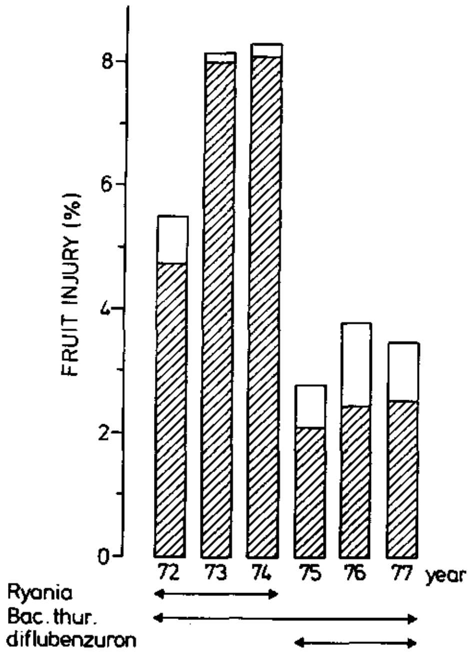


Fig. 2. Fruit injury, caused by insects in IPM apple orchards 1972-1977. Cross-hatched bars indicate caterpillar damage. Insecticides used against caterpillars are indicated below the histogram (After: DE REEDE and ALKEMA 1981).

1) Biological control by massrearing and releasing parasites. Strains of *Trichogramma embryophagum* and *T. cacoeciae* (Hymenoptera, Trichogrammatidae) were released in experimental orchards to control *A. orana*. DE JONG reported the following about his experiments: "Satisfactory results were obtained in some trials, but bad weather often limited the activity of the parasites, so the effects were unreliable. A lack of hosts in commercial orchards seriously limited survival in winter and repeated releases of this egg parasite were necessary. Moreover, the parasites proved extremely susceptible to pesticides" (DE JONG 1980). GRUYS and VAAL carried out release trials with *Colpoclypeus florus* (Hymenoptera, Eulophidae) and investigated the degree of parasitization of *A. orana* and other leafroller species present in their experimental orchard. They reported that although all important leafroller species were parasitized, the rate of parasitization was too low to be effective (GRUYS and VAAL 1984).

2) Sterile insect technique for controlling *A. orana*. This method can reduce populations of *A. orana* to an extremely low level, but requires continuous release of large numbers of moths, to cope with immigrants. Fruit injury by other leafrollers, however, could not be limited sufficiently, since these increased in numbers (ANKERSMIT 1980). Because of the above results and the expense involved, ANKERSMIT concluded that this technique is economically unfeasible.

3) Control with Baculo-viruses. In experiments on the use of Baculo-viruses against *A. orana* a very great reduction of *A. orana* was achieved, but reduction of fruit injury was insufficient. This discrepancy was again attributable to other leafroller species, which are not killed by the virus (BLOMMERS pers. comm., DICKLER and HUBER 1983, PETERS et al. 1983). Another factor limiting application is the high cost of production of the virus.

4) Disruption of mating, using the pheromone of *A. orana*. Although in several experiments this technique resulted in a 95-98% suppression of the number of moths, caught in pheromone traps, mating activity was not always inhibited sufficiently. Consequently the larval population of the next generation could not always be kept below the economic threshold (CHARMILLOT 1981, VAN DEVENTER et al. 1981). More fundamental studies of the behaviour of *A. orana* are now being carried out, and may lead to improvement of this technique (C. VAN DER KRAAN, pers. comm.).

5) The use of *Bacillus thuringiensis*. In previous studies, *Bacillus thuringiensis* (Dipel) had only a slight effect on *A. orana*. Preliminary evidence indicates, however, that the number of *A. orana* declined and became economically insignificant after

some years of IPM (DE JONG and GRUYS 1975). This suggests the possibility that, if IPM were applied for several years, *Bacillus thuringiensis* might give sufficient control of the other leafroller species in IPM-orchards. This aspect is investigated in chapter 1.

6) The use of selective chemical insecticides. Diflubenzuron showed promise against several leafroller species, although it is ineffective against *A. orana* (GRUYS 1975). It was still necessary, however, to investigate the impact of diflubenzuron on the leafroller fauna present in IPM-orchards (chapter 1). Epofenonane and fenoxycarb are insect growth regulators with juvenile-hormone activity. When applied during the last-larval stage, they interfere with normal metamorphosis. Most leafroller species hibernate as young instar larvae and complete their larval development in spring. The period of their last larval stages are not synchronised. It remained to be investigated whether control of all leafroller species by this method is hampered by phenological differences between the various species (which may possibly result in too many sprayings), and also whether application in spring is sufficient to reduce the following generation to such an extent that the population level remains low during the rest of the year. Results of these investigations are presented in chapter 2 and 3. In addition we investigated whether a temperature-sum model could be developed to predict the emergence of the last-instar larvae of leafrollers in the field, in order to simplify the work involved in selecting the correct time for fenoxycarb or epofenonane application (this is currently based on collection and rearing of leafroller larvae in an outdoor insectary) (chapter 4). The main findings are discussed in the general discussion.

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## Chapter 1

# Leafrollers in Apple IPM regimes, based on *Bacillus thuringiensis*, on diflubenzuron or on epofenonane in the Netherlands.

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ABSTRACT

Three selective insecticides for leafroller control were evaluated as part of research efforts for refinement of Integrated Pest Management (IPM) in apple orchards in the Netherlands. Population levels, injury to fruits and degree of parasitism of leafrollers were studied in 0.5-1 ha plots of an experimental orchard. Plots were sprayed during 5 consecutive years with either Dimilin (diflubenzuron), a chitine synthesis inhibitor, Dipel, a strain of *Bacillus thuringiensis* or epofenonane, a juvenile hormone analogue. Dipel and Dimilin were not sufficiently effective in reducing population levels and degree of fruit injury. Hard to control pests in Dipel treated plots were especially *Pandemis heparana*, *Spilonota ocellana* and *Laspeyresia pomonella* and in Dimilin treated plots *P. heparana* and *Adoxophyes orana*.

Epofenonane could not be evaluated properly because of interference by immigration of moths from nearby untreated plots.

Keywords
Integrated Pest Management, apple orchard, Tortricidae, leafrollers, Noctuidae, selective insecticides.

## INTRODUCTION

The summer fruit tortricid *Adoxophyes orana* (F. v. R.), *Archips podana* (SCOP.) and *Pandemis heparana* (DENN. et SCHIFF.) are the major external fruit feeding leafroller species in apple orchards in north-western and southern Europe. They need to be controlled once or twice a year (BASSINO et al. 1979, FRÉROT et al. 1982, GRUYS 1982, MANI 1968). In moderate and cool climates and modern orchards of small, smooth-stemmed trees, they may be even more injurious than the codling moth *Laspeyresia pomonella* (L.) (GRUYS 1982). The current use of broad-spectrum insecticides for control of these pests in commercial orchards is not compatible with the Integrated Pest Management (IPM) in the Netherlands, where the control of the fruit tree red spider mite, *Panonychus ulmi* (KOCH), by its phytoseiid predators is crucial (GRUYS 1982).

Discontinuation of these broad-spectrum chemicals may cause a complex of nearly ten leafroller species to thrive, resulting in more than 10% fruit injury (GRUYS 1982, DICKLER and GEHR 1981).

The aim of the present study was to test the implementation of three selective compounds, namely Dimilin, a chitine synthesis inhibitor based on diflubenzuron, Dipel based on *Bacillus thuringiensis* and epofenonane, a juvenile hormone analogue, for control of leafrollers in IPM in apple orchards. All three compounds are known as useful insecticides against several orchard pests, and harmless against beneficial insects and mites (GRUYS 1980, SCHELTES (in press)). However, Dimilin did evoke an outbreak of the woolly apple aphid, *Eriosoma lanigerum*, due to the killing of predatory *Forficula auricularia* (RAVENSBERG 1981) and therefore should be applied with caution.

## MATERIALS AND METHODS

### *Location of test plots and spraying program*

The studies were carried out at the experimental orchard "De Schuilenburg" in Kesteren in the Netherlands, between 1975-1979. The orchard was divided into 13 plots of 0.5-1 ha (Fig. 1) and was planted in 1965/66 with spindlebush trees on dwarfing rootstocks of the apple cultivars Golden Delicious, Cox's Orange Pippin, Belle de Boskoop, James Grieve and Jonathan in alternating rows. Two plots were treated with Dipel WP (*Bacillus thuringiensis* Berl.), four with Dimilin (diflubenzuron 50WP) and one with epofenonane (epofenonane 500EC). In 4 plots (IPM-0) leafroller

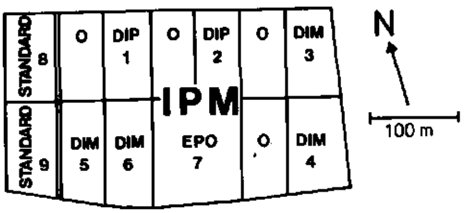


Fig. 1. Experimental set-up in the spindle bush orchard. DIP: Dipel; DIM: Dimilin; EPO: epofenonane; STANDARD: broad-spectrum insecticides; 0: no leafroller control; IPM: Integrated Pest Management.

control was omitted and in 2 plots (STANDARD) broad-spectrum insecticides were used.

Dipel, Dimilin and epofenonane were sprayed around blossoming time in spring. This was continued for several years. The action of epofenonane is limited to the period of metamorphosis of leafrollers. Therefore, control with this compound was aimed at reducing the post-hibernation generation to such degree that the following generation(s) do(es) not rise to harmful numbers.

Dipel and Dimilin were sprayed also in the summer. The former during the time of egghatch of *A. orana* and the latter around July $1^{st}$ before the oviposition period of the codling moth. The amounts applied are given in Table 1. Plots 1, 2, 5, 6, 7 and the IPM-0 plots adjacent to plot 1, were not included for the evaluation of the effect of insecticides on fruit injury in 1979, because additionally, the mating disruption technique with pheromone of *A. orana* was used. The use of insecticides against other insect pests did not interfere with the leafroller control, because of the choice of chemical or because of the timing with respect to the lifecycle of leafrollers. The insecticides used were endosulfan, white oil and pirimicarb.

A 0.5 ha plot (0-plot) containing more than 39 year old apple bushes, which was separated from the other plots by 8 rows of large cherry trees, was also used for observations. This plot received only fungicide treatments.

The STANDARD plots were sprayed twice with phosalone (0.90 kg a.i./ha), azinfos-methyl (0.56 kg a.i./ha), methidathion (0.45 kg a.i./ha) or carbaryl (1.13 kg a.i./ha) or once with permethrin (0.06 kg a.i./ha) in the spring and at time of egghatch of the $1^{st}$ and $2^{nd}$ generation of *A. orana*.

The sprayings were done with a mist blower with 150-200 l/ha water.

Table 1. Applied rates of formulated product of Dipel, Dimilin and epofenonane in May (M) and June-July (J) in 1975-1979.

| Insecticide | Plot | Applied rate (kg/ha) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1975 | | 1976 | | 1977 | | 1978 | | 1979 | |
| | | M | J | M | J | M | J | M | J | M | J |
| Dipel | 1 | 3.0[ab] | - | 3.0[a] | - | 3.0[ab] | 3.0 | 3.0[ab] | 3.0 | 3.0[ab] | 3.0[1] |
| | 2 | - | - | 6.0[a] | - | 6.0[ab] | 6.0 | 6.0[ab] | 6.0 | 6.0[ab] | 6.0[1] |
| Dimilin | 3 | 1.5[b] | - | 1.8[b] | - | 1.2[ab] | 0.6 | 1.2[ab] | 0.6 | 1.2[ab] | 0.6 |
| | 4 | 1.5[b] | - | 1.8[b] | - | 3.0[ab] | 1.2 | 2.4[ab] | 1.2 | 2.4[ab] | 1.2 |
| | 5 | 1.5[a] | - | 1.8[a] | - | 1.5[a] | - | 1.2[a] | 0.6 | 1.2[a] | 0.6[1] |
| | 6 | 1.5[b] | - | 1.8[b] | - | 1.5[b] | - | 1.2[b] | 0.6 | 1.2[b] | 0.6[1] |
| epofenonane | 7 | - | - | 6.0[ab] | - | 6.0[ab] | - | 6.0[ab] | -[2] | 6.0[ab] | -[1 2] |

[1]Mating disruption technique of *A. orana* was used in addition to the insecticide treatment. This was also performed in the IPM-0 plots, adjacent to plot 1.
[2]Dimilin against codling moth in addition to epofenonane in spring.
Index a=pre-blossom; b=post-blossom; ab=pre and post-blossom, each at half rate.

*Sampling of larvae*

The population density of leafrollers under the various insecticide regimes was assessed in the spring by collecting 100 or 200 clusters randomly of the cultivar Belle de Boskoop in each plot at green cluster and by counting the number of larvae. The samples were taken before any treatment of the plots and thus reflect the effect of treatments of the preceding year. The composition of leafroller species was established by close searching of entire branches for at least 100 larvae from each plot, which were reared upto the adult stage of either host or parasite on an artificial diet (ANKERSMIT 1968), in 1.5 x 5 cm glass vials under outdoor conditions in an insectary.

The density of *A. orana* was also assessed at the end of July, when webs of full-grown larvae of this species were found in shoottips. Two hundred randomly chosen shoottips per plot of Belle de Boskoop and James Grieve were inspected. The species composition was established by collection of at least 100 larvae from shoottips from each plot. Adults, non-eclosed pupae or dead larvae were identified according to BENTINCK and DIAKONOFF (1968), and EVENHUIS and VLUG (1972), and emerged parasites according to EVENHUIS (1976).

*Fruit injury*

The proportion of the apple harvest injury by leafrollers and other caterpillars was determined by examining samples of 1000-2000 apples of Golden Delicious, Cox's Orange Pippin, Belle de Boskoop, James Grieve and Jonathan. The apples were picked from 20 systematically chosen trees per plot for each cultivar. The 30-year old apple bushes were not included in these observations.

Three types of external fruit feeding by caterpillars were distinguished:

1) Early caterpillar damage, caused in spring. Fruits bear corked-over scars and are often disfigured. This injury can be attributed to winter moth (*Operophtera brumata* L.), noctuids (*Orthosia* spp.). Leafrollers, present in spring such as *P. heparana*, *A. podana*, *A. rosana* (L.) and *Spilonota ocellana* (F.) (Fig. 2) may also contribute to this injury.
2) July damage is of two types: (a) shallow, irregular formed scars from old larvae of *A. orana* as indicated in Fig. 1, (b) small dry feeding excavations from young larvae.
3) Late-summer damage. Clusters of fresh small feeding excavations, caused by young stages of several leafroller species from August onwards, before they

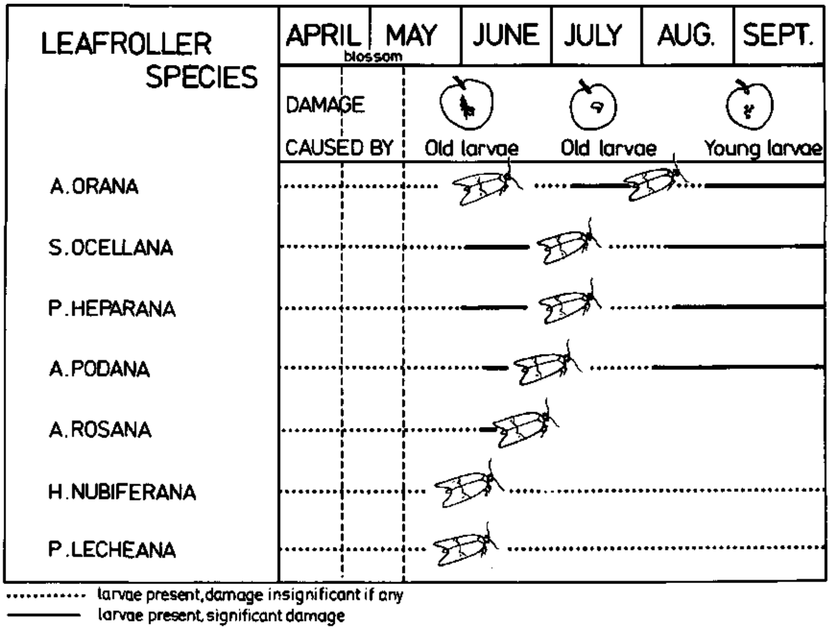


Fig. 2. Periods during which leafrollers may cause external fruit feeding damage. May till half of June: early caterpillar damage: July: July damage: August-September: late summer damage.

hibernate (Fig. 2).

In addition to the harvest samples, the proportion of wormy fruits by the codling moth (*Laspeyresia pomonella*) was also estimated in fruits underneath sample trees after harvest.

Statistical analysis on larval counts and fruit-damage assessments was performed after the transformation $\ln(x+1)$.

## RESULTS

### *Population levels and parasitism of leafrollers in untreated plots*

Ten leafroller species were found in spring in plots without leafroller control, viz. in order of decreasing numbers *S. ocellana, P. heparana, Hedya nubiferana* (H.W.), *A. orana, A. podana, Ptycholoma lecheana* (L.), *Pandemis cerasana* (HB.)

and *Acleris* sp. Between the IPM-0 plots there was considerable variation of densities within each year, except in 1976. However, the mean population densities in these plots were fairly constant during the period 1976-1979 (Fig. 3). We therefore averaged the densities during these four years, instead of treating them separately (Fig. 4). The mean densities of the total leafroller population in the IPM-0 plots and in the untreated large bushes (0-plots) were 13.0 and 12.7 larvae per 100 clusters respectively. The densities of the separate species were rather similar (Fig. 4). *P. heparana* was significantly more numerous in IPM-0 than in 0-plots (Student t-test, analysis of variance).

The leafroller samples taken in July consisted for 80-90% of full-grown *A. orana* larvae and for 10-20% of young instars of *Pandemis* sp., *Archips* sp. and *Acleris* sp. The population density of *A. orana* was low in 1976, reached a peak in 1977, exceeding the economic threshold (5 larvae/100 shoots) in 1977 (IPM-0 and 0-plots) and in 1978 (IPM-0 plots) (Fig. 5: grey bars). It declined thereafter.

The rate of parasitism of larval samples of *A. orana*, taken in July was high in 1976-1978, but lower in 1979 (Table 2). About 90% of the emerged parasites consisted of *Colpoclypeus florus* WALKER (Chalcidoidea, Eulophidae). In 1979, 80% of the parasite population was made up of *C. florus*, *Teleutaea striata* (GRAVENHORST) and *Scambus brevicornis* (GRAVENHORST), occurring in about similar numbers. Other parasite species, mentioned in Table 3, were found in low

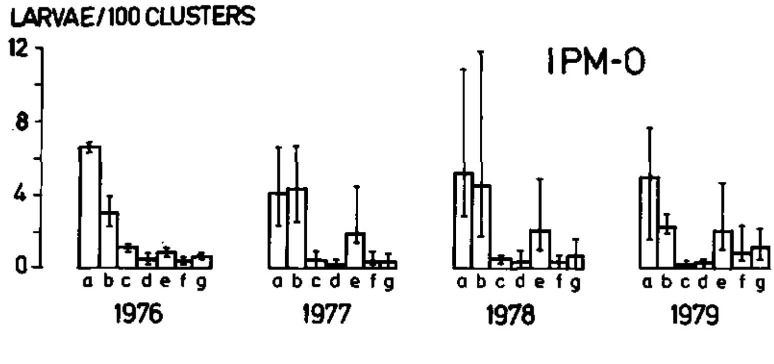


Fig. 3. Larval densities of different leafroller species on cv. Belle de Boskoop in May in 1976-1979 in IPM-0 plots. (a) *S. ocellana*, (b) *P. heparana*, (c) *A. orana*, (d) *A. podana*, (e) *H. nubiferana*, (f) *P. lecheana* and (g) other leafrollers. Range of densities in the plots is indicated by vertical bars.

