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Studies on Adoxophyes orana, the major leaf-roller pest in apple orchards in the Netherlands

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The summerfruit tortrix moth, *Adoxophyes orana* F. v. R. (Lep., Tortricidae) can be considered as the key-pest in Dutch apple orchards. In commercial orchards, it is general practice to control the larvae of this moth species with broad-spectrum insecticides. Correct timing of the sprays is essential, because they are only sufficiently effective against newly emerged larvae in search for fresh leaves. Prediction of the timing is based on the heat-summation method using phenological observations with sex pheromone traps on moths of the preceding generation and temperature recordings. This forecasting system plays a major role in our programme of supervised control which is now in operation in about 25% of the orchards. The number of sprays is then reduced by half.

Introduction of an integrated control programme into practice is much hampered by the fact that no insecticide is available for selective control of *A. orana*. Diflubenzuron is not active enough and the insect growth regulator, epofenonane, will not become commercially available, although it showed much promise. Therefore much attention is being given to the development of other methods of selective control, e. g. parasites, baculoviruses and sex pheromones (mating-disruption method).

The summerfruit tortrix moth, *Adoxophyes orana* (F. v. R.) (Lepidoptera: Tortricidae) is widely distributed over Eurasia. It can be found from the extreme west, in Western and Central Europe, through Russia and China, to the extreme east, in Japan. This moth has been described for the first time on birch in 1834, but later reports showed that it could live on a wide variety of plants with a preference for Rosaceae, like apple, pear, plum and rose. Before World War II, it never was reported as a pest.

Until 1939, it was not recorded in the Netherlands. But after that, it quickly became the major insect pest in the apple and pear orchards. Since 1948, much of our time (in particular d. J.) has been devoted to this moth.

DEVELOPMENT OF *A. ORANA* INTO A PEST IN THE NETHERLANDS

In former years, the codling moth, *Laspeyresia pomonella,* was the most destructive pest in Dutch apple orchards. But soon after introduction of the first modern insecticides like DDT and parathion, it proved to be controlled quite easily and lost most of its significance as a pest. Since then, *A. orana* has become our major orchard pest (De Jong, 1951; De Jong, 1980a). This moth has at least two generations per year, in contrast to all other competing orchard leaf-rollers, which gives it a much higher reproductive potential than the other leaf-rollers. Modern spraying equipment, such as mistblowers, does not with certainty reach the larvae, which are well protected by their webs during most of their life-time. On the other hand, spraying with insecticides against *A. orana* mostly has a disastrous effect on its natural enemies, which could keep the population of the moth on an acceptable level (Minks & Gruys, 1980).