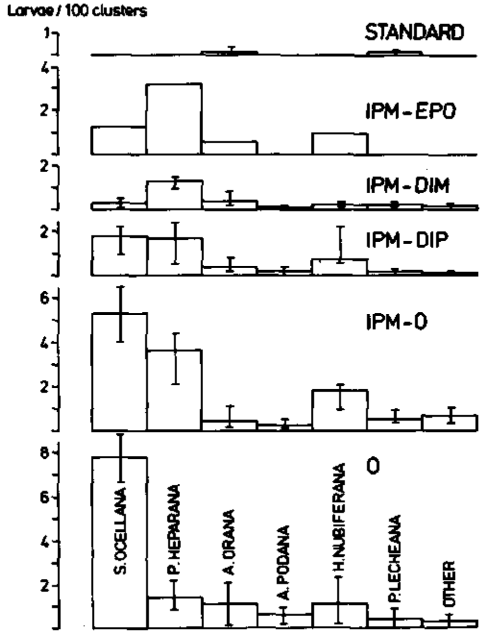


Fig. 4. Mean densities of different leafroller species on cv. Belle de Boskoop in 1976-1979. IPM-EPO concerns 1978. Range of annual fluctuations is indicated by vertical bars.

numbers. The significance of the parasitism of *A. orana* in summer is illustrated in Fig. 5 (grey and white bars). Obviously parasitism resulted in a reduction of the population of *A. orana* below the economic threshold in 1977 and 1978, and consequently reduced fruit injury by the next generation.

The rate of parasitism of *P. heparana*, *S. ocellana*, *H. nubiferana* and *A. orana*, occurring in spring in IPM-0 was much lower (Table 2). The degree of parasitism of *A. orana* in spring could only be determined in 1976 and amounted to 34%. In other years the numbers collected were too low for determination, as was also the case for the species not mentioned in Table 2. A great variation of hymenopterous species were reared from the larvae in spring (Table 3). In contrast to the July samples none of them clearly dominated.

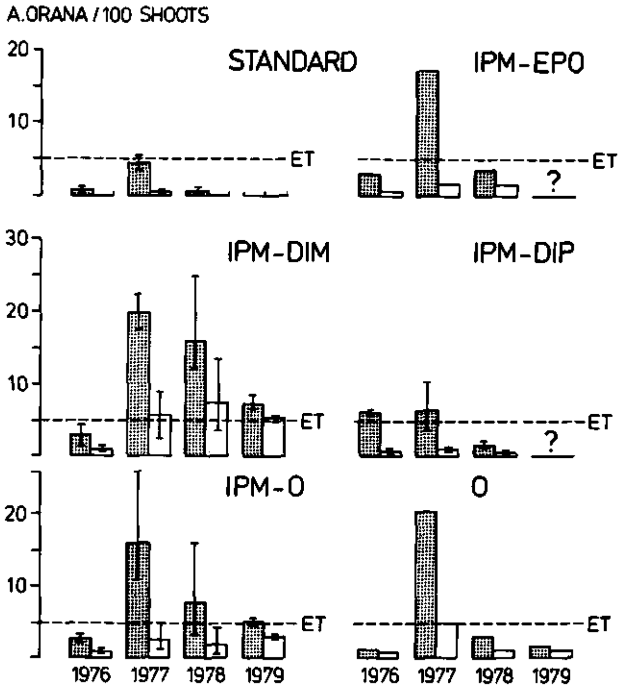


Fig. 5. Mean numbers of *A. orana* larvae per 100 shoots in July in the various treatments, before (grey colomns) and after (white columns) substraction of parasitized specimen. Standard deviation (vertical bars) and economic threshold (ET) are indicated.

*Fruit injury by caterpillars in IPM-0 plots*

Injury caused by external and internal feeding, caused by caterpillars, such as winter moth, noctuids and leafroller species, ranged from 7.5 to 22.6% in the apple harvest of IPM-0 plots during 1975-1979 (Table 4). The most important damage due to external feeding was caused by caterpillars in spring and in late-summer. The proportion of wormy fruits by codling moth showed great variation between years (Table 4). Injury by *Pammene rhediella* (Cl.) was hardly found.

*Relation between population of A. orana and injury to fruits in July*

The relation between the number of *A. orana* in samples, taken in July, and the proportion of July fruit injury after harvest of Belle de Boskoop and James

Table 2. Rate of parasitism (%) of *P. heparana*, *S. ocellana*, *H. nubiferana* and *A. orana*, collected in IPM-0 plots in May and July in 1976-1979. Between brackets, total number of larvae collected.

| Year | May | | | | July |
|---|---|---|---|---|---|
| | *P. heparana* | *S. ocellana* | *H. nubiferana* | *A. orana* | *A. orana* |
| 1976 | 16(109) | 17(224) | 4(28) | 34(35) | 78(220) |
| 1977 | 9(78) | 12(69) | 8(40) | - | 84(324) |
| 1978 | 8(50) | 12(57) | 0(30) | - | 76(326) |
| 1979 | 6(61) | 6(138) | 5(55) | - | 43(159) |

Table 3. Species of hymenopterous parasites, reared from *S. ocellana*, *P. heparana*, *H. nubiferana*, collected in May and from *A. orana*, collected both in May and July in untreated plots in 1976-1979.

| Species | May | July |
|---|---|---|
| Ichneumonidae | | |
| *Scambus brevicornis* (GRAVENHORST) | x | x |
| *Teleutaea striata* (GRAVENHORST) | x | x |
| *Glypta* sp. | x | x |
| *Itoplectis* sp. | | x |
| *Lissonota errabunda* (HOLMGREN) | | x |
| Braconidae | | |
| *Apanteles ater* (RATZEBURG) | x | x |
| *Apanteles* sp. | x | x |
| *Ascogaster rufidens* (WESMAEL) | x | x |
| *Ascogaster quadridentatus* (WESMAEL) | x | |
| *Braunsia rufipes* (NEES) | x | |
| *Macrocentrus* sp. | x | |
| *Meteorus ictericus* (NEES) | x | x |
| *Microdus dimidiator* (NEES) | x | x |
| Chalcidoidea | | |
| *Colpoclypeus florus* (WALKER) | | x |

Table 4. Mean proportion of damaged fruits by caterpillars in IPM-0 plots during harvest of cultivars Golden Delicious, Cox's Orange Pippin, Belle de Boskoop, James Grieve and Jonathan in 1975-1979.

| Type of damage | Proportion damaged fruits (%) | | | | |
|---|---|---|---|---|---|
| | 1975 | 1976 | 1977 | 1978 | 1979 |
| external fruit feeding | | | | | |
| early caterpillar damage | 3.7 | 1.6 | 4.4 | 2.1 | 3.6 |
| July damage | 1.7 | 0.6 | 1.9 | 0.8 | 1.5 |
| late-summer damage | 5.7 | 6.6 | 8.7 | 3.8 | 11.4 |
| internal fruit feeding | | | | | |
| wormy-fruits' | 1.4 | 8.4 | 7.6 | 0.8 | 1.0 |
| Total | 12.5 | 17.2 | 22.6 | 7.5 | 17.5 |

'apples harvested and collected underneath the sample trees are pooled.

Grieve are given in Figs. 6 and 7. Larval samples from other cultivars were not taken. Belle de Boskoop showed higher susceptibility to July damage than James Grieve. This may be due to differences in crop structure. Because *A. orana* was assumed to be the main cause of July fruit injury special attention was paid to this species during sampling in July. To investigate whether other causes of July damage were overlooked an analysis of covariance was performed on the proportion of fruit damage with the applied insecticide, irrespective of rate used, as main factor and the number of sampled *A. orana* in July as covariable. Sixty nine and 71% of the variation in the July damage of Belle de Boskoop could be attributed to *A. orana* in 1977 and 1978 (Table 5: see $100R^2$). These data were 11 and 43% in 1976 and 1979, when population levels of *A. orana* were rather low in all plots (Table 5, Fig. 6). After elimination of the variation in the July damage, which was correlated with larvae counts of *A. orana*, still a significant effect of the factor "insecticide" remained, except in 1978. This indicates that insecticide treatments in some cases may also have affected other factors causing July damage than *A. orana*. These may be other harmful leafroller species, which were undetected by our sampling procedure and our timing: we counted only on shoottips and only during the period that full-grown *A. orana* larvae were present. The higher July damage at similar *A. orana* densities in IPM-0 compared to other plots, is an indication that the unknown pest was relatively more numerous in these plots. The analysis of covariance of fruit damage of cultivar James Grieve, showed a lower correlation

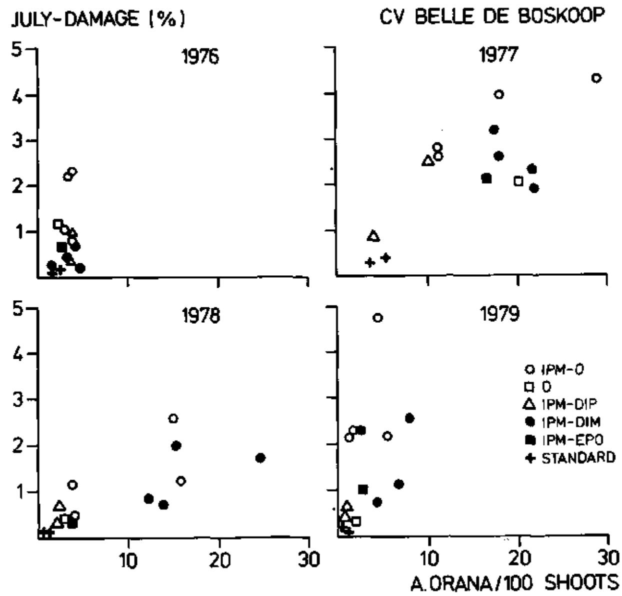


Fig. 6. Relation between July fruit damage at harvest of Belle de Boskoop and number of *A. orana* per 100 shoots in July during 1976-1979.

(66% in 1977, 18-24% in other years) between damage and larvae counts of *A. orana*, but also a significant insecticidal effect after correction for the covariable in 1976 and 1978.

When only the *A. orana* larvae, which were not parasitized by *C. florus*, were taken as covariable the correlation between fruit damage and the number of sampled larvae did not improve (Table 5), notably for the data concerning 1976 and 1977. This indicates that parasitism does not contribute to a reduction of July damage. Apparently, some larvae had already inflicted injury to fruits before parasitism became effective.

*Population levels and parasitism of leafrollers in Dipel plots*

The composition of leafroller species in Dipel treated plots was more or less similar to untreated plots, although the densities of most species was lower (Fig. 4): Dipel treated plots showed an average of 59% reduction in leafrollers compared to IPM-0 plots (Table 6). The reduction could be attributed to a significant decrease

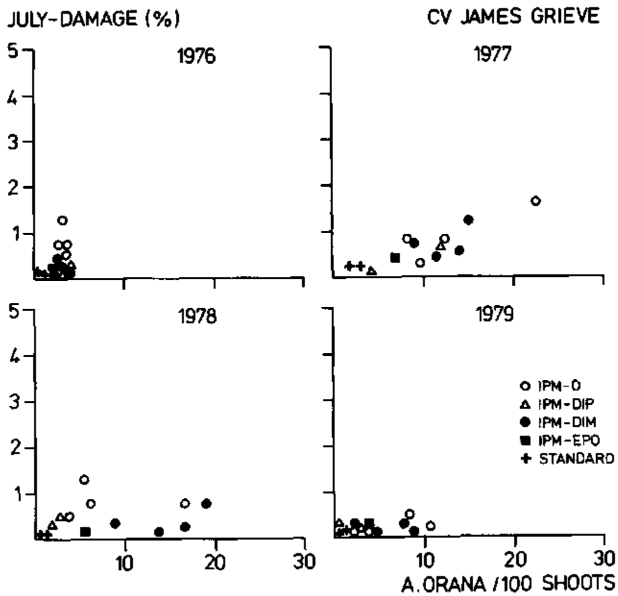


Fig. 7. Relation between July fruit damage at harvest of James Grieve and number of *A. orana* per 100 shoots in July during 1976-1979.

of *S. ocellana* and *P. heparana*. Doubling the rate of Dipel application reduced the *P. heparana* and *H. nubiferana* populations even further, resulting in an almost 80% decrease of the total population (Fig. 8). Control of *S. ocellana* was not improved.

The summer generation of *A. orana* was kept below the economic threshold in 1977 and 1978 in the plots where Dipel was applied at double rate, but not in 1977 in the plots where it was applied at the single rate (3 kg Dipel per ha) in spring and in June. When Dipel was only sprayed in spring (1976) the density of *A. orana* in summer was even higher than in untreated plots (Fig. 5).

The level of parasitism of *A. orana* by *C. florus* was apparently unaffected by Dipel treatment (Fig. 9). The rate of parasitization of leafrollers during spring in Dipel plots, which could only be determined for *P. heparana* in 1977, did not differ significantly from that in IPM-0 plots (unpublished data).

Table 5. Variance analysis of the effect of the different control measures on July leafroller damage in the harvest of cv. Belle de Boskoop with the number of sampled *A. orana* larvae in July as covariable: (1) inclusive and (2) exclusive parasitized larvae by *C. florus*. F-values and squares of correlation coefficient in percentages ($100R^2$).

| Source | df | 1976 | | 1977 | | 1978 | | 1979 | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | $100R^2$ | F | $100R^2$ | F | $100R^2$ | F | $100R^2$ |
| (1) Covariable | | | | | | | | | |
| Total no. larvae | 1 | 3.0 | 11 | 71.0 | 69 | 23.2 | 71 | 16.5 | 43 |
| Main effect | | | | | | | | | |
| Insecticide | 5 | 3.2(*) | 62 | 5.0* | 24 | 0.5 | 7 | 3.0(*) | 39 |
| Residual | 7 | - | 27 | - | 7 | - | 22 | - | 18 |
| Total | 13 | - | 100 | - | 100 | - | 100 | - | 100 |
| (2) Covariable | | | | | | | | | |
| Larvae minus *C. florus* | 1 | 0.1 | 1 | 16.4 | 31 | 24.3 | 63 | 14.5 | 37 |
| Main effect | | | | | | | | | |
| Insecticide | 5 | 2.2 | 73 | 5.9* | 56 | 1.4 | 19 | 3.6(*) | 45 |
| Residual | 7 | - | 26 | - | 13 | - | 18 | - | 18 |
| Total | 13 | - | 100 | - | 100 | - | 100 | - | 100 |

Significance level: (*) $P < 0.10$, * $P < 0.05$, F-test.

Table 6. Mean reduction of leafrollers in spring in the various treated plots compared to IPM-0 plots (= 0% reduction), averaged over 1976-1979.

| Species | Reduction (%) | | | |
|---|---|---|---|---|
| | Dipel | Dimilin | epofenonane' | standard |
| *S. ocellana* | 66** | 94** | 70** | 100** |
| *P. heparana* | 53(*) | 64* | 27 | 100** |
| *A. orana* | 9 | 3 | -20 | 67* |
| *A. podana* | -17 | 74 | 100 | 95 |
| *H. nubiferana* | 55 | 89** | 48 | 99 |
| *P. lecheana* | 60 | 60(*) | 100(*) | 90* |
| Total reduction | 59** | 80** | 58** | 98** |

Significance levels: (*) P <0.10, * P <0.05, ** P <0.01: Student t-test, analysis of variance.
Remark: Mean density of the total leafroller population in IPM-0 was 13 larvae/100 clusters.
' concerns only 1978.

*Fruit injury by caterpillars in Dipel plots*

The reduction of external fruit feeding damage by leafrollers (July and late-summer injury) was insignificant, when Dipel was applied only in spring (1975, 1976). An additional spraying in June resulted in 32-50% reduction, compared to IPM-0 plots in 1978-1979 (Table 7: plot 1). Doubling the rate gave a slight improvement (plot 2). Codling moth was unaffected (Table 8).

Early caterpillar damage was unaffected by application of Dipel at the single rate and only moderately reduced at the double rate (Table 9).

*Population levels and parasitism of leafrollers in Dimilin plots*

Dimilin reduced the total leafroller population by 80%, compared to IPM-0 (Table 6, Fig. 4). The population of *S. ocellana, H. nubiferana* and *A. podana* was reduced considerably, although the effect on the latter species was not statistically significant. The population of *P. heparana* could only be reduced by 50% by spraying 1.2 kg Dimilin/ha in spring (recommended rate for winter moth, noctuids) and

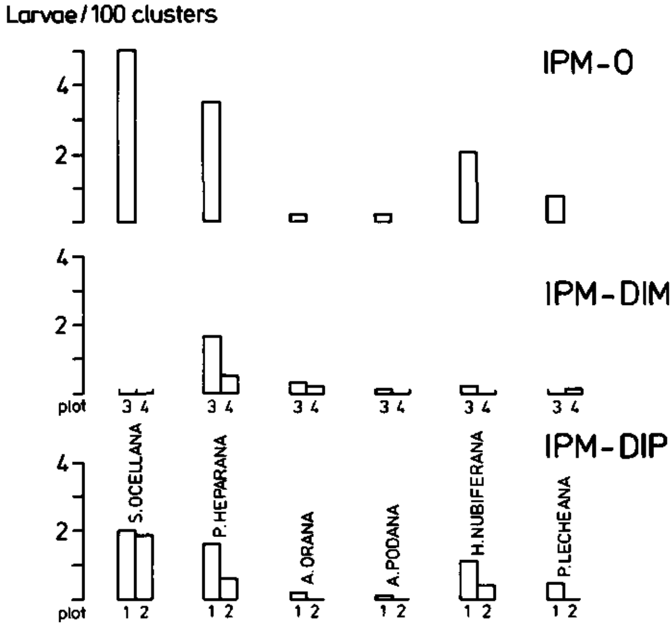


Fig. 8. Comparison of the densities of six different leafroller species in plots with various insecticide treatments: Plot 1: Dipel 6 kg/ha/year in May and June; Plot 2: Dipel 12 kg/ha/year in May and June; Plot 3: Dimilin 1.2 kg/ha in May and 0.6 kg/ha in July; Plot 4: Dimilin 2.4 kg/ha in May and 1.2 kg/ha in July.

0.6 kg/ha in summer (recommended rate for codling moth). Application at double rate resulted in 80% control of this species (Fig. 8). No effect was observed on the summer generation of *A. orana* (Fig. 5). Sprayings carried out at the time of egg hatch of *A. orana* were also ineffective (unpublished data).

The level of parasitism of *A. orana* by *C. florus* during summer of 1977 and 1978 was lower in some of the Dimilin plots, compared to IPM-0 plots, inspite of similar host population densities (Fig. 9). Whether this is due to an adverse effect of Dimilin on the parasite population is doubtful because reduced parasitism was not found in other Dimilin plots or in other years.

The rate of parasitism of *P. heparana*, the only species which could be collected in sufficient numbers in Dimilin plots during the spring of 1976-1979, did not differ significantly from the IPM-0 plots (unpublished data).

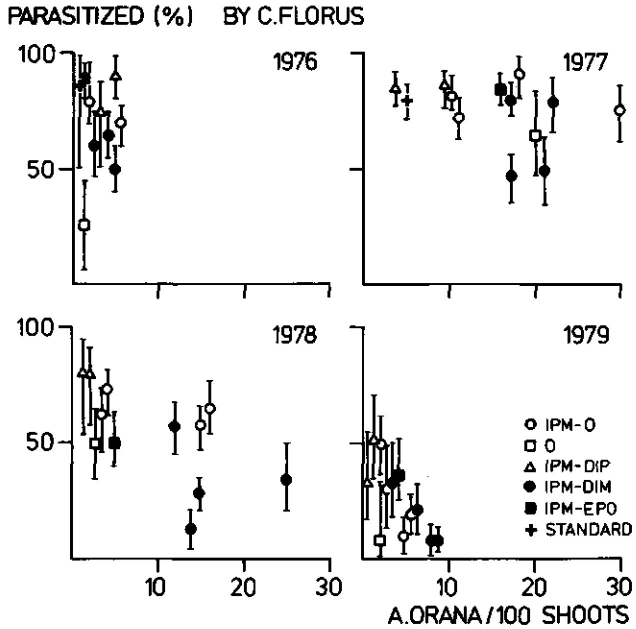


Fig. 9. Rate of parasitism of *A. orana* by *C. florus* in the various plots in relation to *A. orana* densities in July.

*Fruit injury by caterpillars in Dimilin plots*

External fruit feeding damage, caused by leafrollers (July and late-summer damage) was reduced by 66-83%, when Dimilin was applied at double rate in spring and summer (Table 7: plot 4, 1977-1979). Only in 1978 was this treatment sufficient to keep fruit injury below 1%. Application at lower rates resulted in slightly lower reduction of fruit injury.

The proportion of wormy fruits was diminished greatly after spraying Dimilin in spring and summer (Table 8: plots 3 and 4 in 1977, all plots in 1978-1979). Even a single spraying, performed around bloom, kept fruit injury far below 1%, when the injury level was low (1.4%) in IPM-0 plots (1975). This was not the case, when injury levels of about 8% occurred in the controls (1976, 1977). Spraying at petal fall gave better results than pre-blossom sprayings. A single spraying in July was not included in our program.

Table 7. Effect of the various insecticide treatments on external fruit feeding damage by leafrollers (July and late-summer damage) compared to IPM-0 plots (=0% reduction), averaged over five cultivars.

| Insecticide[1] | Plot | Reduction (%) | | | | |
|---|---|---|---|---|---|---|
| | | 1975 | 1976 | 1977 | 1978 | 1979 |
| Dipel | 1 | 11 | 7 | 32 | 50** | - |
| | 2 | - | 31 | 57* | 67** | - |
| Dimilin | 3 | 64(*) | 76** | 49* | 46* | 69 |
| | 4 | 47(*) | 68** | 66* | 83** | 73 |
| | 5,6 | 48(*) | 53* | 50* | 54** | - |
| epofenonane | 7 | - | 42* | 54* | - | - |
| broadspectrum chemicals | 8,9 | 89* | 94** | 93** | 96** | 98* |

[1] see Table 1 for applied rates.
Significance levels: see Table 6.

Early caterpillar damage was reduced by 66-88% in 1975-1978 and by 49-59% in 1979 with a single post-blossom spraying or with two sprayings (pre-blossom and petal fall) at the rate of 1.2-1.8 kg/ha (Table 9: plots 3 and 6). This was sufficient to keep early caterpillar damage below 1%, except in 1979. Pre-blossom spraying was less effective. Doubling the rate of application resulted in only marginal improvement.

*Population levels and parasitism of leafrollers and fruit injury in the epofenonane plot*

Due to unforeseen circumstances only data of 1978 could be used for analysis. The leafroller population, comprising *S. ocellana*, *P. heparana*, *A. orana* and *H. nubiferana* was reduced by 58%, compared to IPM-0 plots (Fig. 4, Table 6). The *P. heparana* population appeared hardly to be affected. The same holds for the

Table 8. Effect of the various insecticide treatments on fruit injury by codling moth, compared to IPM-0 (=0% reduction), averaged over five cultivars.

| Insecticide[1] | Timing in May[2] | Plot | Reduction (%) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1975 | 1976 | 1977 | 1978 | 1979 |
| Dipel | preB+postB[3] | 1 | 0 | 30 | 4 | 38 | 40* |
| | preB+postB[3] | 2 | - | 23 | 30 | 25 | -60* |
| Dimilin | preB+postB[4] | 3 | 86 | 79* | 92** | 100(*) | 100** |
| | preB+postB[4] | 4 | 86 | 92** | 99** | 100(*) | 100** |
| | postB | 6 | 79 | 77* | 92* | 88 | 100** |
| | preB | 5 | 50 | 42(*) | 84** | 100(*) | 90** |
| epofenonane | preB+postB | 7 | - | -21 | 9 | - | |
| broadspectrum chemicals | preB+postB | 8,9 | 93* | 98** | 99** | 100* | 100** |

[1] See Table 1 for applied rates.
[2] preB=pre-blossom spraying, postB=post-blossom spraying (petal fall).
[3] in 1976 only pre-blossom spraying.
[4] in 1975 and 1976 only post-blossom spraying.
Significance levels: see Table 6.

Table 9. Effect of the various insecticide treatments on early caterpillar fruit damage, compared to IPM-0 (=0% reduction), averaged over five cultivars.

| Insecticide[1] | Timing in May[2] | Plot | Reduction (%) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1975 | 1976 | 1977 | 1978 | 1979 |
| Dipel | preB+postB[3] | 1 | -32 | 24 | -8 | -16 | 12(*) |
| | preB+postB[3] | 2 | - | 81* | 49 | 56(*) | 47* |
| Dimilin | preB+postB[4] | 3 | 78 | 88* | 82* | 72* | 59* |
| | preB+postB[4] | 4 | 68 | 75(*) | 86* | 76* | 63* |
| | postB | 6 | 73 | 69(*) | 77* | 66* | 63* |
| | preB | 5 | 54 | 38 | 61(*) | 52(*) | 49* |
| epofenonane | preB+postB | 7 | - | -78 | 26 | - | - |
| broadspectrum chemicals | preB+postB | 8,9 | 84(*) | 88* | 95** | 96** | 91** |

See Table 8 for footnotes [1]-[4].
Significance levels: see Table 6.

post-hibernation (Table 6) and summer generation of *A. orana* (Fig. 5). Side-effects on parasitism levels of the summer generation of *A. orana* were not observed (Fig. 9). The weak effect of epofenonane on leafroller populations gave correspondingly feeble results in fruit injury reduction, which amounted to only 54% (Table 7). As would be expected from the timing of spraying, there was no effect on codling moth (Table 8). Effects on early caterpillar damage were insignificant (Table 9).

## DISCUSSION

Nearly all ten different external fruit feeding leafroller species, occurring in the large bush apple trees, that had not received insecticides for 10 years, were also found in the IPM-0 plots. *A. orana* was most numerous in summer, whereas *S. ocellana*, *P. heparana* and *H. nubiferana* were relatively dominant in the spring. Such a variety of leafroller species, probably due to discontinuation of broadspectrum insecticides, was also encountered in other apple orchards practicing IPM (DE REEDE, ALKEMA and L.H.M. BLOMMERS, in prep.). In addition to these external fruit feeding species, codling moth was a pest during warm summers. Omission of leafroller control led to a total fruit injury level (external and internal damage) of 8.8-13.9% during 1975-1979.

The rate of parasitism was generally low, except in the summer generation of *A. orana*, which was heavily parasitized, especially by *C. florus* during 1976 and 1977. Even during years in which the initial population density of the larval population of *A. orana* in the summer was as high as to enflict too much July damage, the pest stayed under its economic threshold for late-summer damage. However overwintered larvae of *A. orana* and other species, including *S. ocellana*, *P. heparana* and *H. nubiferana*, remained free of parasitism by *C. florus* in the spring, presumably because the parasite is virtually absent at that time (EVENHUIS 1974, GRUYS 1982, GRUYS and VAAL 1984).

The effect of the selective insecticides on the level of parasitism of *A. orana* by *C. florus* could not be established as side-effects of broadspectrum insecticides on parasitism in the standard plots were also absent.

Under the Dipel regimes the total leafroller population density was roughly halved. *P. heparana*, *H. nubiferana* and especially *S. ocellana* were difficult to control. Even high dosages of Dipel gave only moderate reduction of damage by leafrollers and other external fruit feeding caterpillars. These results are in agreement with previous observations in several commercial orchards (DE REEDE and ALKEMA 1981).

Application of Dimilin reduced the population levels of *S. ocellana*, *H. nubiferana* and *A. podana* greatly and that of *P. heparana* to about one third, but *A. orana* was not affected. External fruit injury by the total leafroller population was only reduced by half. Early caterpillar damage was kept at low level by one spraying at petal fall.

Dimilin was most effective in controlling codling moth. One spraying at petal fall sufficed for some 80% reduction of wormy fruits, which is quite satisfactory for the low levels of codling moth encountered during the past years in modern orchards in the Netherlands. At higher densities, as occurred in 1976 and 1977, an additional spraying at 0.6 kg/ha around July $1^{st}$ resulted in almost total control.

An excellent effectiveness of Dimilin against codling moth was also reported by WEARING and THOMAS (1978), WESTIGARD (1979), CRANHAM (1978) and DE REEDE and ALKEMA (1981), but less satisfactory control was reported by BOWER and KALDOR (1980), BOWER (1980) and HOYING and RIEDL (1980). Factors such as population density and timing of spraying may have played a role.

Restriction of epofenonane application to spring, the only possible strategy was insufficient for leafroller control in our experiments. These results are in contradiction with previous observations in small-scale field experiments, in which *A. orana* and *P. heparana* were susceptible to epofenonane (DE REEDE et al., 1984). The effectivity of epofenonane and a related compound in reducing the population of *A. orana* was shown in experiments in several commercial orchards (SCHMID et al., 1978, CHARMILLOT et al., 1983). Immigration of moths from adjacent IPM-0 and IPM-DIM plots during summer may have blurred any original effect in our experiments. More appropriate field experiments to evaluate epofenonane and a related product for leafroller control will be reported elsewhere.

Clearly, neither Dipel nor Dimilin can provide full control of caterpillar damage, when compared with broadspectrum insecticides, which hardly spare any leafroller.

None of the selective insecticides tested disturbed the relation between the fruit-tree red spider mite, *Panonychus ulmi* and its phytoseiid predators. Consequently, the phytophagous mite population remained far below the economic threshold (GRUYS 1982).

## RÉSUMÉ

Trois insecticides sélectifs pour le contrôle des tordeuses sont évalués. Ce travail constitue une partie des efforts de recherches menés aux Pays-Bas, pour l'amélioration de la lutte intégrée dans les vergers.
Nous avons étudié les niveaux de population de tordeuses, les dommages causés par celles-ci aux fruits, ainsi que le degré de parasitisation dans un verger expérimental divisé en parcelles de 0.5 à 1 ha.
Pendant 5 années consécutives, les différentes parcelles ont été vaporisées à l'aide de Dimiline, un inhibiteur de la synthèse de chitine, de Dipel, un agent bactérien, et enfin d'époofénonane, un analogue de l'hormone juvénile.
Le Dipel et la Dimiline se sont révélés peu effectifs dans la réduction des taux de population ainsi que du degré des dommages. Les pestes particulièrement difficiles à contrôler sont, respectivement, dans les terrains traités par le Dipel: *Pandemis heparana* (DENN. et SCHIFF.), *Spilonota ocellana* (F.) et *Laspeyresia pomonella* (L.) et dans les terrains traités par la Dimiline: *P. heparana* et *Adoxophyes orana* (F.V.R.). Nous avons pu évaluer l'effet de l'époofénonane de manière adéquate, en raison de reïnfestations par des papillons venant des terrains avoisinants, ces derniers hébergeant des populations élevées de tordeuses.

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Chapter 2

# Field tests with the Insect Growth Regulators, epofenonane and fenoxycarb, in apple orchards against leafrollers and side-effects on some leafroller parasites.

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ABSTRACT

The Insect Growth Regulators with juvenile hormone activity, fenoxycarb and epofenonane, were applied either to separate apple trees, which were artificially inoculated with *Adoxophyes orana* (F.v.R.) and *Pandemis heparana* (DENN. et SCHIFF.), or in apple orchards infested with several naturally occurring leafroller species. The susceptibility of leafrollers to fenoxycarb was very high and the persistence of active foliar residue lasted at least four weeks. The leafroller parasites *Apanteles ater* (RATZEBURG) and *Colpoclypeus florus* (WALKER) during their development in or on the host, appeared to be less susceptible to both epofenonane and fenoxycarb than the host itself.

Keywords
juvenile hormone analogue, epofenonane, fenoxycarb, leafroller, tortricid, apple orchard, *Adoxophyes orana*, *Pandemis heparana*, *Apanteles ater*, *Colpoclypeus florus*, insect growth regulator

## INTRODUCTION

Leafrollers, such as *Adoxophyes orana* (F.v.R.), *Archips podana* (SCOP.) and *Pandemis heparana* (DENN. et SCHIFF.) are, together with *Panonychus ulmi* (KOCH) keypests in topfruit growing in Western Europe. In the Netherlands one to four sprayings with broad-spectrum insecticides are carried out, especially against *A. orana*. If the use of these chemicals is discontinued, as required for integrated pest management (IPM) in apple orchards, leafroller species other than *A. orana* may become numerous (GRUYS 1982, ANKERSMIT et al. 1977, DE JONG and GRUYS 1975). The question arised whether a mixed population of different leafroller species could be controlled by Insect Growth Regulators (IGR) with juvenile hormone activity.

Previous laboratory studies on the effects of these type of IGR's on *A. orana* (SCHOONEVELD and ABDALLAH 1975, SCHOONEVELD and WIEBENGA 1974, SCHOONEVELD et al. 1976) indicated their potential for application in controlling this insect. In the present experiments particular attention was paid to factors occurring under field conditions in IPM-orchards, harbouring several leafroller species: (1) susceptibility of different leafroller species (2) persistence of foliar residue (3) side effects on some leafroller parasites.

## MATERIALS AND METHODS

### *Application against leafrollers*

Epofenonane (chemical name: 6,7-epoxy-3-ethyl-1-(p-ethylphenoxy)-7-methylnonane, code: Ro 10-3108) and fenoxycarb (chemical name: ethyl(2-(p-phenoxyphenoxy)ethyl) carbamate, code: Ro 13-5223) were kindly supplied by Dr. R. Maag Ltd., Dielsdorf, Switzerland. These were applied either on single trees or in orchards until "runoff" using a handcompression, knapsack or power operated hose sprayer (1500 l/ha) or more concentrated using a mistblower (150 l/ha).

The tests (2 to 3 replicates) on single trees were carried out on *A. orana* and *P. heparana*, obtained from mass culture (ANKERSMIT 1968). Trees were infested with either freshly moulted last larval instars or the instar preceding this. Other trees were inoculated with eggbatches.

As for experiments where orchards were treated, the effects of the IGR's on the naturally occurring leafroller population, namely *A. orana*, *P. heparana*, *A. podana*, *Spilonota ocellana* (DENN. et SCHIFF.) and *Archips rosana* (L.) were monitored.

Caterpillars were restricted in bags (15x20 cm) of fine-meshed gauze. In order to determine the timing of the pupae-adult moult in the field, a similar batch of larvae was maintained on an artificial diet under outdoor conditions. Caterpillars collected from the field which were still alive were reared under outdoor conditions on leaves from the original plots for another week and thereafter kept on artificial diet (ANKERSMIT 1968).

The effect of the application was scored according to ABDALLAH (1972). Score 0 indicated no effect, score 1 indicated pupae with minor aberrations, while the highest score 7 is given to caterpillars of larger than normal size with well-developed antennae. Larval mortality without morphogenetic effects was not accounted to spraying effects. In newly emerged adults morphogenetic effect ranging from rudiments of larval abdominal legs to crumpled wings and incomplete pupa to adult moult were noted. Laboratory studies showed a correlation between these criteria and reduced reproduction (SCHOONEVELD and ABDALLAH 1975, MASNER et al. 1981). The percentage of individuals which did not develop into a normal adult, will be called percentage of effect.

The persistence of active foliar residue of fenoxycarb and epofenonane under field conditions was studied by picking leaves at various times after spraying. The leaves were offered in the outdoor insectary in glass vials to either freshly moulted last larval instars or to the instar preceding this of *A. orana* and *P. heparana*, obtained from mass culture.

*Side-effects on leafroller parasites*

Side-effects of the IGR's on *Colpoclypeus florus* (WALKER), a gregarious ectoparasite of *A. orana*, were studied in the laboratory. Fourth or fifth larval instars of *A. orana* were obtained from trees, which had been infested with egg-masses. The larvae were collected 12 days after spraying and placed on leaves from originating plots and reared in vials (10x2 cm) at 20 degrees Celsius and 16 hr photoperiod together with a couple of 1 to 3 days old mated female wasps of *C. florus*. Six weeks later the number of adult parasites and the number of non-eclosed pupae were counted. Both parasite and host originated from mass cultures (P. GRUYS and F. VAAL, 1984 in press ). Side-effects on two endoparasitic wasps viz. *Apanteles ater* (RATZEBURG) (Hymenoptera: Braconidae) and *Tranosema arenicola* (THOMSON) (Hymenoptera: Ichneumonidae) parasitizing *Archips rosana* (L.), were observed in the field. Parasites were identified according to EVENHUIS and VLUG (1983).

## RESULTS

*Effects on leafrollers*

In single tree experiments, fenoxycarb, applied at 5g/100 l, and epofenonane, applied at 5ml/100 l, caused severe morphogenetic effects in *A. orana* and *P. heparana* (Table 1). Fenoxycarb appeared to be effective even at a concentration

Table 1. Mean scores of morphogenetic effects and percentage of effect of fenoxycarb and epofenonane on *A. orana* and *P. heparana*, placed in bags on trees after spraying. In brackets total number.

| Species | Treatment[1] | Rate a.i. per 100 l[4] | Mean score [2] | Effect (%)[3] |
|---|---|---|---|---|
| *A. orana* | fenoxycarb (50WP) | 50 g | 6.7 (32) | 100 |
| | | 5 g | 4.7 (25) | 96 |
| | | 0.5 g | 5.1 (21) | 95 |
| | epofenonane (500EC) | 50 ml | 6.5 (43) | 97 |
| | | 5 ml | 5.4 (23) | 90 |
| | | 0.5 ml | 0.7 (25) | 29 |
| | untreated | - | 0.3 (50) | 14 |
| *P. heparana* | fenoxycarb (50WP) | 50 g | 5.9 (41) | 100 |
| | | 5 g | 5.3 (43) | 100 |
| | epofenonane (500EC) | 50 ml | 4.0 (48) | 69 |
| | untreated | - | 0.7 (41) | 29 |

[1] 50 WP: Wettable powder 50% a.i., 500 EC: emulsifiable concentrate 500 g a.i./l.
[2] Scoring of effect (range 0-7) according to ABDALLAH (1972).
[3] Effect is calculated as: (Number, which did not develop into a normal adult/Total number, recovered in bags) x 100%.
[4] Applied until runoff.

of 0.5g/100 l in *A. orana*. In the case of *P. heparana*, the morphogenetic effect of epofenonane was considerably less than that of fenoxycarb even at the highest concentration of 50 ml/100 l (Table 1). Treatment of fullgrown *A. orana* larvae, which emerged on trees, inoculated with eggbatches, resulted in similar morphogenetic effects as those observed by treatment of released larvae, inspite of the fact that the former group displayed a variability of about 3 weeks in the final larval moult (Table 2). The application of epofenonane and fenoxycarb against leafrollers present naturally in orchards, namely larvae of *A. orana*, *A. podana*, *S. ocellana*, *P. heparana* and *A. rosana* also resulted in severe deformations (Table 3). Even application via overtree irrigation (Location Geldermalsen) was highly effective.