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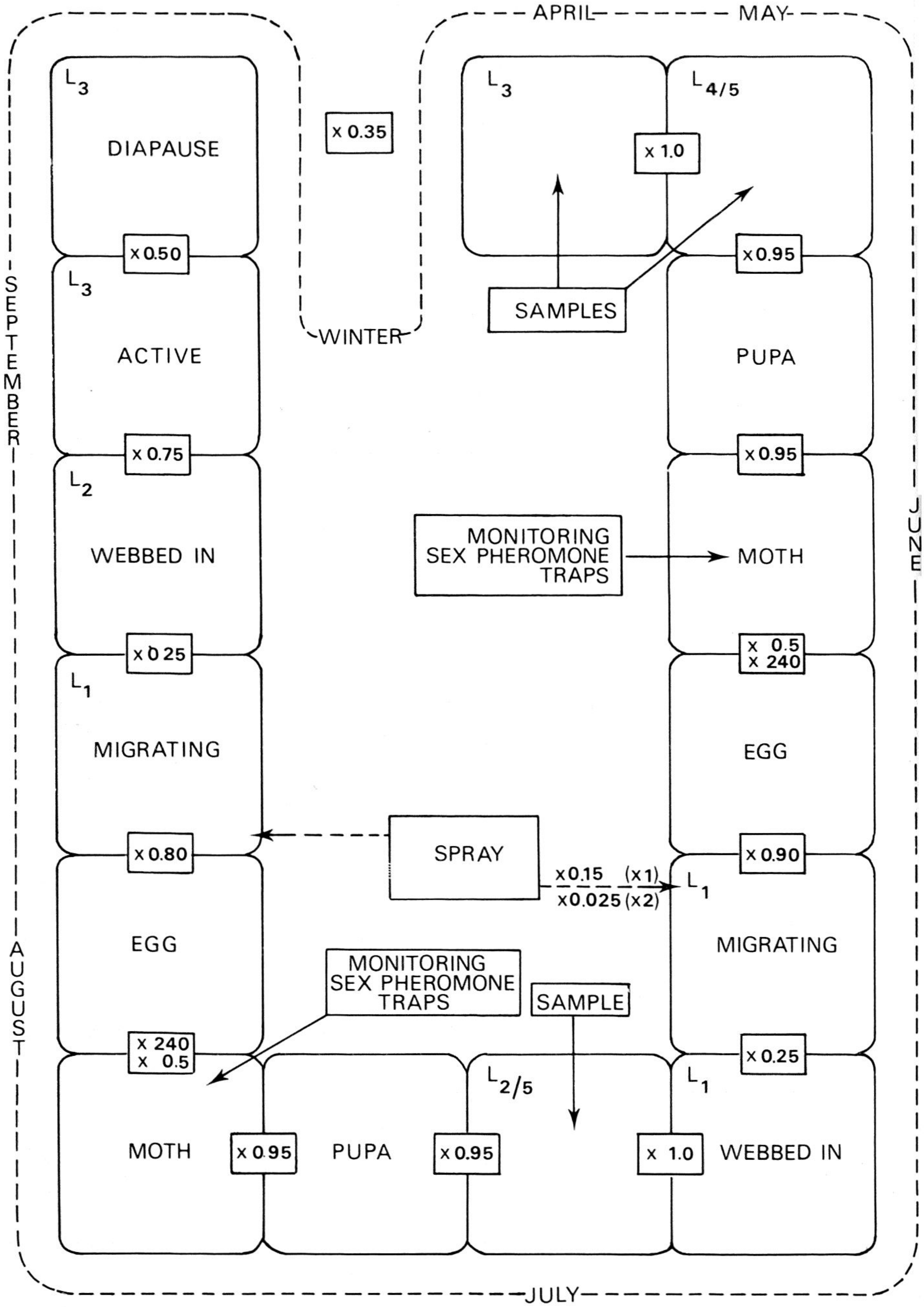

Fig. 1: The annual life-cycle of *Adoxophyes orana* in the Netherlands, presented with the survival rates between the different stages in its development, the usual times of sampling of the larvae and monitoring of the moths and the time and effect of the insecticidal sprays on the survival rates.

Other factors favouring the development of *A. orana* are related to the more intensive cultural methods that have come into use in the last 30 years. They include closer planting with smaller and shorter trees, chemical regulation of the growth or productivity of the tree, better control of the water supply, regular tillage and use of herbicides. In particular, the strong growth of young shoots, caused by heavy dressings with nitrogen provides a good habitat and stimulates the development of *A. orana* larvae in June and July (De Jong & Gruys, 1975).

In conclusion, *A. orana* is an insect pest characteristic of well maintained orchards. The Netherlands is the only country in Europe where *A. orana* has persisted as the major insect pest for many years, perhaps because of climate but also because of methods of culture. At the moment, reports from Switzerland, Germany, Northern Italy and Yugoslavia indicate a growing importance of *A. orana*.

QUANTITATIVE ASPECTS OF THE ANNUAL LIFE-CYCLE OF A. ORANA

Fig. 1 gives a quantitative impression of the development of the *A. orana* population through the year. It summarizes our experience during our long-term studies on this moth (De Jong & Van Dieren, 1974).

The cycle starts in April (top of the figure, right from the middle) when the hibernating third-instar larvae (L_3) become active again and start feeding on the opening buds. There is hardly any mortality during the further development of these larvae in April and May (indicated by x 1.0). The following moults from larvae to pupa and from pupa to moth each give a loss of 5%. Assuming that the sex ratio is 1:1, only half of the population lay eggs, which are estimated at 240 per female moth. About 90% of the eggs hatch. These freshly hatched first-instar larvae suffer from great losses by suffocation and hunger, if they do not reach their feeding places within a few hours. They can easily be carried away by the wind. Only 25% survive. They make their webs and again nearly all individuals (95%) reach the pupal and adult stage.