The foliar residue of fenoxycarb was persistent for several weeks (Figs. 1 and 2). The percentage effect of one single spraying at a rate of 5 g a.i./100 l

Table 2. Mean scores of morphogenetic effects and percentage of effect after two sprayings with fenoxycarb and epofenonane on *A. orana*, artificially raised by attaching eggmasses on leaves.* In brackets total number.

| Treatment[1] | Rate a.i./100 l/ application[4] | Mean score[2] | Effect (%)[3] |
|---|---|---|---|
| fenoxycarb (50WP) | 50 g | 5.4 (42) | 100 |
| | 5 g | 3.7 (18) | 83 |
| epofenonane (500EC) | 50 ml | 4.7 (22) | 96 |
| | 5 ml | 4.0 (46) | 100 |
| untreated | - | 2.7 (28) | 70 |

[1] 50 WP: Wettable powder 50% a.i., 500 EC: emulsifiable concentrate 500 g a.i./l.
[2] Scoring of effect (range 0-7) according to ABDALLAH (1972).
[3] Effect is calculated as: (Number, which did not develop into a normal adult/Total number, recovered in bags) x 100%.
[4] Applied until runoff.

* A batch of larvae, collected before spraying, showed a mean score of 0.1 (n = 58) and a mortality of 5%.

Table 3. Mean score of morphogenetic effects and percentage of effect of sprayings with fenoxycarb and epofenonane on naturally occurring leafrollers in spring. In brackets total number.

| Locality[4] | Treatment[1] | Rate a.i./ha application | No. of applications | Species | Mean score[2] | Effect (%)[3] |
|---|---|---|---|---|---|---|
| Betuwe 1 | fenoxycarb (25WP) | 150 g[5] | 2 | *A. orana* | 5.2 (25) | 100 |
| " 2 | " | 150 g[6] | 1 | " | 4.2 (13) | 100 |
| " 2 | " | 150 g[6] | 2 | *A. podana* | 6.0 (21) | 100 |
| " 2 | " | 150 g[6] | 1 | " | 3.6 (11) | 82 |
| " 3 | fenoxycarb (50WP) | 75 g[7] | 2 | *S. ocellana* | 2.1 (21) | 95 |
| " 3 | " | 75 g[7] | 1 | " | 1.9 (15) | 80 |
| " 3 | untreated | - | - | " | 0.7 (15) | 53 |
| " 3 | fenoxycarb (50WP) | 75 g[7] | 2 | *P. heparana* | 3.1 (18) | 100 |
| " 3 | " | 75 g[7] | 1 | " | 2.4 (22) | 91 |
| " 3 | untreated | - | - | " | 0 (14) | 0 |
| Flevopolder | epofenonane (500EC) | 750 ml[5] | 2 | *A. rosana* | 3.9 (20) | 95 |
| N.E.-polder | epofenonane (500EC) | 750 ml[5] | 2 | " | 3.0 (20) | 95 |
| | | 750 ml[5] | 1 | " | 4.0 (27) | 96 |

[1] 25-50 WP: Wettable powder 25-50% a.i., 500 EC: emulsifiable concentrate 500 g a.i./l.
[2] Scoring of effect (range 0-7) according to ABDALLAH (1972).
[3] Effect is calculated as: (Number, which did not develop into a normal adult/Total number, recovered in bags) x 100%.
[4] Betuwe: 1 Avezaath, 2 Geldermalsen and 3 Lienden.
[5] Mistblower, approximate 150 l/ha.
[6] Overtree irrigation, approximate 1500 l/ha.
[7] Hose spraying, 1500 l/ha.

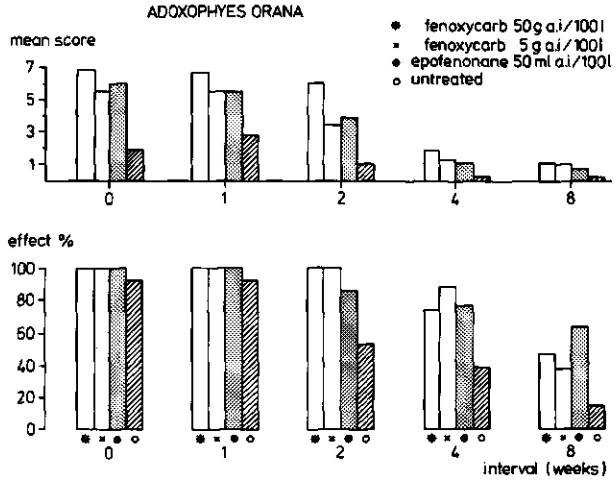


Fig. 1. Persistence of active foliar residue of fenoxycarb and epofenonane with respect to time in weeks, as determined by observing the morphogenetic effect on *A. orana* (n = 15) in the insectary which were offered leaves, picked from trees at various times after spraying.

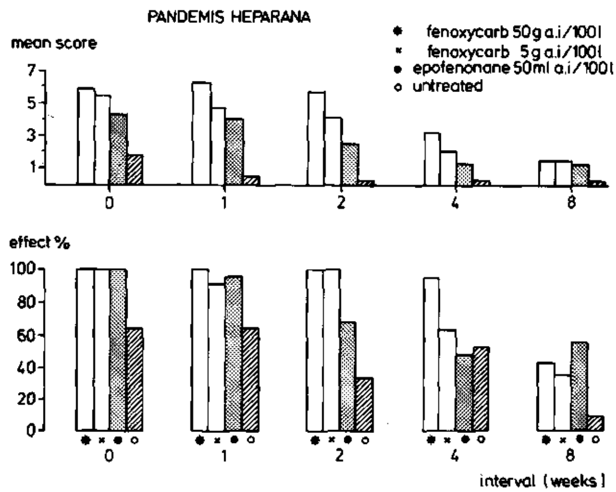


Fig. 2. Persistence of active foliar residue of fenoxycarb and epofenonane with respect to time in weeks, as determined by observing the morphogenetic effect on *P. heparana* (n = 25) in the insectary, which were offered leaves, picked from trees at various times after spraying.

was close to hundred until the fourth week and decreased thereafter to 40 percent. The persistence of epofenonane on leaves however, appeared to be shorter (Figs. 1 and 2).

Contamination of the controls could not be prevented, inspite of the precautionary measures taken in the field (guard trees, separate backpack sprayer for fenoxycarb) and in the laboratory.

*Side effects on leafrollers parasites*

Fewer adults of C. *florus* per host appeared to develop in A. *orana* larvae, collected from fenoxycarb treated than from untreated trees in fieldtests in the previous year. This observation was confirmed by a laboratory experiment. A high percentage of the parasite pupae failed to eclose in the fenoxycarb treatment compared to the control and the epofenonane treatment (Table 4).

*Apanteles ater*, a gregarious endoparasite found in *A. rosana* appeared to be affected by both fenoxycarb and epofenonane. The host population in this case was also augmented by attaching eggmasses, obtained from a field population, to trees. A month after restriction of larvae in bags on trees and after spraying, which was carried out when 25 percent were in their final larval stage, still a lot of larvae were present in the bags. These appeared to be parasitized mainly by *A. ater*. The number of adult parasites per host was lower when the hosts had been sprayed (Table 4).

The solitary endoparasite *Tranosema arenicola* appeared not to be affected by two sprayings with fenoxycarb with an interval of three weeks (150 g a.i./ha/ spraying) in a 0.5 ha plot. The magnitude of parasitism in 140 and 67 *A. rosana* larvae, collected from untreated and treated plots respectively, sampled two days after the second spraying, was 22 and 24 percent. In this experiment however fenoxycarb had been sprayed approximately three weeks before the pupal moult of the host, which itself was also unaffected.

## DISCUSSION

There is already some field experience with the control of *A. orana* using epofenonane and fenoxycarb. The percentage of leafroller damage to fruits due to this species could be kept low by spraying twice during spring, in Switzerland and in The Netherlands (SCHMID et al. 1978, CHARMILLOT et al. 1983, DE REEDE, ALKEMA and L.H.M. BLOMMERS in prep.). The object of the present study was to investigate whether a mixed population of leafroller species could be controlled

Table 4. Effect of fenoxycarb and epofenonane on *Colpoclypeus florus* and *Apanteles ater* developing on or in respectively the host *A. orana* and *A. rosana*. Mean number of non-eclosed pupae, adults and percentage of pupal mortality of the parasite.

| Parasite | Treatment | Rate a.i./ 100 l[1] | Nr. of hosts[2] | | Nr. of parasites/host | | | Pupal mortality (%) |
|---|---|---|---|---|---|---|---|---|
| | | | total | parasitized | non-eclosed pupae | adults | total | |
| *C. florus* | untreated | - | 37 | 23 | 0.8 | 9.6 | 10.4 | 8 |
| | epofenonane | 50 ml | 31 | 14 | 3.4 | 12.2 | 15.6 | 22 |
| | fenoxycarb | 5 g | 38 | 21 | 10.4 | 1.5 | 11.9 | 87 |
| *A. ater* | untreated | - | - | 13 | 0.1 | 17.2 | 17.3 | 1 |
| | epofenonane | 50 ml | - | 30 | 5.2 | 9.7 | 14.9 | 35 |
| | fenoxycarb | 5 g | - | 48 | 4.6 | 11.7 | 16.3 | 28 |

[1] applied by backpack sprayer untill runoff, approximate 1500 l/ha.
[2] mean scores of morphogenetic effects of unparasitized *A. orana* were 0.1, 5.9 and 6.2 in respectively untreated, epofenonane and fenoxycarb.

by the Insect Growth Regulator fenoxycarb.

Factors which have to be considered with mixed populations are a) the susceptibility of each species to the compound and b) the variation of the phenology of the susceptible stage of the concerned species.

To get similar results fenoxycarb could be applied at lower concentrations than epofenonane in our fieldtests on *A. orana* and *P. heparana*. This is in agreement with experiments of DORN et al. 1981. Another indication for the potency of fenoxycarb was the fact that it was hard to prevent contamination of control plots with this compound. This did not occur with earlier studies using epofenonane.

All tested species, namely *A. orana*, *A. podana*, *S. ocellana* and *P. heparana* appeared to be susceptible to fenoxycarb, when applied in orchards at a rate of 75 or 150 g a.i./ha. A spraying with epofenonane at 750 ml a.i./ha even affected *A. rosana*, inspite of its dense leafrolls.

The considerable persistence on leaves is an important property of fenoxycarb in connection with differences in the phenology of last larval instars within species, but also between species. The persistence of epofenonane, though shorter than that of fenoxycarb, appeared sufficient to cover the period of emergence of the last larval instar of *A. orana*. Two sprayings were nevertheless necessary, because of the vigourous leafgrowth in spring (SCHMID et al. 1978). To control a mixed population, consisting of phenologically early (*A. orana* ) and late species (*S. ocellana, P. heparana*) together, three sprayings will probably be necessary, taking into account the leafgrowth during May-June.

Several authors have reported that endoparasites are also affected after treatment of the lepidopteran host with juvenile hormone or juvenile hormone analogue (VINSON 1974, SMILOWITZ et al. 1976, GRANETT et al. 1975, OUTRAM 1974); other endoparasites were found to be tolerant (WILKINSON and IGNOFFO 1973, SCHEURER et al. 1975, SECHSER and VARLY 1978). In the present study, fenoxycarb and epofenonane do seem to affect the gregarious endoparasite *A. ater*, when its host *A. rosana* is sprayed, as indicated by the failure of a percentage of pupae to eclose. There was a difference between the epofenonane and the fenoxycarb treatment. Such an effect of a juvenile hormone treatment on the pupal-adult moult is a more common feature in Hymenoptera and Diptera than in Lepidoptera (HSIAO and HSIAO 1969, POSTLETHWAIT 1974, ZDAREK and HARAGSIN 1974, BECKAGE and RIDDIFORD 1982).

Another endoparasite, *Tranosema arenicola* with *A. rosana* as host, appeared unaffected in a 0.5 ha plot, sprayed with fenoxycarb against other phenologically earlier leafroller species.

The ectoparasite *C. florus* can take a heavy tall of the summer generation of *A. orana* (GRUYS 1982, EVENHUIS 1974). Therefore we included this parasite in the present study. The parasite pupae failed to eclose after spraying the fullgrown larval host, *A. orana*, and the host plant with fenoxycarb. This percentage was much lower after epofenonane treatment. Under field conditions however, *C. florus* is abundant only from July onwards, while IGR applications against leafrollers are routinely performed in May. In large scale experiments, after spraying in May, no side-effects could be observed on *C. florus* in July (DE REEDE, unpublished).

Although our studies indicate some side-effects on the parasite population they also show that a considerable percentage of these parasites survive IGR treatments. This is a positive aspect when compared with broadspectrum insecticides, which kill both host and parasite. Another positive aspect is that the predator *Typhlodromus pyri* (SCHEUTEN) (Acarina: Phytoseiidae) is tolerant to sprayings with fenoxycarb and epofenonane (GRUYS 1980, DE REEDE, unpublished). This property is important for the implementation of IGR in IPM programmes for apple orchards. In conclusion, the susceptibility of different leafroller species, the considerable persistence of foliar residue and the apparent harmlessness to predacious mites and some parasites justifies large scale experimental applications of fenoxycarb, especially in IPM. Leafroller damage to fruits in orchards, sprayed successively for some years and the significance of immigration of moths after spraying are being investigated.

## RÉSUMÉ

*Essais contre certaines tordeuses de l'époféononane et du fénoxycarbe (régulateurs de croissance des insectes), et actions sur quelques uns de leurs parasites*

Le fénoxycarbe et l'époféononane (régulateurs de croissance des insectes) ont été appliqués soit sur des pommiers isolés, artificiellement inoculés avec *Adoxophyes orana* (F.V.R.) et avec *Pandemis heparana* DENN. und SCHIFF.), soit dans des vergers, contaminés naturellement par plusieurs espèces de tordeuses. Sur les arbres isolés, le fénoxycarbe appliqué à raison de 5 g de composé actif/100 l et l'époféononane de 5 ml de composé actif/100 l, affectent la morphogenèse d'*A. orana* et *P. heparana*. Le fénoxycarbe agit sur *A. orana* même à une concentration de 0,5 g de composé actif/100 l. Dans les vergers, la vaporisation d'époféononane (750 ml de composé actif/ha) et de fénoxycarbe (75-150 g de composé actif/ha) a déformé sévèrement les larves d'*A. orana*, d'*Archips podana* (SC.), de *Spilonota ocellana* (F.) de *P. heparana* et d'*Archips rosana* (L.). Les résidus foliaires actifs ont persisté au moins 4 semaines, comme l'ont montré les effets morphogénétiques observés chez *A. orana* et *P. heparana*. Au cours de leur développement, sur ou à l'intérieur de l'hôte, les parasites de tordeuses *Apanteles ater* (RATZEBURG) et *Colpoclypeus florus* (WALKER), sont moins sensibles à l'époféononane et au fénoxycarbe que l'hôte lui-même. Des expériences ultérieures à plus grande échelle sont nécessaires pour évaluer l'utilisation des régulateurs de croissance des insectes contre les tordeuses dans le contrôle intégré des vergers.

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Chapter 3

# The use of the Insect Growth Regulators fenoxycarb and epofenonane against leafrollers in Integrated Pest Management in apple orchards.

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ABSTRACT

The applicability of the Insect Growth Regulators (IGR) with juvenile-hormone activity, epofenonane and fenoxycarb, was investigated in an Integrated Pest Management (IPM) program in six apple orchards during 1977-1983. In some of these orchards *Adoxophyes orana* was the main pest species, and in others *Pandemis heparana, Archips podana* and *Archips rosana* were predominant.

The IGR was sprayed twice at the time of emergence of last-instar larvae in spring, and resulted in adequate reduction of the numbers of the leafroller complex during the rest of the year. Reinfestation by moths never resulted in an increase to a harmful population level. IGR treatments kept fruit damage by leafrollers at a low level.

Keywords: Integrated Pest Management, apple orchard, tortricid, *Adoxophyes orana, Pandemis heparana, Archips podana, Archips rosana*, epofenonane, fenoxycarb, Insect Growth Regulator, juvenile-hormone activity.

## INTRODUCTION

Caterpillars, particularly tortricids, are an important cause of injury to the fruit in apple orchards. Their control is a major issue in research on Integrated Pest Management (IPM), because the insecticides usually recommended for this purpose (pyrethroids, azinfos-methyl, methidathion) disrupt essential elements of the beneficial arthropod fauna (GRUYS 1980a, 1982).

Of the many species of leafrollers to be found in orchards *Adoxophyes orana* (F.v.R.), *Pandemis heparana* (DENN. et SCHIFF.), *Spilonota ocellana* (F.), *Archips podana* (SCOP.) and *Archips rosana* (L.) are generally the most harmful. The damaging species, or complexes of species, differ between locations. Generally in the Netherlands, in orchards with a history of broad-spectrum insecticides, *A. orana* is the major pest. However, if the use of these pesticides is discontinued, a complex of caterpillar pests, in which other species predominate, takes over (GRUYS 1982).

The selective agent Dipel (*Bacillus thuringiensis* BERL.) and Dimilin (diflubenzuron) have been shown to be ineffective for control of *A. orana* and *P. heparana* in previous experiments (VAN DER GEEST and WASSINK 1980, DE REEDE, GRUYS and VAAL chapter 1).

In this paper we present experiments on leafroller control, using Insect Growth Regulators (IGR) with juvenile-hormone activity. These compounds, when applied at certain larval stages, interfere with normal metamorphosis (MASNER 1981, DE REEDE et al. 1984). The application was carried out at the time of emergence of last-instar larvae in spring, with the aim of limiting the numbers of the leafroller population during the rest of the year. Two problems were studied: a) whether the original effect of IGR is blurred by immigration, particularly by the bivoltine species *A. orana* and b) whether control of a range of species is possible with only two applications per year.

## MATERIAL AND METHODS

### *Experimental orchards*

Experiments were carried out in six orchards of 0.3-9.0 ha (referred to below as IPM-orchards), planted with spindlebush trees. Two IPM-orchards (locations Andijk and Dronten) were surrounded by meadows or arable land and at least 150 m away from any other orchard. The other IPM-orchards were wholly or partially surrounded by orchards with a conventional spraying program. Geldermalsen, Avezaath, Dronten, Marknesse and St. Oedenrode are in the Central and Southern Netherlands; Andijk in the North West of the Netherlands. The Geldermalsen orchard consisted of a high density planting.