The number of eggs per female laid in August is the same as in June but a lower proportion hatch, particularly of those eggs laid during the last part of the period (average 80%). Again, only 25% of the first-instar larvae develop further but in the course of September the weather becomes increasingly unsuitable for the

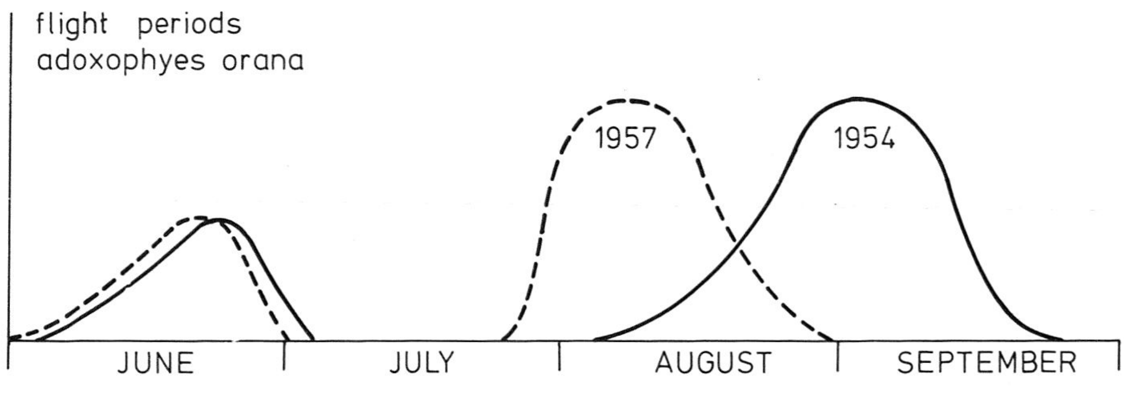

Fig. 2: Comparison between the times of the *Adoxophyes orana* flight periods in 1954 and 1957.

larvae. Only 25% have time to reach third instar, the right stage for hibernation. Another 50% of the larvae do not succeed in making a good winter web. And mortality during the winter is estimated at 65%. Some observed causes of loss were: leafdrop, pruning, predation by birds and fungal and bacterial diseases.

From the different factors, it can be calculated that each active larva of the spring generation will give 25 larvae in July and that the summer generation will multiply with another 3 times, to give an annual multiplication factor of 75.

These figures indicate that a population of *A. orana* has sufficient potentials for quick development to a pest level. The figures are averages based on experience over a period of more than 10 years collected from orchards with a regular spraying routine and thus with hardly any activity of natural enemies of *A. orana*.

INFLUENCE OF WEATHER ON THE PHENOLOGY OF A. ORANA

In years with normal weather, 1 *A. orana* has two generations in the Netherlands. Beside daylength, temperature is a decisive factor in the development of this moth. Many examples of this can be found for the flight periods of *A. orana,* which we have recorded with light and later with sex pheromone traps since 1950. In fig. 2, the flight periods of 1954 and 1957 are compared (DE JONG & BEEKE, 1976). The first flight period took place at almost the same time, but July and August 1954 were cool and slowed down the development so much that the peak of the second flight came only in the first week of September, whereas in 1957 the warm weather gave an early peak in the first week of August: a difference of 4 weeks!

In laboratory studies, we confirmed the decisive influence of temperature on the development of the eggs, larvae and pupae of *A. orana* (fig. 3). The experiments were at constant temperatures but the data were comparable with the daily averages of the fluctuating temperatures outside. With such data, one can calculate the rate of development of the different stages of *A. orana.*

This can be used in the following discussion about the phenology of the second flight. Temperatures in July and August determine the time of flight. This, in its turn, determines the success of the further development of *A. orana* for the coming winter. If the flight is late, the chance increases that some of the female moths do not lay eggs because of the cooler weather. And the larvae that hatch from any eggs, which already have been laid before, will have an increasingly low chance of reaching hibernation (L_3), when the temperatures are getting lower in September and October. In many years, the conditions are good for further development but in the cold autumn of 1972, we calculated that eggs laid after August 21 would not develop into hibernating larvae (DE JONG, 1980b). In addition, the flight was also very late so that only 18% of the eggs would reach the third larval stage. In 1974, the autumn was also cool and August 22 was calculated as the fatal date. But in that year the flight was early and 80% of the eggs gave rise to hibernating larvae. For further information about the period 1969–1975, see table 1.