*Application and timing of IGR*

From 1977 to 1981, the Insect Growth Regulator epofenonane, formulation 50% EC (6,7-epoxy-3-ethyl-1-p-ethylphenoxy)-7-methylnonane) was used and from 1982 (in some orchards also in 1981) fenoxycarb, formulation 25% WP (ethyl(2-(p-phenoxyphenoxy) ethyl) carbamate), was used. The former was sprayed at 1.2 l/ha and the latter at 0.6 kg/ha formulated product. Juvenile-hormone activity was demonstrated in laboratory and field experiments with various insect species (DORN et al. 1981).

Initially a threshold was chosen of 2 larvae/1000 clusters for IGR-application. For this, leafrollers were sampled on 600 randomly choosen clusters of each cultivar at green cluster (MASSEE 1954). This laborious assessment is omitted since 1982, because the threshold had been exceeded nearly always in previous years.

The application of IGR was timed at the emergence of the last-instar larvae. For this timing whole branches were searched for leafrollers in the IPM-orchards between green cluster stage and petal fall (MASSEE 1954). The collected leafrollers were brought into an outdoor insectary and reared separately in glass vials (5 cm length and 1.5 cm diameter) on artificial diet (ANKERSMIT 1968). Their development was followed by measuring the head capsules twice or three times a week. The time when 30% of the larvae had moulted from the penultimate to the ultimate larval stage, was chosen as the first application date, because shortly thereafter the oldest larvae start to pupate. The second spraying was executed two weeks after the first. The emerging adults were identified eventually according to BENTINCK and DIAKONOFF (1968). Emerged parasites were identified according to EVENHUIS (1976) and EVENHUIS and VLUG (1983), their hosts according to EVENHUIS and VLUG (1972).

In the first year of this study, sprayings were directed at *A. orana* in all IPM-orchards. Thereafter the time of spraying was selected for control of the dominant leafroller species in the larval samples.

*Application of other pesticides*

In addition to IGR the following pesticides were used: diflubenzuron against winter moth (*Operophtera brumata* L.) and noctuids (*Orthosia* spp.), bromophos against the common green capsid (*Lygus pabulinus* L.) and pirimicarb against aphids, using the rates and action thresholds given by GRUYS (1980a) and GRUYS et al. (1980). Diflubenzuron was applied against codling moth (*Laspeyresia pomonella* L.) when more than 5 moths/week were caught in pheromone traps in 2 consecutive weeks (CRANHAM 1978). Triangular type traps from the Institute of Pesticide Research Wageningen were used.

Endosulfan was applied sometimes at bud burst stage (MASSEE 1954) to control woolly aphid (*Eriosoma lanigerum* HAUSM.), affecting also the winter moth. In 1980 and 1981 endosulfan was sprayed in combination with white oil, material known to be toxic to egg masses of *A. rosana*. The latter spraying was performed with 1500-2000 l water/ha, all others with 150-200 l water/ha.

Carbaryl was used for fruit thinning on Cox's Orange Pippin and Golden Delicious at Andijk in 1979-1983 and on all cultivars at Dronten in 1980. It was used in Andijk against *A. podana* (SCOP.) at the end of August in 1979, when the IGR spraying was discontinued. The fungicides captan and bupirimate were applied regularly (GRUYS 1980a).

*Larval counts and pheromone traps of A. orana*

The population density of *A. orana* was estimated in both IPM- and nearby conventionally treated orchards in July, when fully-grown larvae are present. Sampling was done randomly on 400-600 shoottips at the top of trees (1-2 shoottips per tree) of the various cultivars. The rearing and identification of collected larvae was as described above.

To get an indication of the number of moths immigrating into the experimental orchards, pheromone trap catches of *A. orana* were recorded (triangular type traps from the Institute for Pesticide Research at Wageningen) twice or three times a week during the two annual flight periods of this insect. The pheromone impregnated caps were replaced just before the second flight period.

*Fruit damage*

Fifteen hundred to 2000 apples per cultivar from 2-3 sites in each IPM-orchard were inspected for caterpillar damage at harvest. Three types of fruit damage were distinguished: a) early caterpillar damage, caused at the end of May till half June. Fruits bear corked-over scars and are often disfigured. This injury can be attributed to winter moth and noctuids and to leafroller species such as *P. heparana*, *A. podana* and *A. rosana*; b) July-damage, caused by older larvae of mainly *A. orana* in July-August. This can be recognized as deeper and irregular excavations; c) late summer damage. This appears as tiny circular excavations on the fruit surface. They are caused by young stages of leafrollers before they hibernate.

## RESULTS

### *Infestation level and species composition*

The degree of infestation by leafrollers at green cluster was generally low in the IPM-orchards. The average value for the various cultivars ranged from 0 to 1.8%. Similar low levels of infestations were found in the conventionally treated orchards. The threshold for IGR application, as used initially (0.2%) was nevertheless exceeded in most years in the IPM-orchards, except in Andijk and Marknesse, in 1979 and in Dronten in 1980.

The species composition of the samples in spring is presented in Fig. 1 and Table 1. In Marknesse, Dronten and Andijk, the numbers of *P. heparana* or *Archips* spp. were equal to or higher than those of *A. orana*. In St. Oedenrode the density of *Clepsis spectrana* (L.) was relatively higher. In the IPM-orchards Avezaath and Geldermalsen, however, *A. orana* was dominant.

The number of *A. orana* moths recorded in pheromone traps was lower in IPM-orchards Andijk and Dronten as compared to the nearest conventionally sprayed orchards during the first 3 to 4 years (Table 2). In this respect, the other IPM-orchards showed hardly any difference. Since the first two IPM-orchards were also the most isolated from nearby orchards, migration of moths between orchards may explain these observations. Nevertheless, in well isolated as well as in non-isolated orchards, the economic threshold for *A. orana* (5% infested shoottips according to GRUYS et al. 1980) was rarely exceeded.

Parasitization seems to play a minor role in the population development of leafrollers in the IPM-orchards as is indicated by the often low percentages of parasitized larvae, collected in July (GRUYS and VAAL 1984) (Table 3). *Colpoclypeus florus* WALKER (Chalcidoidea, Eulophidae) was the most common parasite. As for the larval samples taken in spring, the parasitization level was even lower, namely 10 to 20%. These larvae were parasitized by many different species (EVENHUIS 1976).

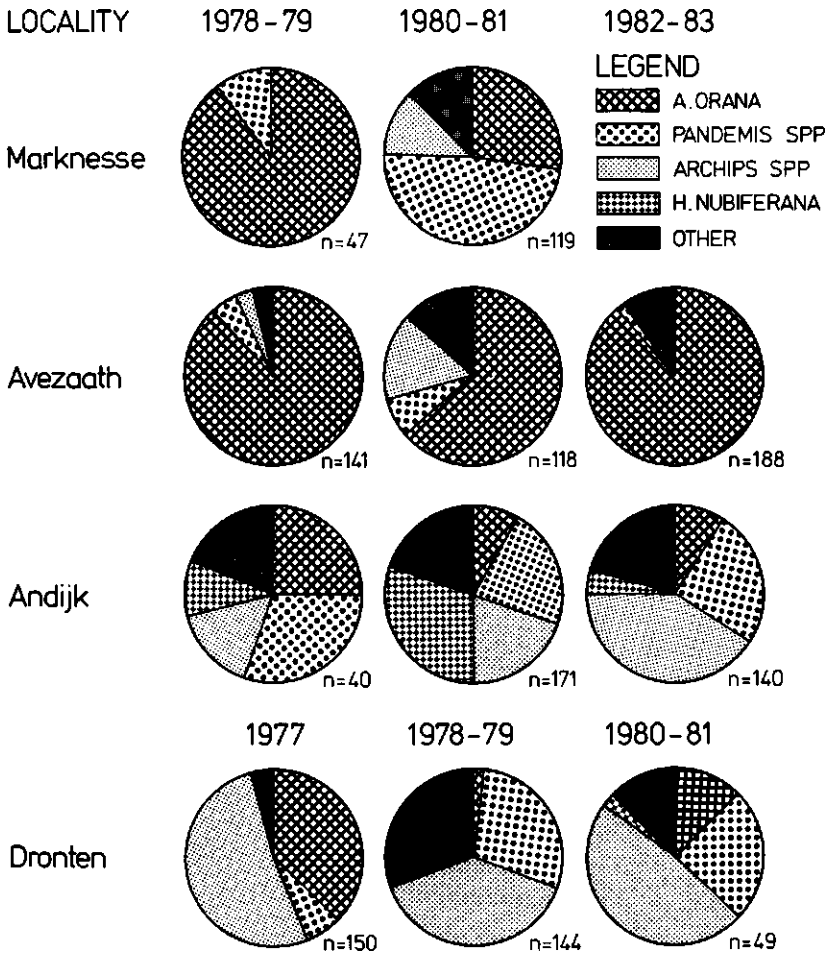


Fig. 1. Species composition of leafrollers, collected in IPM-orchards in May 1977-1983.

Table 1. Species composition of leafrollers, collected in IPM-orchards at Geldermalsen and St. Oedenrode in spring 1982-1983. In brackets total number.

| Species | composition (%) | | | |
|---|---|---|---|---|
| | Geldermalsen | | St. Oedenrode | |
| | 1982 (95) | 1983 (157) | 1982 (88) | 1983 (58) |
| *A. orana* | 92 | 84 | 20 | 40 |
| *C. spectrana* | 0 | 0 | 48 | 16 |
| *P. lecheana* | 1 | 1 | 11 | 10 |
| *P. heparana* | 3 | 1 | 5 | 2 |
| unidentified | 4 | 16 | 16 | 32 |

*Fruit damage at Avezaath, Geldermalsen and St. Oedenrode*

Leafroller species, such as *P. heparana*, *Archips* spp. and *Acleris* spp., which cause early caterpillar fruit damage, were not found in larval samples in these three IPM-orchards. Early caterpillar damage will therefore not be considered here. Shallow fruit feeding, irregular in form and extend (July-damage) was hardly apparent. In fact, most damage at harvest was clearly late-summer damage, but even this damage remained at a low level (Fig. 2: cross-hatched bars). Comparison of the fruit damage in the different IPM-orchards is difficult due to the variation between cultivars within orchards. The degree of fruit injury was relatively higher in Geldermalsen than in Avezaath and St. Oedenrode. The higher degree of fruit injury in the Geldermalsen orchard may be attributed to the poor isolation, together with the small size of the plot.

*Fruit damage at Andijk, Dronten and Marknesse*

Fruit damage caused by leafrollers in these IPM-orchards should be attributed mainly to pre-hibernation larvae of *P. heparana* and *A. podana* and to a lesser extent, of *A. orana* (Fig. 1). July- and late-summer damage was generally less than 1% in both isolated and non-isolated orchards (Fig. 2).

Higher injury levels were found after discontinuation of IGR sprayings at Andijk and Marknesse in 1979 but not at Dronten in 1980. At Andijk, many young instars

Table 2. Number of moths, caught in pheromone traps in May-June (1st flight period) and number of larvae of *A. orana* on shoottips in July in IPM-orchards and in orchards with conventional leafroller control in 1977-1983.

| Locality | Orchard | Area (ha) | Distance to IPM (meter) | Pre-dominating species | Number of pheromone traps | *A. orana*/pheromone trap | | | | | | | *A. orana* larvae/100 shoots | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 |
| Andijk | IPM | 4.5 | - | *A. podana* *P. heparana* | 6 | - | 3 | 3 | 4 | 2 | 2 | 0 | - | 0.2 | 0 | 0 | 0 | 0 | - |
| | conventional | - | 300 | - | 4 | - | 52 | 17 | 72 | 47 | - | - | - | 2.5 | 1.7 | 2.4 | 1.4 | - | - |
| Dronten | IPM | 0.5 | - | *A. rosana* *P. heparana* | 2-4 | 11 | 10 | 1 | 1 | 1 | - | - | 2.7 | 0 | 0.4 | 0 | 0 | - | - |
| | conventional | - | 150 | - | 1-4 | 108 | 46 | 23 | 6 | 5 | - | - | 9.0 | 0.6 | 0.3 | 0 | 0 | - | - |
| | conventional | - | 350 | - | 1-4 | 107 | 28 | 15 | 1 | 4 | - | - | 5.5 | 0.1 | 0.4 | 0 | 0.5 | - | - |
| | conventional | - | 500 | - | 1-2 | 126 | 54 | 32 | 7 | 9 | - | - | - | 4.8 | 0 | 0 | 0 | - | - |
| Marknesse | IPM | 1.0 | - | *P. heparana* | 3-4 | - | 30 | 5 | 1 | 2 | 3 | - | - | 6.5 | 5.8 | 0 | 0.3 | 0.3 | - |
| | conventional | - | 15 | - | 1-2 | - | 10 | 6 | 5 | 2 | - | - | - | 0.3 | 0 | 0 | 0 | - | - |
| | conventional | - | 15 | - | 1-4 | - | 26 | 4 | 3 | 5 | - | - | - | 37.4 | 0.8 | 0 | 0.8 | - | - |
| Avezaath | IPM | 7.0 | - | *A. orana* | 4-12 | - | 12 | 3 | 4 | 5 | 25 | 7 | - | 0.8 | 1.6 | 0.5 | 0 | 1.3 | 2.7 |
| | conventional | - | 15 | - | 2 | - | 36 | 16 | - | - | - | - | - | - | 1.5 | - | - | - | - |
| | untreated | - | 100 | - | 1-4 | - | 71 | 5 | 9 | 26 | - | - | - | - | 10.8 | 1.0 | 0.3 | - | - |
| Geldermalsen | IPM | 0.3 | - | *A. orana* | 2 | - | - | - | - | - | 54 | 73 | - | - | - | - | - | 6.2 | 4.3 |
| | conventional | - | 5 | - | 1 | - | - | - | - | - | 82 | 88 | - | - | - | - | - | - | - |

Table 3. Percentage parasitization of *A. orana* in samples, taken in IPM-orchards in July. In brackets: number collected.

| Locality | Year | Parasitization |
|---|---|---|
| Avezaath | 1979 | 15(48) |
| | 1980 | 7(27) |
| | 1982 | 18(42) |
| Marknesse | 1978 | 24(37) |
| | 1979 | 78(50) |
| | 1981 | 43(85) |
| Geldermalsen | 1982 | 36(55) |

of *A. podana* were observed during late August and caused considerable fruit injury to Benoni apples. Injury in other cultivars was prevented by spraying carbaryl.

Early caterpillar damage of Belle de Boskoop cultivar in Marknesse (1981, 1982) and in Andijk and Dronten (1980, 1981) was not higher than 1% and 0.6% respectively. Here, this type of fruit injury should be attributed mainly to leafrollers, since winter moth and noctuids were not found in caterpillar samples, taken according to GRUYS et al. (1980). High levels of the same damage occurred at Marknesse (1979) and at Dronten (1977) and were caused probably by winter moth and by noctuids and *A. rosana*, respectively. The latter was present in large numbers locally before the start of these studies and its damage could not be prevented during the first year of IGR application.

It is unlikely that fruit thinning of Cox and Golden Delicious with carbaryl in Andijk (1979-1983) and in Dronten (1980) has influenced the leafroller population, because this treatment is executed in early June, when only some fullgrown caterpillars are present.

## DISCUSSION

The results of this study indicate that both epofenonane and fenoxycarb can effectively be used against leafrollers, notably *A. orana* in Dutch apple orchards. Although a good effect is manifest also on other species (DE REEDE et al. chapter 2), the early damage by such species as *A. rosana* cannot be prevented in the same season: the data for Dronten 1977 show this clearly.

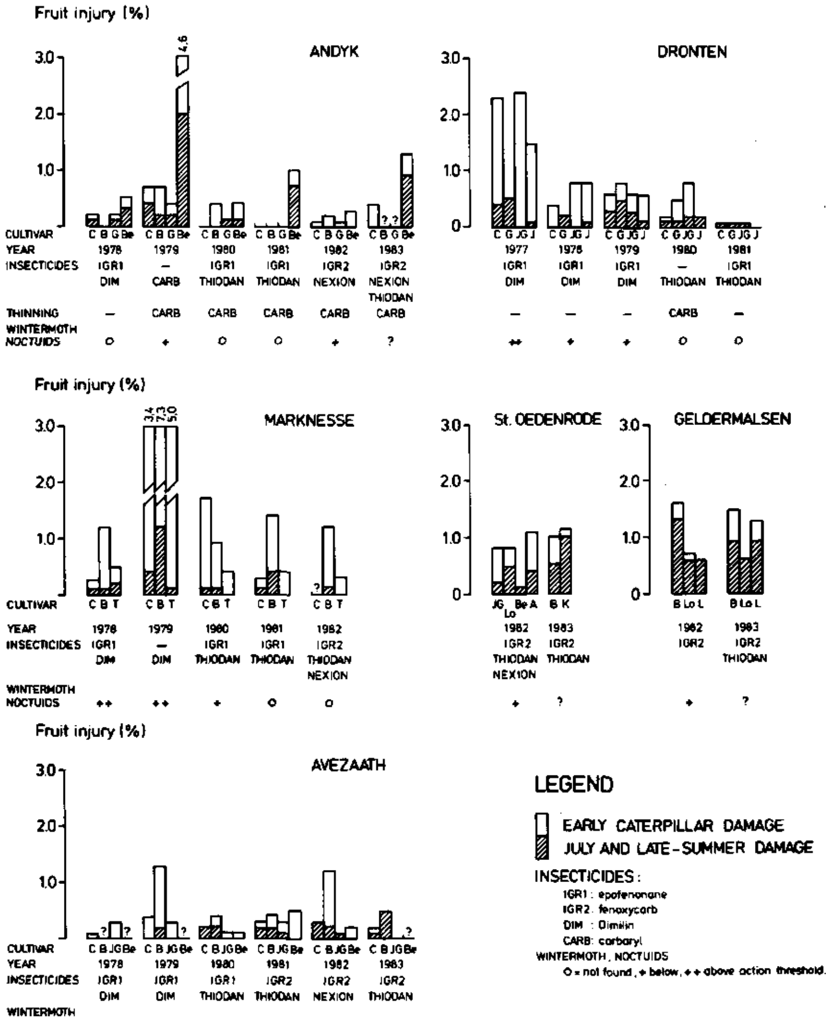


Fig. 2. Fruit injury by caterpillars: early caterpillar damage inflicted in spring; and shallow fruit feeding, inflicted in summer or late-summer. Insecticides applied and numerousness of larvae of winter moth and noctuids are shown below the histograms.
Cultivars: C: Cox's Orange Pippin, B: Belle de Boskoop, G: Golden Delicious, Be: Benoni, JG: James Grieve, J: Jonathan, T: Tydeman's Early, Lo: Lombarts Calville, A: Alkmene, K: Karmijn de Sonnaville, L: Laxton's Superb.

The seemingly greater importance of leafroller species other than *A. orana* in IPM orchards is mainly due to a lack of observations in other places. Especially, both *Archips*-species are more widespread and numerous than is generally believed (BLOMMERS pers. comm.). Their control with the IGR's appears to be also effective, as indicated for example by the upsurge of *A. podana* and *P. heparana* at resp. Andijk and Marknesse, when IGR was not applied in 1979. As all species except *A. orana* have less than two generations per year, their recovery from insecticidal action should be slower in time. Only during the first year of IGR appication, an additional treatment with another type of insecticide should be recommended in cases that species like *A. rosana* which cause early damage are too numerous. This is rather unusual in well kept orchards.