In hot summers, as in 1975 and 1976, the second flight of *A. orana* was so early and the growth of the larvae so quick, that daylength (ANKERSMIT, 1968) and temperature did not limit part of the population from developing further to another adult generation (DE JONG & BEEKE, 1976; DE JONG, 1980b). In 1976, we caught moths in sex pheromone traps until the 3rd week of October.

Such moths would not produce any offspring. So we can conclude that late or early second flights are favourable for pest control. However, these early flights produce so many big, 4th and 5th instar larvae that more damage to fruit can be expected.

RELATION BETWEEN FRUIT DAMAGE AND POPULATION DENSITY

In contrast to larvae of the codling moth, *A. orana* larvae mostly cause external damage to the fruits that often does not go much deeper than the skin. It is a type of damage that primarily decreases the quality of apples and pears. The caterpillars do not show special preference for the fruit and we have the impression that in years with a strong growth of the shoots, fruit damage is lower than one would expect from the number of larvae present in the orchard. The larvae of

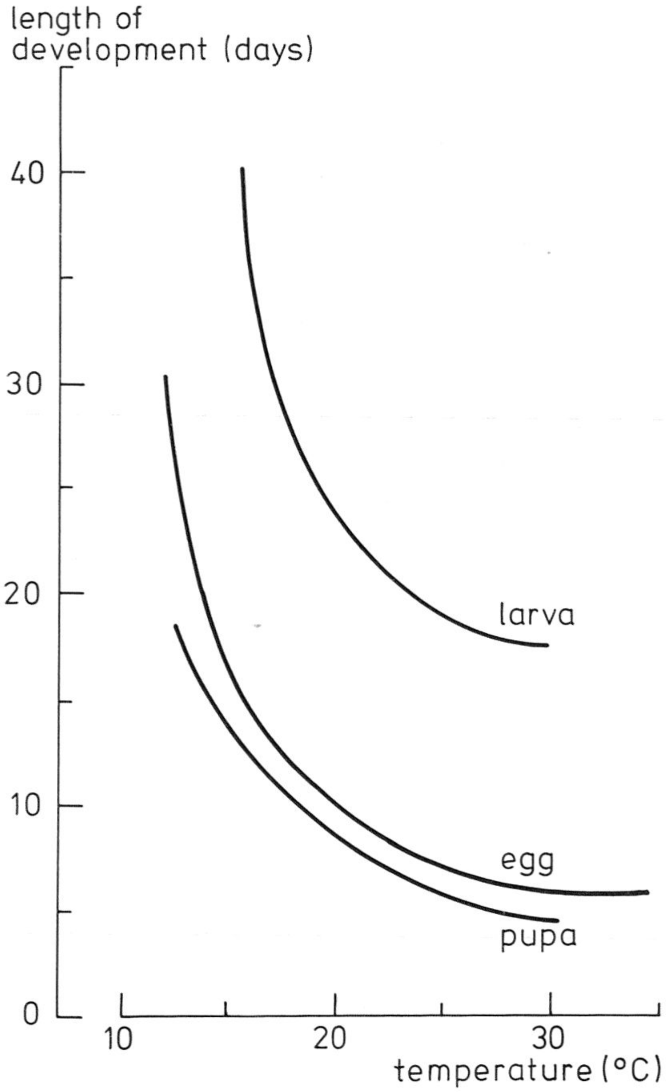

Fig. 3: The rate of development of the eggs, larvae and pupae of *Adoxophyes orana* at a series of constant temperatures.

Table 1: The relation between the phenology of the second flight of *Adoxophyes orana* and the proportion of moths that is effective for the hibernating generation in the period 1969–1975.

Year	Phenology of the second flight	Latest date for effective egg-laying	Proportion of moths of the second flight which gives hibernating offspring (%)
1969	early	September 27	100
1970	normal	September 16	100
1971	normal	September 10	100
1972	late	August 21	18
1973	normal	September 14	100
1974	early	August 22	80
1975	early	September 14	100

the July generation cause the most dangerous damage because every small disturbance will grow to large proportions during further development of the fruit. The larvae of the generation during August and September give scattered spots of skin-feeding. Those spots can act as sources of infections for diseases, in particular if the fruit is stored for longer time.

In general, 1–2% of the crop with damage caused by leaf-rollers is acceptable for the grower.