In general, population levels of *A. orana* and late summer injury to fruit were more elevated in the least isolated orchards, especially where the plots were rather small, e.g. Marknesse and Geldermalsen. Immigration of female moths or influx of neonate larvae by wind might have been responsible for this. Similarly CHARMILLOT et al. (1983) observed more damage on borderline trees in non-isolated orchards of larger size.

The number of male moths caught in pheromone traps proved to be a less useful figure for estimating moth densities. It reflected the reduction of moth density due to IGR application only in the most isolated orchards. The higher numbers caught during the first flight in other places contrast with an almost absence of both caterpillars and damage in July and indicates that male moths of *A. orana* originate from neighbouring orchards and are more mobile than females.

For several reasons (low density of caterpillars in spring and the relative uselessness of the pheromone traps in estimating moth densities) a close comparison between control of *A. orana* by IGR and conventional insecticide is difficult. The low frequency of caterpillars and their damage in July provide, however, sufficient support to the equal efficacy of the new compounds, when compared with broad-spectrum insecticides. As far as natural control in IPM orchards appears to have little impact on *A. orana* in spring, the applicability of the IGR's has not to be restricted to these orchards.

This study was devised primarely to evaluate the implementation of IGR's in a still experimental IPM program (GRUYS 1982). In the program we intend to maintain complete natural control of the fruit tree red spider mite (*Panonychus ulmi*) and the rust mite (*Vasates schlechtendali*) by sparing the predacious mite *Typhlodromus pyri*. For lack of other selective compounds, the use of the IGR's was the only possible way to control leafrollers. The regular, year after year application of these compounds demonstrated their sufficiency in practice. The results on the relatively small, non-isolated orchard plots at Geldermalsen and Marknesse show, moreover, that field experiments as are usually conducted to compare the efficacy of a new compound with both positive and negative controls, would not have been feasible in this case.

The lack of a practical action threshold may be felt as another drawback of our approach, but is offset by the experience that *A. orana*, or leafrollers in general, need to be checked in nearly every Dutch orchard each year. Whereas epofenonane was preliminarely withdrawn for commercial reasons, the recent authorisation of fenoxycarb for use in apple orchards in the Netherlands, means that a feasible IPM program has been completed for apple orchards. In order to facilitate the timing of application of this IGR, we have developed simulation models for the phenological development of overwintered larvae of *P. heparana* and *A. orana* (DE REEDE and H. DE WILDE, chapter 4).

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## Chapter 4

# Phenological models for *Pandemis heparana* (DENN. et SCHIFF.) and *Adoxophyes orana* (F.v.R) (Lepidoptera: Tortricidae) for timing the application of Insect Growth Regulators with juvenile-hormone activity.

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ABSTRACT

Control of leafrollers, using Insect Growth Regulators with juvenile-hormone activity (IGR), is a major issue in research on Integrated Pest Management in apple orchards. The IGR is applied at the time of emergence of the last-larval instar of leafrollers, thus causing a disturbance of the metamorphosis which follows. Simulation models on the development of *Pandemis heparana* (DENN. et SCHIFF.) and *Adoxophyes orana* (F.v.R.) were developed, partly on the basis of experiments, partly on data from the literature, to predict the time of emergence of the various stages, particularly of the last instar. The models use the state-variable approach, and include only temperature as a driving variable. Simulated curves of emergence of last-instar larvae, pupae and moths correspond well with observations on field-collected larvae, reared upto adult stage in an outdoor insectary. The course of pheromone trap catches showed a delay relative to the calculated and observed curves for the eclosion of the pupae. Various causes for this difference are suggested, but the influence of none of them has been studied.

To investigate whether the time of IGR application could be related to a temperature sum, the relation between emergence curves of last-instar larvae and temperature sum was studied for several years. For this purpose simulated curves were used, because observations on emergence of last-instar larvae covered only two years.

Keywords: simulation model, temperature sum, phenology, juvenile-hormone mimic, Insect Growth Regulator, Integrated Pest Management, apple orchard, *Pandemis heparana*, *Adoxophyes orana*, Tortricidae, leafrollers

## INTRODUCTION

Tortricids are an important cause of injury to fruit in apple orchards. While the codling moth, *Laspeyresia pomonella* (L.), is by far the most devastating orchard tortricid world-wide, external fruit feeding leafrollers also inflict considerable damage (GRUYS 1982). *Adoxophyes orana* (F.v.R.) is abundant in northwestern and central Europe, and *Pandemis heparana* (DENN. et SCHIFF.) and *Archips podana* (SCOP.) in southern Europe (BASSINO et al. 1979, DICKLER 1982, FRÉROT et al. 1982, MANI 1968).

Most external fruit feeding leafroller species hibernate as second- or third-instar larvae, start feeding at the end of March (INJAC and DULIC 1982), and damage buds, leaves, inflorescences and fruits. Damage to fruit is caused mainly by larvae in the following generation(s).

The control of tortricids requires accurate timing, especially when the susceptible stage is brief. The insecticides usually recommended for this purpose (pyrethroids, azinfos-methyl, methidathion, carbaryl) are applied at egghatch for control of codling moth, summer fruit tortricid *A. orana* and *P. heparana*, because newly hatched larvae are the most susceptible (CHARMILLOT and BLASER 1983). The timing of these sprayings are often based on temperature sums for egg development. calculated from the date of the $1^{st}$ capture of moths in pheromone traps (CHARMILLOT 1980, MINKS and DE JONG 1975, RIEDL et al. 1976, SAUPHANOR 1981, WELCH and CROFT 1983).

The insecticides normally recommended for use against these pests, however, disrupt other members of the arthropod fauna, which control other pests, notably *Typhlodromids* (GRUYS 1980). For this reason, much effort has been directed in research on Integrated Pest Management (IPM) towards the use of selective Insect Growth Regulators (IGR) with juvenile-hormone activity (CHARMILLOT et al. 1983, GRUYS 1982, DE REEDE et al. chapter 2, SCHMID et al. 1978). The IGR is applied at the time of emergence of last-instar larvae and disturbs the following metamorphosis in leafrollers (CHARMILLOT et al. 1983, DORN et al. 1981, MASNER et al. 1981, SCHMID et al. 1978, SCHOONEVELD and ABDALLAH 1975).

The dominant leafroller species in IPM apple orchards in the Netherlands are *A. orana*, *P. heparana* and *Archips* sp. Our attention is focussed on the first two species, which appear early and late in spring respectively.

Our aim is to find decision rules for IGR application to replace the laborious field observations on the time of emergence of last-instar larvae. A temperature sum could be used as such decision rule. Although phenological observations of

*P. heparana* are available for six years, data on emergence of last-instar larvae, covered only two years. It was therefore impossible with these data to investigate whether the time of emergence of last-instar larvae is related to a fixed temperature sum.

Instead, a simulation model is constructed and validated with phenological data on last-larval instars, pupae and moths. This model predicts the time of emergence of different stages, in particularly, the last-larval stage.

After having simulated the phenological development of the last-larval stage, of the pupa and of the moth for a series of years, these were related with temperature sums. This relation could be used to select the time of IGR application to coincide with the emergence of last-instar larvae. Although the phenological observations on the last-larval instar of *A. orana* were more complete than of *P. heparana*, we followed the same procedure for both species.

## MATERIAL AND METHODS

### *Modeling*

As only the post-hibernation generation is the target for control with IGR, we did not consider the following generation(s). Fig. 1 shows a flow diagram, according to FORRESTER (1961), of the model simulating the development of *P. heparana*. On the basis of our laboratory experiment (Table 1), the population was divided into post-hibernation larvae developing through either 4 or 5 larval stages. Development was simulated using the subroutine, BOXCAR, listed by DE WIT and GOUDRIAAN (1978). This subprogram mimics dispersion in time (GOUDRIAAN 1973). The temperature-dependent rate of flow, through the developmental stages is calculated with time steps of one hour, to allow for diurnal fluctuations in temperature. This time step is smaller than 1/4 of the smallest time coefficient (DE WIT and GOUDRIAAN 1978), so that numerical errors due to inappropriate time steps are prevented.

The input data for the model consist of the mean and standard deviation of the developmental periods of the various stages at different temperatures. These were determined experimentally. The driving variable, temperature, is computed as a sinusoidal curve through the daily maximum and minimum temperature as is listed by RABBINGE (1976). Daily maximum and minimum temperatures were taken from a Stevenson screen, at 1.5 m, at the meteorological station at Wageningen, because temperature data from Kesteren, measured in the insectary, were only

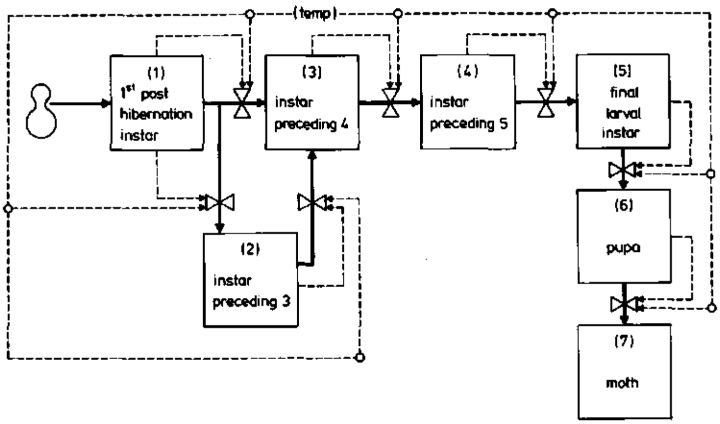


Fig. 1. Flow diagram of the model of the post-hibernation generation of *Pandemis heparana*. Rectangles-state variables; duplicated triangles-rate of change; between brackets-driving variables; circles-auxiliary variables; solid lines-flow of material; broken lines-flow of information.

available for 1982. In this year the accumulated temperature sum above 8°C (developmental threshold for leafrollers, see Table 2 and FLUCKIGER and BENZ (1982)), measured from March $1^{st}$ till July $1^{st}$ in the insectary, was reached only 4 days later at Wageningen.

A flow diagram of the model of development of the post-hibernation generation of *A. orana* is given in Fig. 2. All larval stages, except the last one, are represented by one variable. The effect of temperature on the rate of flow through the various developmental stages is computed according to a non-linear function (LOGAN 1976). These data were taken from the simulation model of FLUCKIGER and BENZ (1982) and FLUCKIGER (1982).

Mortality was not included in these models, as we only simulate the emergence pattern of different stages. The *P. heparana* and *A. orana* models use the state variable approach (DE WIT and GOUDRIAAN 1978).

*Determination of duration of developmental stages of P. heparana*

Larvae of *P. heparana* were collected in May-June from apple trees at the Experimental Orchard "De Schuilenburg" at Kesteren and placed singly in glass

Table 1. Mean duration (days) of different stages of *Pandemis heparana*, which developed through three or four larval moults, after leaving their hibernation webs. In brackets: standard deviation.

| Temp. | No. larval moults | No. individuals | developmental stage | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1<br>1st instar post-hibern. | 2<br>instar preceding (3) | 3<br>instar preceding (4) | 4<br>instar preceding (5) | 5<br>final larval instar | 6<br>pupal stage |
| 11 | 3 | 9 | 57.9 (14.4) | - | 23.1 (3.2) | 21.6 (4.8) | 36.1 (9.9) | - |
| | 4 | 2 | 57.5 | 29.5 | 24.5 | 19.0 | 33.0 | - |
| | mean | 11 | 57.8 (12.9) | - | 23.4 (4.2) | 21.2 (4.8) | 35.5 (8.9) | - |
| 13 | 3 | 10 | 41.5 (13.1) | - | 16.1 (4.4) | 15.0 (3.4) | 22.0 (3.5) | 28.4 (1.7) |
| | 4 | 1 | 50.0 | 30.0 | 17.0 | 51.0 | 26.0 | - |
| | mean | 11 | 42.3 (12.7) | - | 16.2 (4.2) | 18.3 (11.3) | 22.4 (3.5) | - |
| 16 | 3 | 14 | 25.1 (4.1) | - | 8.8 (1.7) | 9.1 (1.3) | 14.9 (2.6) | 18.3 (1.4) |
| | 4 | 4 | 24.5 | 9.5 | 8.3 | 8.0 | 21.5 | 19.5 |
| | mean | 18 | 24.9 (4.3) | - | 8.7 (1.6) | 8.9 (1.4) | 16.3 (5.7) | 18.6 (1.4) |
| 19 | 3 | 8 | 22.9 (7.9) | - | 6.6 (1.1) | 7.8 (1.8) | 12.0 (1.5) | 13.0 (0.5) |
| | 4 | 2 | 23.5 | 5.5 | 5.5 | 7.0 | 12.5 | 13.5 |
| | mean | 10 | 23.0 (7.3) | - | 6.4 (1.1) | 7.6 (1.6) | 12.1 (1.4) | 13.1 (0.6) |
| 22 | 3 | 7 | 11.1 (1.5) | - | 5.3 (1.1) | 5.8 (0.5) | 8.6 (0.7) | 9.9 (0.6) |
| | 4 | 10 | 13.4 (2.5) | 4.9 (0.5) | 5.2 (1.3) | 5.3 (0.6) | 9.6 (1.3) | 10.8 (2.8) |
| | mean | 17 | 12.4 (2.4) | - | 5.2 (1.3) | 5.5 (0.6) | 9.1 (1.2) | 10.5 (2.2) |

Table 2. Regression equation of development rate ($day^{-1}$) on temperature (°C), $r^2$, and the development threshold (DT) for each developmental stage of *Pandemis heparana*.

| Developmental stage | No. | Regression equation | $r^2$ | DT (°C) |
|---|---|---|---|---|
| 1. $1^{st}$ instar post-hibernation | 67 | Y = 0.00567 * temp - 0.04968 | 0.79 | 8.6 |
| 2. instar, preceding (3) | 19 | Y = 0.01657 * temp - 0.15580 | 0.91 | 9.4 |
| 3. instar, preceding (4) | 67 | Y = 0.01450 * temp - 0.11647 | 0.82 | 8.0 |
| 4. instar, preceding (5) | 67 | Y = 0.01240 * temp - 0.08964 | 0.85 | 7.2 |
| 5. final larval instar | 67 | Y = 0.00724 * temp - 0.04968 | 0.90 | 6.9 |
| 6. pupal stage | 52 | Y = 0.00709 * temp - 0.0583 | 0.90 | 8.2 |

vials (1.5 x 5 cm). They were reared on an artificial diet (ANKERSMIT 1968) in an outdoor insectary. We assumed that this medium did not influence the development rate of *P. heparana*, as was also not the case for *A. orana* (FLÜCKIGER and BENZ, 1982). Emerged moths were allowed to deposit their egg batches in plastic boxes of 27 x 17.5 x 15 cm covered by a polyethylene sheet in the insectary. The freshly hatched larvae were reared also on artificial medium in the insectary until hibernation webs were made. On February $1^{st}$ of the following year the glass vials containing larvae were placed in five constant temperatures, 11, 13, 16, 19 and 22°C, at 16 hr photoperiod and about 80% R.H. Larvae which left the hibernation webs were transferred to vials with artificial diet. This medium was replaced once or twice a week. The developmental period of pupae was not determined at 11 degrees, as previous experiments had shown a high mortality at this temperature (DE REEDE, unpublished). Next to dates of pupation and emergence of moths, the time of larval moults of *P. heparana* was determined by measuring head capsules or by checking moulted headcapsules daily (11-19°C) or twice daily (22°C). Emerged moths were sexed.

The inverse of developmental period (=rate of development) appeared to be related linearly to temperature. It was thus possible to use multiple regression analysis to test the effects of sex on developmental period.

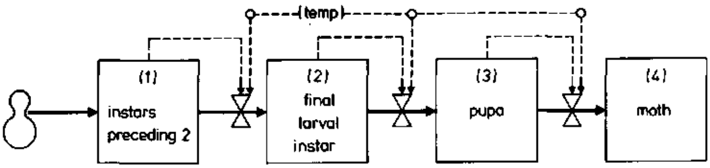


Fig. 2. Flow diagram of the model of the post-hibernation generation of *Adoxophyes orana*. Symbols see Fig. 1.

*Validation*

For validation, data on the time of emergence of the final-larval instar were used. For *A. orana*, these data are available from 1976-1983, except for 1979. In addition, dates of pupation and eclosion of pupae were usually also available. Observations on emergence of last-instar larvae of *P. heparana* were available for only two years and observations on time of pupation and moths emergence covered four years. No observations on larval instars preceding the final instar are available for either species.

These emergence curves were determined in larval samples of *A. orana* and *P. heparana*, collected in orchards in the central Netherlands, between the green cluster stage (end of April) and the end of blossoming (mid-May). The sample sizes ranged from 50 to 258 larvae. The differences in sample size were due to large variation in population densities in the different years. Collected larvae were reared singly on artificial diet to the adult stage (as described above), in the outdoor insectary at the Experimental Orchard "De Schuilenburg", Kesteren. Pupation and pupal eclosion were checked at least twice a week. To determine the time of the moult from penultimate into ultimate larval instar, headcapsules were measured under a dissecting microscope.

In addition to larval samples, the daily pheromone trap catches of *A. orana* and *P. heparana* at the orchard "De Schuilenburg" were used for validation.

## RESULTS

### *Developmental periods of P. heparana at constant temperatures*

The number of moults in post-hibernation *P. heparana* varied in our laboratory experiment. Most individuals moulted 3 or 4 times before pupation; only 4 specimen out of 71 moulted less than 3 times. These observations were not used further. The mean and the standard deviation of the duration of each stage are given in Table 1. There was no significant difference between the sexes, except in the final larval stage (Table 3). Instar duration did not differ significantly between larvae with three moults and those moulting four times before pupation (Table 3).

Table 3. F-values from regression-analysis on main effects calculated for the different developmental stages of *Pandemis heparana*.

| Source | df | developmental stage | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1[1] 1st instar post-hibern. | 2[1] instar preceding (3) | 3 instar preceding (4) | 4 instar preceding (5) | 5 final larval stage | 6[1] pupal stage |
| Main effects | | | | | | | |
| temp. | 1 | 210.7** | 164.2** | 236.4** | 303.2** | 503.9** | 376.4** |
| sex | 1 | 0.5 | <0.1 | 1.1 | <0.1 | 13.6** | 0.7 |
| No. moults | 1 | 0.1 | - | 1.4 | 2.6 | 2.6 | 2.8 |
| Residual | 63 | | | | | | |

[1]Degrees of freedom of residual for stage 2 and 6 are resp. 16 and 48.
Significance level: ** P <0.01, F-test.

*Simulation of P. heparana*

In the model we use the linear regressions of developmental rates on temperature (equations 2 to 6 in Table 2) for temperatures between the developmental threshold and 25°C for all stages, except for the $1^{st}$ post-hibernation instar. So linear extrapolated developmental thresholds are used. Developmental rates at temperatures higher than 25°C are given the value found at 25°C. For the $1^{st}$ post-hibernation instar, measured developmental rates are used, because from graphs it was concluded that these deviated from linearity at low temperatures. A developmental threshold of 6°C is used.

When the observed differences in developmental rate between sexes was introduced into the model, the simulated emergence of females was only 1-4 days later than that of males. Protandry of the same magnitude has been observed by MANI (1968). In the following simulations we use, therefore, the mean developmental rates for both males and females.

Simulated emergence curves showed less dispersion in time than was observed in field-collected larval samples in the insectary. To get a better agreement of the simulated with the observed emergence pattern of last-instar larvae, pupae and moths, we enlarged the standard deviation of the $1^{st}$ post-hibernation instar which resulted in an enlarged dispersion in emergence of following stages. Generally, good agreement was achieved when the simulated transition pattern from the $1^{st}$ post-hibernation instar to the next was made to follow a Poisson distribution (Fig. 3). However, in 1979 and 1980 simulated curves were still steeper than observed curves.

The curves of observed catches of moths and predicted eclosion of pupae corresponded well at the lower point, but thereafter they gradually diverged (except in 1980), the curve of observed catches being delayed relative to the simulations.

*Sensitivity analysis*

To investigate the sensitivity of the model to temperature changes, simulations were performed with systematic increases of maximum temperature, starting from February the $1^{st}$. Systematic increase of 1°C and 2°C advanced the emergence curve by 1-10 and 8-15 days respectively, in 1978-1983. Delays of 3-10 and 6-18 days respectively occurred after lowering the maximum temperature by 1°C and 2°C.

In order to investigate the sensitivity of the model to the choice of the developmental threshold of the first post-hibernation instar, simulations were also performed with the developmental threshold of 9°C from the regression equation

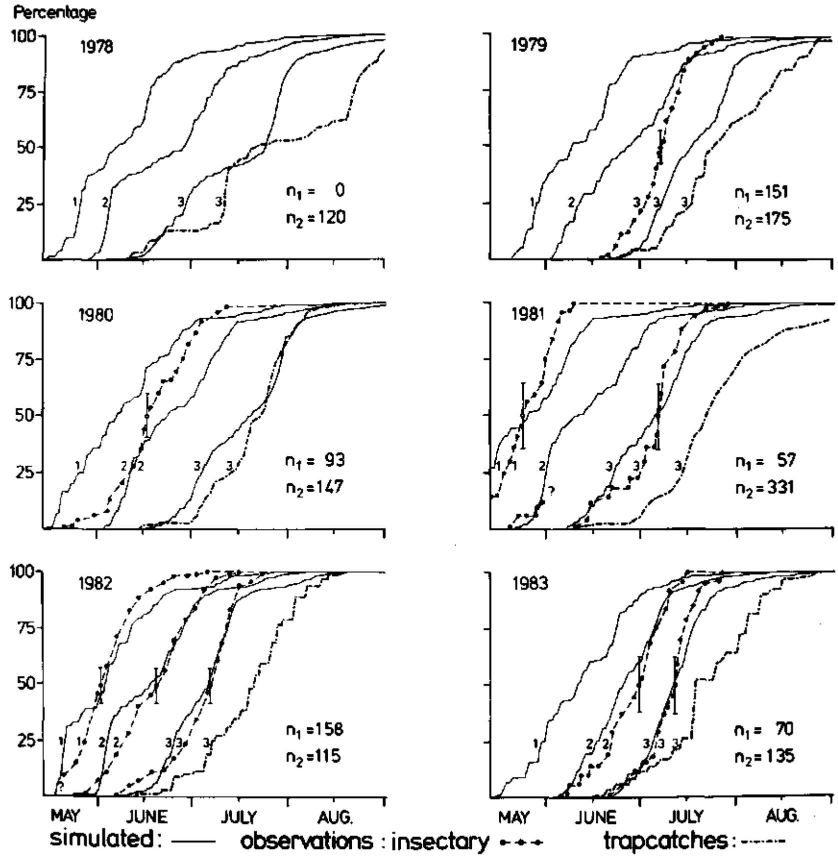


Fig. 3. Simulated emergence of last instar larvae (1), pupae (2) and moths (3), compared with observations on field-collected larvae of *Pandemis heparana* in the outdoor insectary ($n_1$), and with the course of pheromone trap catches (3) ($n_2$). Vertical bars indicate confidence interval (95%) of the 50% estimate of the observations.

for this instar (Table 2). This postponed the 50% point of the emergence curve by 0-6 days in 1979-1983, and by 15 days in 1978. The simulations with the developmental threshold of 6°C showed better correspondance with the observations than simulations performed with the linear extrapolated threshold.

*Simulations of A. orana*

Simulation of the emergence of the final-larval instar of *A orana* corresponded well with the observations on field-collected larvae in the insectary (Fig. 4). The greatest deviation is one week. Only in 1981 did the lower halves of the curves show a rather large discrepancy.

The 50% point of the simulated curve of pupation occurred about 1-7 days later than was observed in the insectary in 1976-1983, but coincided better with the curve of pheromone trap catches.

*Temperature summation model*

Simulated curves for the emergence of last-instar larvae, pupae, and moths of *P. heparana* and *A. orana* are plotted against the accumulated temperature sums for the different years (Figs. 5,6). A developmental threshold of 8°C was chosen from the data of FLÜCKIGER and BENZ (1982) and from our own data (Table 2). Temperature was summed from an arbitrarily chosen date, 1 January.

The graphs are not exactly similar for the different years. Deviations are due to the assumed linear relationship between developmental rate and temperature in the thermal summation method, which is not linear in the simulation models. In the *A. orana* model a non-linear function (LOGAN 1976) is used. In the *P. heparana* model the relation between developmental rate and temperature is non-linear for the first post-hibernation instar and above 25°C developmental rates of all stages are held constant.

In connection with IGR application, prediction of 30% emergence of last-instar larvae is relevant, because that is shortly before the oldest larvae start to pupate. According to Figs. 5 and 6 30% emergence of last-instar larvae corresponds on the average with 187 daydegrees for *P. heparana* (range in 1978-1983: 165 to 195) and with 87 daydegrees for *A. orana* (range in 1976-1983: 75 to 100) above a base temperature of 8°C.

Predicted dates by using the mean temperature sum for 30% emergence of last-instar larvae and predicted dates from simulations corresponded rather well.

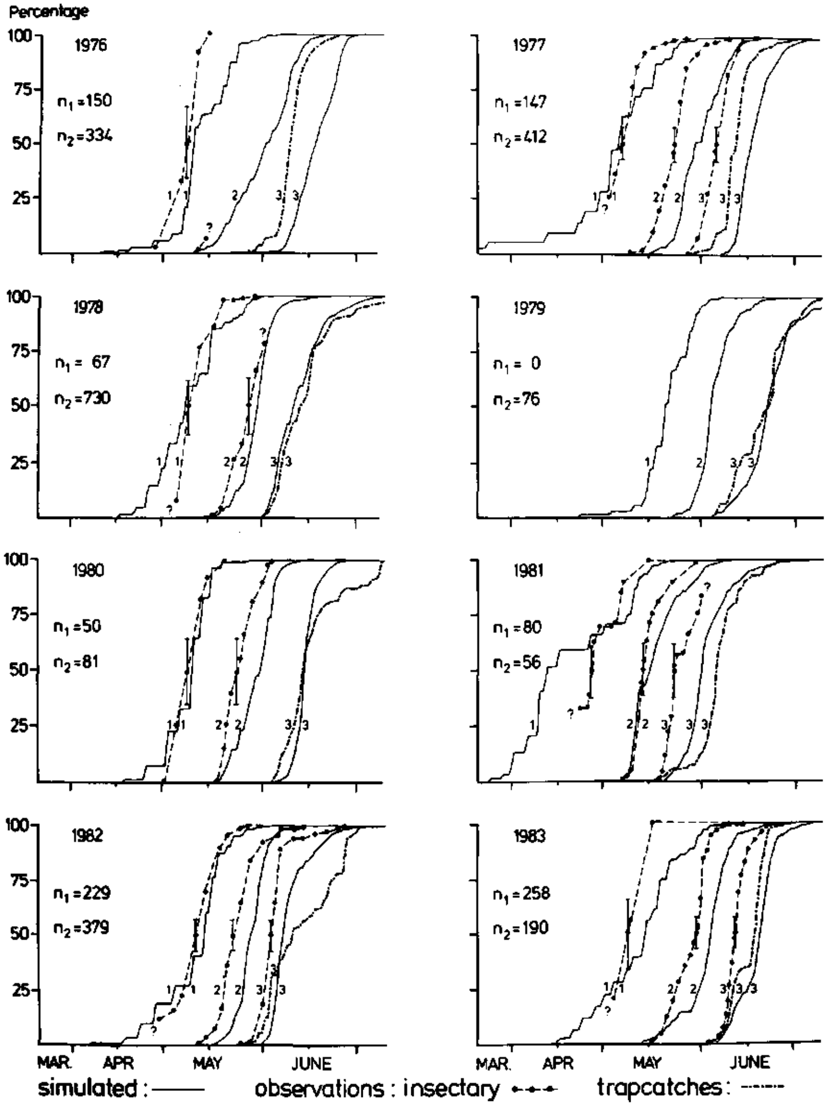


Fig. 4. Simulated emergence of last-instar larvae (1), pupae (2) and moths (3), compared with observations on field-collected larvae of *Adoxophyes orana* in the outdoor insectary ($n_1$), and with the course of pheromone trap catches (3) ($n_2$). Vertical bars indicate confidence interval (95%) of the 50% estimate of the observations.

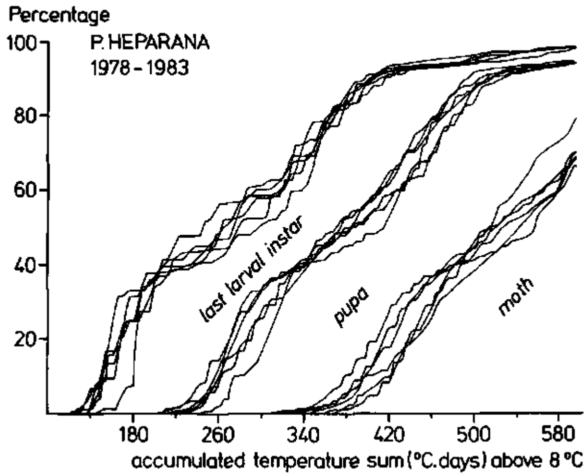


Fig. 5. Relation between simulated emergence curves of last-instar larvae, pupae and moths of *Pandemis heparana* and the accumulated temperature sum above 8°C from January 1st in 1978-1983.

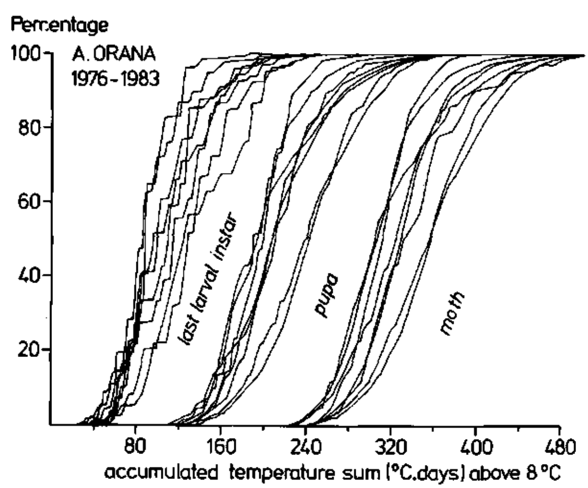


Fig. 6. Relation between simulated emergence curves of last-instar larvae, pupae and moths of *Adoxophyes orana* and the accumulated temperature sum above 8°C from January 1st in 1976-1983.

Deviations of maximally 3 days occurred for *P. heparana* in 1978-1983 and for *A. orana* in 1977-1983. In 1976 prediction by thermal summation was 6 days early compared to the simulation model for *A. orana*. The choice of 30% emergence of last-instar larvae for the time of spraying may have been too early in 1981, because there was an interval of more than three weeks before the first pupae were formed, due to a period with low temperatures.

## DISCUSSION

Prediction of emergence of last-instar larvae by thermal summation corresponds well with that predicted by simulation models. The former method is easier, however, and yields simple decision rules for the time of application of IGR's with juvenile-hormone activity. To disturb metamorphosis in leafrollers the first spraying is applied after the first last-instar larvae have emerged, but before pupation takes place. Figs. 5 and 6 may serve to determine the time of the first application, depending on the species which are present. The time of the second spraying depends largely on the rate of dilution of the residu by leaf growth (CHARMILLOT and BLASER 1983), and on the habitat choice of the larvae, with respect to fresh and old leaves.

In the simulation models of *P. heparana* and *A. orana* calculation of post-diapause development is started as soon as the temperature rises above a certain threshold (being the lowest temperature at which development takes place). This assumes that diapause development has already been completed, and that no post-diapause development can occur until the temperature rises above this threshold. Since simulated and observed time of emergence corresponded well for a number of years, there is no reason to change this assumption. In their review, TAUBER and TAUBER (1976) list several insect species for which this type of diapause termination has been demonstrated. In some other species, however, specific factors such as photoperiod, food, moisture, etc. are required to terminate autumnal-hibernal diapause. In insects with a summer diapause a specific stimulus is often needed for termination (TAUBER and TAUBER 1976). The time of the first catches in pheromone traps corresponded well with the first pupal eclosions in the insectary, but thereafter a delay occurred, probably due to a combination of factors reducing flight activity e.g. low evening temperatures, windspeeds higher than 1 meter/second, and heavy rain fall (JANSEN 1958, DE JONG 1982, MANI 1968, SAUPHANOR 1981). Insufficient quantitative knowledge of the influence of these factors on the flight activity, made pheromone trap catches inappropriate for validation. Because these factors were not included in the model, only observations on development of field-collected larvae, brought into the outdoor insectary, could be used for validation of the models.

Temperatures measured in a Stevenson screen were used in the simulation models, although temperature differences of about 8°C may occur in foliated apple trees (RABBINGE 1976), and there are even larger temperature differences between exposed and shaded sites before the trees are in leaf (JERMY 1964, PRIMAULT 1954). Nevertheless, the simulated emergence curves showed good agreement with the observed emergence pattern for the last instar in field-collected larvae of *A. orana*. As to *P. heparana*, the observed dispersion in emergence was larger than was simulated. It is unlikely to attribute this to temperature differences within the apple trees, because otherwise a larger dispersion in development of *A. orana* would also have been expected. It is more likely that the standard deviation of the developmental rate of *P. heparana* was underestimated in our laboratory experiment. Only individuals, which moulted 3 or 4 times before pupation were considered, whereas specimen, which moulted fewer times (4 out of 71 in our experiment), were not included in the model. This fraction might be greater in field populations than was assumed.

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## General discussion

*Apple IPM in the Netherlands and other West-European countries*

Natural control of the fruit tree red spider mite *Panonychus ulmi* (KOCH) was shown to be successful in the Netherlands and England in the mid- and late-seventies in IPM apple orchards, but failed in other West-European countries (IOBC 1980). It was not possible to identify the reasons for the different results, because conditions differed between the experiments in the various countries. In 1980 the IOBC working party on integrated control in orchards proposed a standardized experimental procedure for testing the potential of phytoseiids (IOBC 1980). For the sake of comparison, it was essential that factors other than climate be as similar as possible, particularly with respect to the choice of pesticides. The procedure, therefore, recommended only pesticides which had been shown to be compatible with the natural control of *P. ulmi* by phytoseiids. The proposed field tests should give answers to the following questions:

a) Is natural control of mites adequate in the different West-European climatic conditions?

b) Which species of predators are responsible for biological control of mites?

c) Which species of leafrollers are important when other pests, particularly codling moth, are selectively controlled?

Recent publications suggest that biological control of spider mites is feasible also in Italy and Switzerland. *Typhodromus pyri* SCHEUTEN is the most common phytoseiid. In Italy (South Tirol) it concerned orchards with a low level of infestation by leafrollers, so sprayings with broad-spectrum insecticides against these can be omitted (WALDNER and PETERMAIR 1983). The choice of pesticides against other pests was made according to the proposed procedure. In other orchards in South Tirol biological spider mite control proved to be successful, in spite of some sprayings with organophosphorous insecticides (BOSCHERI and VON ARNHEM (1984). Similarly, biological control of *P. ulmi* by *T. pyri* appeared not to be disturbed by sprayings with azinphos-methyl in orchards in Switzerland (BAILLOD and GUIGNARD 1984). Thus, in these cases the use of some broad-spectrum organophosphorous insecticides is compatible with the natural control of spider mites. Resistance of phytoseiids to azinphos-methyl is a corner-stone of apple IPM in the USA (CROFT 1982). In the Netherlands, however, native *T. pyri* shows no distinct resistance to azinphos-methyl of any practical value (OVERMEER and VAN ZON 1983).

Upto 1980 there was little evidence about the usefulness of phytoseiids for the natural control of *P. ulmi* in France, West Germany and Poland, and it was suggested that other predators (anthocorids, mirids and the coccinellid *Stethorus* sp.) were more important in this respect (NIEMCZYK 1980, STEINER 1980, WILHELM 1980). However, recently there are indications that phytoseiids play a significant role in the natural control of *P. ulmi* in these countries as well.

Other examples of natural or biological control likely to be disturbed by the use of broad-spectrum pesticides concern less wide-spread pests. Complete and permanent biological control of the coccid *Quadraspidiotus perniciosus* has been achieved in south-western Germany since the introduction of *Prospaltella perniciosi* (NEUFFER 1984). This hymenopterous parasite was a native of the USA and Canada and was released for several years in the sixties. In the Netherlands the leafminer *Stigmella malella* is controlled naturally by the native parasite *Chrysocharis prodice* (GRUYS 1980), while many other parasites and predators provide partial control of pests (Table 1).

The implementation of IPM in apple orchards in the Netherlands was hindered until recently mainly by the lack of effective selective compounds against leafrollers and, in the case of the variety Golden Delicious, also by use of wettable sulphur which is toxic for *T. pyri*. Considering the good results with gibberelins in reducing fruit russeting, one can now also use other fungicides in combination with gibberelins than sulphur.