Extensive counts of larvae on whole trees over a number of years show that damage levels of the crop can best be correlated with the number of larvae at the end of July. We infested trees sprayed «clean» with insecticides some weeks earlier with different numbers of just hatching eggs at the time that the majority of the eggs were also hatching under natural conditions. At the end of July, larvae were counted on these experimental trees not treated with insecticides for the rest of the season (De Jong, 1981). At picking time, the fruit damage was counted.

In the first year of the test, an average of 18 larvae in a sample of 200 shoots corresponded to a fruit damage of 1% at the harvest and in the second year 12 larvae did the same. Results in later years did not differ. The variation is caused by different weather and growing conditions. In the first two years, there was a linear relationship between damage and population at higher levels of infestation (fig. 4).

On these figures, the Advisory Service has based its recommendations for the grower. If more than 20 larvae are found in a sample of 200 shoots taken at random over 1 ha of orchard in the second half of July, at least one spray is advised in August (Van Frankenhuyzen & Gruys, 1975). As we have calculated before (fig. 1) that *A. orana* has a multiplication factor of 25 from May–July, we conclude that the economic threshold in the sample taken in May should be very low: one larva found in a sample of 200 shoots is too much. So one spray against *A. orana* is nearly always necessary in June.

ECONOMIC LOSSES CAUSED BY LEAF-ROLLERS

The average level of damage of apples and pears is estimated at about 4%. Nearly half of this can be ascribed to the activity of leaf-rollers, in particular of *A. orana*. Table 2 shows that this damage would result in a loss of several million guilders per year (De Jong, 1981).

Table 2: Financial losses by fruit damage caused by leaf-roller moths in the Netherlands, calculated from our estimates and based on the production.

Year	production (thousand tons) apples	pears	damage by leaf-rollers (%)	reduction in value per kg damaged fruits (guilders)	total loss by leaf-rollers (million guilders)
1971	520	110	3.5	0.16	1.75
1972	400	100	4	0.20	4
1973	400	60	2	0.25	2.25
1979	400	100	2	0.30	3

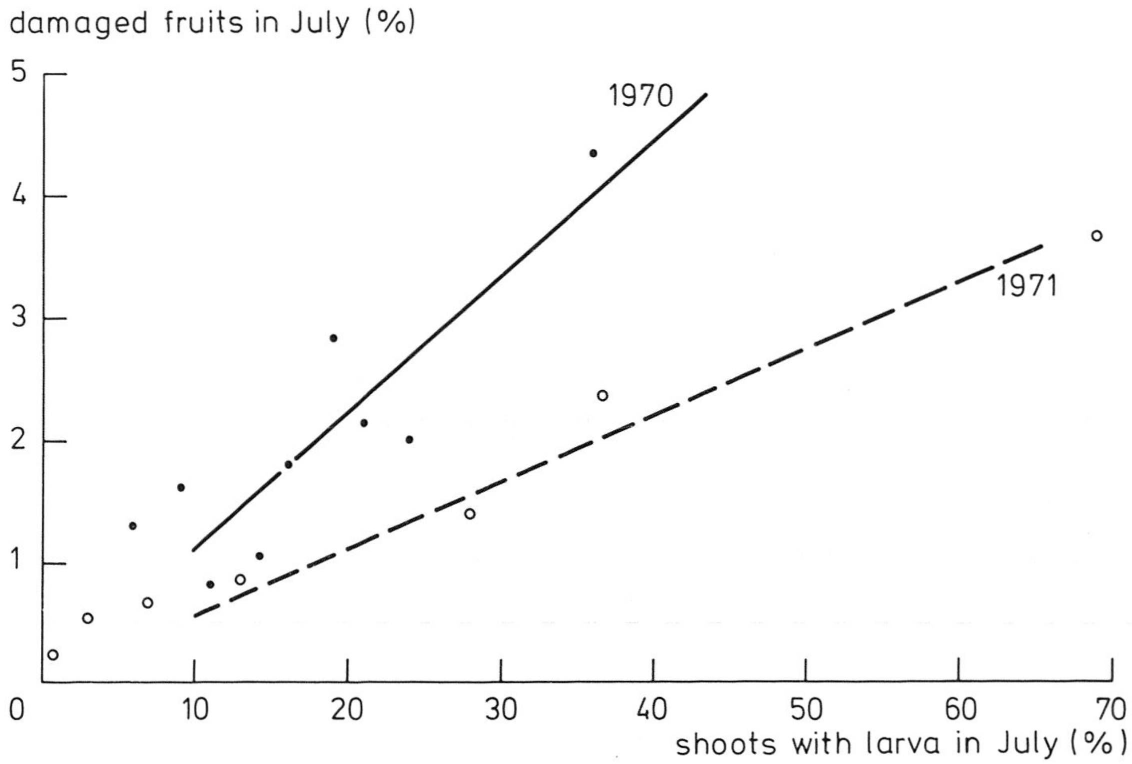

Fig. 4: Relation between the numbers of *Adoxophyes orana* larvae per 100 shoots and the proportion of damaged fruits in 1970 and 1971.

The costs for plant protection measures (pests and diseases) are 15% of the total costs. In our conditions, 90% of the costs have to be spent to the control of fungal and bacterial diseases and 10% on insects and mites.

CONTROL OF *A. ORANA:* GENERAL CONSIDERATIONS

When the fruit grower has to decide whether to spray or not, he has to balance the damage to be expected against the costs of spraying. If he thinks that the damage will exceed the costs, he will spray. But often the decision will not be so easy because the damage depends on many factors, whereas the effect of the spray is not always clearly predictable. When taking the decision, many factors have to be taken into account: How much fruit is there on the trees? Which

Table 3: Application costs and other important characteristics of a number of insecticides widely used against *Adoxophyes orana* in the Netherlands.

Insecticide	total costs of application (guilders/ha)	duration of activity on target insect (weeks)	toxicity to mammals	residue tolerance (mg/kg)	safety interval (days)
parathion	40	1	high	0.5	21
azinphosmethyl	64	2	high	0.4	21
carbaryl	75	1	low	3	4
methidathion	87	2	high	0.2	21
permethrin	74	3	low	1.0	7

variety is it? What are the costs of the insecticide and the spraying? And most important, what is the price to be expected for the fruit? (table 3)

During the past 15 years, azinphosmethyl has been the most frequently used insecticide for the control of *A. orana*. It apparently had the most attractive combination of characteristics for the growers. Its reasonably long residual activity made it possible to kill a great part of the newly hatched larvae that emerged over a period of several weeks. From time to time, we have investigated complaints from certain growers that the leaf-rollers showed signs of resistance, but these signs were always due to wrong timing of the application or to wrong spraying techniques.

Also carbaryl has been used quite frequently since it is suitable for quick treatment because of its short residual activity and also because it is an excellent fruit-thinning agent. Since 1979, permethrin has been permitted for use against caterpillars in orchards and it is getting popular very quickly because of its high efficacy, its long residual activity and its low toxicity to mammals. However, our Advisory Service recommends a certain caution with the use of permethrin because they fear quick development of resistance.

SUPERVISED CONTROL OF *A. ORANA*

In the first years when modern insecticides like DDT were used for the control of caterpillars in our orchards, *A. orana* became the major pest. Spraying schedules with 7–9 insecticide treatments were quite normal. Later, much more caution was used with insecticides. Our knowledge of the biology of *A. orana* was gradually increasing over the years. Sprays appeared to be only sufficiently effective against newly emerged larvae in search for fresh leaves. Right timing of the sprays was essential for success (Minks & De Jong, 1975).

At present, a schedule of sampling is available for all interested growers, in order to get a good impression of the population development of *A. orana,* with emphasis on the period from April–July. About a quarter of the growers are actively involved in the programme. They do part of the sampling, inform the Advisory Service about their observations and they follow courses during the winter. Of course, the data are also available to other growers through the spraying advice provided by the Advisory Service.

The sampling programme for *A. orana* can be summarized as follows:

a) Check hibernated larvae in April or May. Count 200 mixed buds per ha. No spray is necessary against these larvae themselves; they are rarely harmful. But, if one caterpillar is present in this sample, apply at least one spray in June (fig. 1). Instead of sampling 200 buds, a beating sample of 100 branches can be taken when the same threshold of one caterpillar is used.

b) Observe the flight period of the moths in May and June by sex pheromone traps to determine the time of spraying against the larvae of the following (June/July) generation. The timing is also based on temperature recordings. Details of this method have been described earlier (MINKS & DE JONG, 1975). Calculation of the rate of development of the eggs has now been simplified by the use of the temperature disc (fig. 5) (see also DE JONG, 1981). In this way we can avoid the use of trap catches for threshold values, as long as it is still difficult to relate catches and population density in a reliable way. Under auspices of the Advisory Service, a network of sex pheromone traps has been in operation for 5 years at 60 places for routine observations on *A. orana* (DE JONG, 1980b).

c) Check of the larvae at the end of July. Count on 200 shoots taken at random over one ha. If more than 10 larvae are found in the sample, spray once and, if more than 30 larvae, spray twice. Again, the timing of the sprays can be determined with the aid of sex pheromone traps, now by following the moth flight during August and September.