Fig. 1 shows the mean degree of insect damage to fruits, including caterpillar injury in the IPM orchards in the Netherlands over a span of twelve years. The figure shows the insufficient reduction of fruit injury by insects during the period that Ryania, *Bacillus thuringiensis* (Dipel) and diflubenzuron were used for caterpillar control. The use of Insect Growth Regulators (IGR) with juvenile-hormone activity for leafroller control from 1978 onwards (initially epofenonane, later on fenoxycarb) reduced the fruit injury to an acceptable low level (less than 2%). As for the frequency of application of the IGR, two sprayings in spring were sufficient in our experiments. The registration of fenoxycarb in the Netherlands in 1984 completed the list of control agents for the various pests and diseases in IPM apple orchards (Table 1). A scheme of the main chemical control measures is shown in Table 2. A rather similar program is advised in Switzerland by Dr. R. Maag Ltd., which commercializes fenoxycarb since 1984 and 200 ha apple orchards have been sprayed with this IGR in the first year (M.L. FRISCHKNECHT, pers. comm.). The timing of the application of fenoxycarb was determined by sampling of larvae and by

Table 1. Control agents against pests and diseases in IPM apple orchards in the Netherlands.

| Pests or diseases | Control agents available at present | |
|---|---|---|
| | Main agent | Additional |
| Acari | | |
| *Panonychus ulmi* | *Typhlodromus pyri* | (fenbutatinoxide, clofentezine, white oil) |
| apple rust mite (*Aculus schlechtendali*) | *Typhlodromus pyri* | fenbutatinoxide, endosulfan) |
| Lepidoptera | | |
| codling moth, *Pammene rhediella* | diflubenzuron | predators and parasites of larvae and pupae |
| winter moth, noctuids | diflubenzuron | |
| *Adoxophyes orana* | fenoxycarb | *Colpoclypeus florus*, *Teleutaea striata* |
| *Archips podana* | fenoxycarb, diflubenzuron, carbaryl | |
| *Spilonota ocellana*, *Hedya nubiferana* | fenoxycarb, diflubenzuron | |
| *Pandemis* sp., other tortrix moths | fenoxycarb | |
| leafminer (*Stigmella malella*) | *Chrysocharis prodice* | fenoxycarb[1] and diflubenzuron[2] |
| Homoptera | | |
| woolly aphid (*Eriosoma lanigerum*) | endosulfan, pirimicarb | *Aphelinus mali*, *Forficula auricularia* |
| other aphid species | pirimicarb | various parasites and predators |
| *Lepidosaphes ulmi* | white oil, propoxur | various parasites and predators, particularly *Forficula auricularia* |
| Hemiptera | | |
| *Lygus pabulinus* | bromophos at half strength | |
| Hymenoptera | | |
| apple sawfly (*Hoplocampa testudinea*) | bromophos at half strength, thiophanate-methyl | diflubenzuron[2] |
| Coleoptera | | |
| *Anthonomus pomorum*, *Phyllobius oblongus* | endosulfan, carbaryl diflubenzuron | |
| Diptera | | |
| *Dasineura mali* | endosulfan | parasites, particularly *Demades* sp. |

Table 1 (continued).

| Pests or diseases | Control agents available at present: Main agent | Additional |
|---|---|---|
| Fungi | | |
| *Venturia inaequalis* | dodine, captan, fenarimol, thiophanate-methyl | |
| *Podosphaera leucotricha* | bupirimate, triadimefon, bitertanol | |
| *Pezicula* sp. | captan, thiophanate-methyl | |
| *Nectria galligena* | thiophanate-methyl, captan | cutting out of wounds and wound protection |

[1]application directed against leafrollers
[2]application directed against winter moth and noctuids.
Based on GRUYS 1982 and updated.

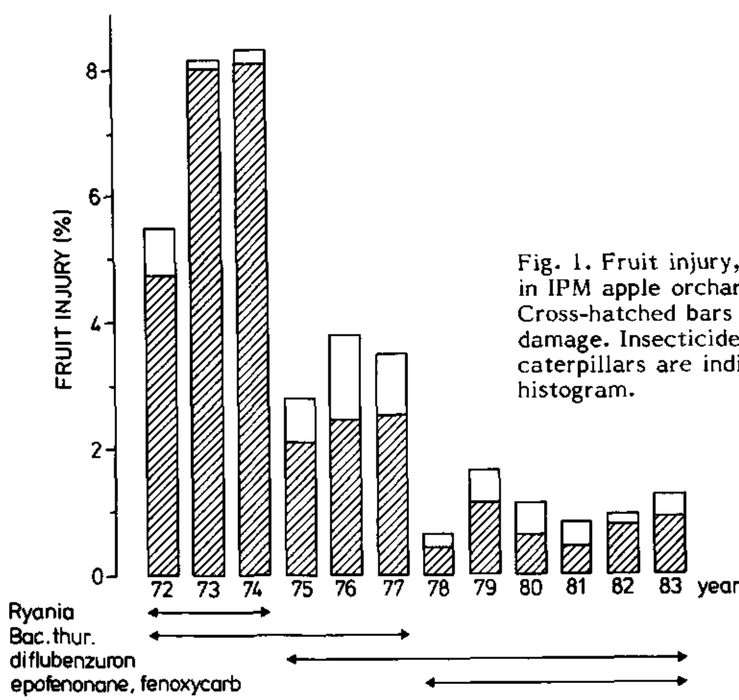


Fig. 1. Fruit injury, caused by insects in IPM apple orchards in 1972-1983. Cross-hatched bars indicate caterpillar damage. Insecticides used against caterpillars are indicated below the histogram.

Table 2. Chemical control of pests in IPM apple orchards in the Netherlands.

| Period | Control based on | |
|---|---|---|
| | experience during foregoing year(s) | use of action thresholds[1] |
| mouse-ear stage | woolly aphid: endosulfan | |
| pink bud stage | | winter moth: diflubenzuron |
| full bloom - | leafrollers: fenoxycarb | winter moth, noctuids: diflubenzuron |
| petal fall | | aphids: pirimicarb |
| | | *Lygus pabulinus:* bromophos |
| around end of June | | codling moth[2]: diflubenzuron |
| July till harvest | | aphids: pirimicarb |

[1]action thresholds, as described by GRUYS et al. (1980)
[2]action threshold: 5 moths per week, caught in pheromone traps during two consecutive years. Timing based on embrionic development.

determining the larval stage. This was executed by the Swiss Federal Research Station Changin (P.J. CHARMILLOT, pers. comm.) and in the Netherlands by the experimental orchard "De Schuilenburg" at Kesteren. Since this method of timing the sprayings is very laborious we have worked on developing easier prediction methods which are discussed in chapter 4 and in the following section.

*Determination of the moment of spraying*

Temperature sums are being used by the Advisory Services of various countries in Europe for the determination of spraying dates of broad-spectrum insecticides against codling moth (CHARMILLOT 1980, CRANHAM 1980, MANI 1980, TOUZEAU 1980) and *Adoxophyes orana* (CHARMILLOT and MEGEVAND 1983, MINKS and DE JONG 1975). Since these sprayings are applied at the time of egg hatch, temperature summation normally commences at the first or the peak of pheromone trap catches.

The use of computer simulations for forecasting fruit pests in Europe is in research stage. Simulation models have been developed for some tortrix moths (BAUMGARTER and CHARMILLOT 1983, FLUCKIGER and BENZ 1982, DE REEDE and DE WILDE chapter 5, TOUZEAU 1980) and show promise for implementation in practice in the near future. In the USA the Predictive Extension Timing Estimator (PETE) model, predicting the development of a tree-fruit pest complex and selected vegetable pests, was developed and first implemented in 1975 (WHALON and CROFT 1984). It was developed for use by extension personnel in the state of Michigan, but was soon adopted by many other deciduous tree fruit-producing states. Other predictive models have been constructed in Mexico and California for the codling moth and in Pennsylvania for spider mites. In the latter model also natural enemies were included. All these prediction systems are at present in the validation stage of development (WHALON and CROFT 1984). In most of these models certain points in the development of the concerned organism in the field (biological reference points) are used to synchronize the models with the development in the field.

For the timing of the control of leafrollers with fenoxycarb, which is sprayed before the flight period, simple biological reference points cannot be used. We developed a simulation model using the temperature as a driving variable, for predicting the phenological development of *A. orana* and *P. heparana* in spring. This model was subsequently simplified in such a way that only the relation between temperature sum and developmental stage was included. Using this relation, only temperature sums need to be calculated for the timing of fenoxycarb application.

If the same temperature sum can be used for leafroller populations in orchards that differ greatly in their geographic position has to be evaluated yet. It may learn us whether we can use the model for timing practical application of fenoxycarb in fruit growing areas in the Netherlands as well as in other West-European countries.

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## Summary

Field trials to compose a coherent system of Integrated Pest Management (IPM) for apple orchards in the Netherlands were started in 1967, when the 12 ha apple orchard "De Schuilenburg" at Kesteren became available for experiments on IPM. Natural control of one of the most severe pests under conventional control, the fruit tree red spider mite *Panonychus ulmi*, is a central part in IPM. Many broad-spectrum pesticides exterminate the predacious mite *Typhlodromus pyri*, which is responsible for the natural control in IPM in the Netherlands. Only selective agents are applied, therefore, against pests which are not, or only partially, naturally controlled, preserving *T. pyri* and other useful arthropods.

The aim of the present study was to investigate the feasibility of the following selective compounds for leafroller control in IPM in apple orchards: (a) a bacterial agent, *Bacillus thuringiensis* (Dipel), (b) a chitine synthesis inhibitor, diflubenzuron (Dimilin) and (c) insect growth regulators (IGR) with juvenile-hormone activity, epofenonane and fenoxycarb.

Initial studies were carried out at the experimental orchard "De Schuilenburg", in 0.5-1.0 ha plots, for five consecutive years. The degree of leafroller fruit damage in untreated plots ranged from 5 to 13%; this damage was caused by a complex of leafroller species. *Adoxophyes orana* was most abundant in the summer, whereas *Spilonota ocellana*, *Pandemis heparana* and *Hedya nubiferana* were dominant in the spring. Under Dipel regimes, both the total leafroller population and the leafroller fruit injury were halved. Dipel was relatively ineffective against *P. heparana*, *H. nubiferana* and, in particular, *S. ocellana*. Dimilin also halved leafroller fruit injury. This compound was very effective against *S. ocellana*, *H. nubiferana* and *Archips podana*. Dimilin, however, did not affect *A. orana* and the population of *P. heparana* was only reduced to about one-third of the blanco value. Leafroller control with epofenonane, which was applied twice in the spring, was not succesful. This may be due to reinfestation from the untreated plots, which lay adjacent to the treated plots in our experimental set-up. Dipel, Dimilin and epofenonane did not appear to affect the level of parasitism of *A. orana* by *Colpoclypeus florus*. However, in this respect the standard plots, treated with broad-spectrum insecticides, gave similar results, so no firm conclusion can be drawn.

A second series of experiments concerned the effect of fenoxycarb and epofenonane. Apple trees were either artificially infested with *A. orana* and *P. heparana* or harboured several naturally occurring leafroller species. The caterpillars were restricted in gauze-bags on leaf-clusters after the apple trees had been sprayed

once or twice, and the morphogenetic effect was observed. Fenoxycarb was effective at a concentration about 10 times lower than that of epofenonane. The foliar residue of fenoxycarb remained active for at least 4 weeks. Laboratory experiments indicated that although the foliar residue of epofenonane caused severe morphogenetic effects on the host *A. orana*, the ectoparasite *Colpoclypeus florus* completed its development on the host. When the host and parasite were exposed to fenoxycarb, however, the parasite often died at the pupal stage. Similar experiments with the endoparasite *Apanteles ater* in the host *Archips rosana* did not reveal higher mortality of the parasite than in the control.

In a following study, large-scale application of fenoxycarb and epofenonane in various IPM apple orchards were tested for several consecutive years. The IPM orchards were carefully selected to include IPM orchards adjacent to conventionally sprayed orchards, and IPM orchards well isolated from other orchards. The population of the leafroller species as well as the leafroller fruit injury level could be kept low by spraying twice in spring, irrespective of the location of the orchard. Re-infestation from adjacent orchards, if it occurred at all, played only a minor role in the final effect.

The determination of the timing of epofenonane and fenoxycarb required sampling of larvae and periodical observations on the larval stage. In order to facilitate the timing simulation models were developed to predict the emergence of the last instar of *P. heparana* and *A. orana* in the field. These models were based on laboratory experiments and on data from the literature and included only the temperature as a driving variable. The simulated curves of emergence of last-instar larvae, pupae and adults corresponded well with the field observations. To investigate whether the time of IGR application could be related to a temperature sum, the relation between emergence curves of last-instar larvae and temperature sum was studied for several years. For this purpose simulated curves were used, because field-observations on emergence of last-instar larvae covered only two years. Using the established relation between temperature sum and developmental stage of the leafroller population, only temperature sums need to be calculated for the timing of applications of IGR's.

## Samenvatting

Door het beschikbaar komen van de 12 ha grote proefboomgaard "De Schuilenburg" in Kesteren in 1967, was het mogelijk een alle plagen omvattend geïntegreerd bestrijdingsprogramma te toetsen. De natuurlijke bestrijding van het fruitspint *Panonychus ulmi*, door de roofmijt *Typhlodromus pyri* stond hierin centraal. Door het gebruik van breedwerkende bestrijdingsmiddelen bij de gangbare bestrijding is deze roofmijt uitgeroeid of wordt deze op een zeer laag populatieniveau gehouden. Het fruitspint kan zich dan tot een plaag ontwikkelen. In de geïntegreerde bestrijding worden selectieve middelen aangewend tegen plagen, die niet of gedeeltelijk natuurlijk bestreden worden. *T. pyri* en andere nuttige arthropoden worden op deze wijze gespaard.

Het doel van dit onderzoek was de bruikbaarheid na te gaan van de volgende selectieve middelen voor de bestrijding van bladrollers in een geïntegreerd bestrijdingsprogramma voor appelboomgaarden:

a) een bacterie preparaat, *Bacillus thuringiensis* (Dipel),

b) een chitine synthese remmer diflubenzuron (Dimilin) en

c) insekten groei regulatoren met juveniel hormoon werking, epofenonane en fenoxycarb.

De eerste proeven werden op de proefboomgaard "De Schuilenburg" uitgevoerd in 0.5-1.0 ha grote veldjes gedurende vijf achtereenvolgende jaren. De mate van vruchtschade door bladrollers bedroeg 5-13% in de blanco veldjes en werd door een complex van bladrollersoorten veroorzaakt. *Adoxophyes orana* was het meest talrijk in de zomer, terwijl *Spilonota ocellana*, *Pandemis heparana* en *Hedya nubiferana* relatief dominant waren in het voorjaar. Onder Dipel regimes werden zowel de totale bladroller fauna als de vruchtschade door bladrollers gehalveerd. *P. heparana*, *H. nubiferana* en vooral *S. ocellana* waren moeilijk met Dipel te bestrijden. Met Dimilin werd de vruchtschade door bladrollers eveneens gehalveerd. Dit insecticide was zeer werkzaam tegen *S. ocellana*, *H. nubiferana* en *Archips podana*. Dimilin had echter nauwelijks effect op *A. orana* en reduceerde de populatie van *P. heparana* slechts tot éénderde vergeleken met de onbehandelde populatie. De bladrollerbestrijding met epofenonane, die tweemaal in het voorjaar werd uitgevoerd, had geen succes. Dit kon worden toegeschreven aan herinfectie vanuit onbehandelde veldjes, die in onze proefopzet grensden aan de behandelde veldjes.

Dipel, Dimilin en epofenonane bleken geen invloed te hebben op de mate van parasitering van *A. orana* door *Colpoclypeus florus*. Definitieve conclusies kunnen echter niet worden getrokken, omdat in de veldjes, die met breedwerkende insecticiden gespoten werden, op dit punt eveneens geen verschil ten opzichte van de onbehandelde

te constateren was.

In een tweede reeks van experimenten werd het effect van fenoxycarb en epofenonane nagegaan. Appelbomen werden ofwel kunstmatig geïnfecteerd met *A. orana* en *P. heparana* of waren van nature aangetast door verschillende bladrollersoorten. De rupsen werden op bladclusters gehuld in hoezen van gaas, nadat de appelbomen een of tweemaal bespoten waren. Morfogenetische effecten werden waargenomen. Fenoxycarb was bij een tienmaal lagere concentratie werkzaam dan epofenonane. Het residu van fenoxycarb op de bladeren bleef minstens vier weken werkzaam.

In laboratoriumproeven werd aangetoond dat de ectoparasiet *Colpoclypeus florus* zich volledig kon ontwikkelen op de gastheer *A. orana*, hoewel deze gastheer ernstige morfogenetische effecten vertoonde door blootstelling aan bladresidu van epofenonane. Bij blootstelling van gastheer en parasiet aan fenoxycarb echter, werd ook sterfte van de parasiet gevonden, met name in het popstadium. In gelijksoortige proeven met de endoparasiet *Apanteles ater* in de gastheer *Archips rosana* werd geen hogere sterfte van de parasiet gevonden dan in de controle.

In een volgend onderzoek werden fenoxycarb en epofenonane gedurende een aantal achtereenvolgende jaren toegepast in verschillende boomgaarden waarin de methode van geïntegreerde bestrijding werd uitgevoerd. Zowel geïsoleerd gelegen boomgaarden, als boomgaarden die aan conventioneel behandelde boomgaarden grensden, werden in het onderzoek betrokken. De populatie van bladrollers en de vruchtschade door bladrollers konden op een laag niveau gehouden worden door twee bespuitingen in het voorjaar, ongeacht de ligging van de boomgaarden. Herinfectie vanuit aangrenzende boomgaarden had nauwelijks enige invloed op het uiteindelijke effect.

Om het tijdstip van toepassing van epofenonane en fenoxycarb te bepalen was het noodzakelijk bladrollerrupsen te verzamelen om periodieke waarnemingen aan hun ontwikkelingsstadium te kunnen doen. Ter vereenvoudiging van het bepalen van het toepassingstijdstip werden simulatiemodellen ontwikkeld, die het moment van verschijnen van laatste-stadium rupsen van *P. heparana* en *A. orana* in het veld voorspellen. Deze simulatiemodellen werden gebaseerd op laboratoriumexperimenten en op gegevens uit de literatuur, en bevatten alleen de temperatuur als sturende variabele. Het gesimuleerde verloop van het moment van verschijnen van laatste-stadium rupsen, van poppen en adulten kwam goed overeen met waarnemingen uit het veld. Om na te gaan of het tijdstip van bespuiten aan een temperatuursom gerelateerd zou kunnen worden, is voor een aantal jaren nagegaan hoe de relatie is tussen het moment van verschijnen van laatste-stadium rupsen en de temperatuursom. Hiervoor werden gesimuleerde verschijningscurven gebruikt, omdat de desbetreffende veldwaarnemingen te weinig jaren betroffen. Door gebruik te maken van de gevonden relatie tussen temperatuursom en ontwikkelingsstadium van de bladrollerpopulatie, behoefde slechts periodiek de temperatuursom te worden berekend voor de bepaling van het toepassingstijdstip.

## Curriculum vitae

*Robert Herman de Reede werd op 12 juni 1948 te Haarlem geboren. In 1968 behaalde hij het eindexamen HBS-B aan het Jac. P. Thijsse lyceum te Overveen. In 1976 studeerde hij af aan de Landbouwhogeschool te Wageningen in de richting Planteziektenkunde met als hoofdvak entomologie en als bijvakken fytopathologie, theoretische teeltkunde en wiskundige statistiek. Van 1976-1978 werkte hij in tijdelijk TNO-dienstverband aan het onderzoek naar de mogelijke doorvergiftiging van vogels door het insecticide Dimilin, dat werd afgerond met de publicatie: A field study on the possible impact of the insecticide diflubenzuron on insectivorous birds (Agro-Ecosystems (1982) 7: 327-342). Van 1979-1981 was hij, wederom in TNO-dienstverband, werkzaam aan het project "Toepasbaarheid van de geïntegreerde bestrijding in de praktijk van de fruitteelt". In 1982 kreeg hij bij de vakgroep Entomologie van de Landbouwhogeschool de gelegenheid dit onderzoek tot een dissertatie te verwerken en in 1983 trad hij in tijdelijke dienst bij deze vakgroep. Sinds mei 1984 is hij werkzaam in de ongedierte bestrijding bij de firma Rentokil.*