This sampling programme has now operated for several years to our great satisfaction. The number of sprays has been reduced to about half of the sprays mentioned above. A total of 1-4 sprays is now necessary during the whole season: 1-2 for the first larval generation and 0-2 for the second one. The use of the new synthetic pyrethroids like permethrin with their long-lasting activity can further diminish the number of applications and will also make the timing of application less critical.

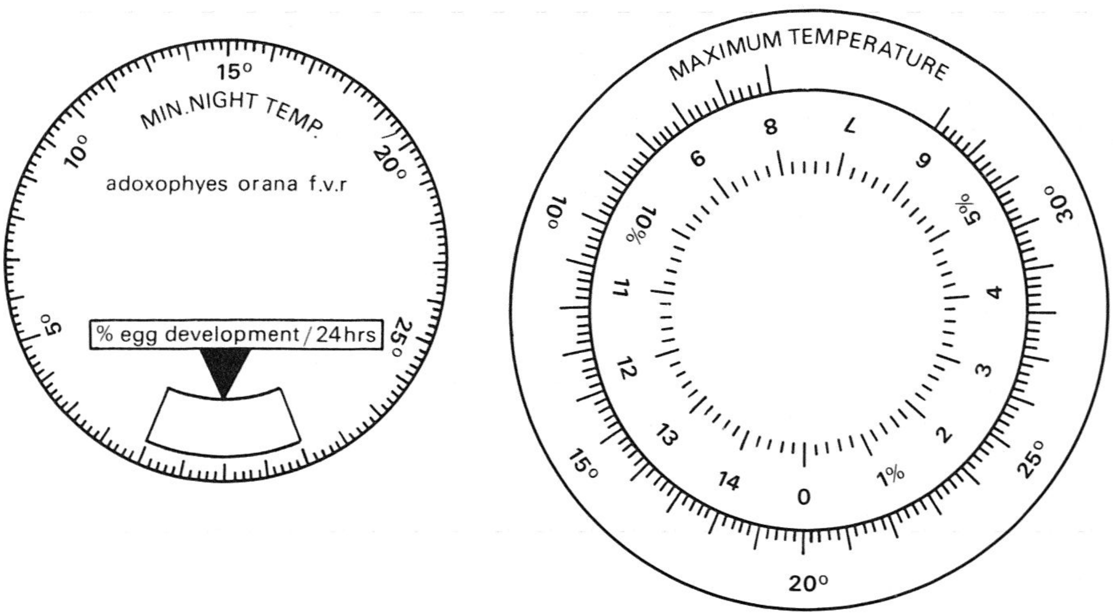

Fig. 5: Temperature disc used for simple determination of the rate of egg-development of *Adoxophyes orana* per 24 hours. The smaller disc at the left is pinned on the disc at the right. If the discs are turned in such a way that the minimum night temperature and the maximum day temperature of a given period of 24 hours are combined, the rate of development of the eggs can be read out in the hole in the smaller disc.

PROSPECTS FOR INTEGRATED CONTROL

Recently, the Netherlands Working Party for Integrated Control of Insect Pests, celebrated its 20th anniversary. Within its frame, all Dutch research in the field of integrated control has been coordinated. The extensive studies to develop an integrated control programme for insect and mite pests in fruit orchards have been summarized in a book edited by MINKS & GRUYS (1980).

Introduction of an integrated control programme in practice is much hampered by the lack of an insecticide for selective control of *A. orana*. Diflubenzuron is not active enough and the insect-growth regulator epofenonane, will not become commercially available, although it showed much promise (DE JONG & BEEKE, 1977; SCHMID et al., 1979). So much attention is being given to the development of other methods of selective control such as parasites, baculoviruses and sex pheromones (mating disruption).

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