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The autumn leafroller: phenology, damage and parasitoids in a Dutch apple orchard*

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Abstract

The phenology of the autumn leafroller, *Syndemis musculana*, a local pest of apple, was studied in order to forecast larval emergence. From 1983-1986, peak flight as determined with sex-pheromone traps was always between 13-18 May. The duration of embryonic development was determined at various constant temperatures and used to estimate the periods of egg hatch in these four years. Each year, most eggs should have hatched in the second decade of June.

Differences in attack rates between apple cultivars seem to be explained largely by the variation in picking time. Larvae are only half grown at the beginning of harvest (cv. James Grieve), and have gone into hibernation when the latest variety (cv. Golden Delicious) is picked. Moreover, the varieties Cox's Orange Pippin and Belle de Boskoop, picked about half time, are liable to receive additional damage by caterpillars brought with the picked fruits into storage.

Various hymenopterous parasites were reared from caterpillars. As the only leafroller in the orchard which hibernates as mature larva, *S. musculana* may promote winter survival of some parasitoids, like the eulophid *Colpyclypeus florus*.

Additional keywords: apple, orchard IPM, *Syndemis musculana*, Tortricidae, *Colpoclypeus florus*, *Tranosema arenicola*, *Teleutaea striata*, *Meteorus ictericus*, *Diadegma*, *Apanteles*, *Macrocentrus*, diflubenzuron.

Introduction

The autumn leafroller (*Syndemis musculana* Hübner; Lepidoptera Tortricidae) is a very local pest of apple. It was first discovered as such in the late seventies, simultaneously in the orchard of this study (Alkema and Vaal, 1980) and at Long Ashton near Bristol in the UK (Glen, 1982). This paper summarizes some additional observations made on this species during the period 1983-1986, with emphasis on the phenology.

Material and methods

All observations were conducted at 'De Schuilenburg'. More information about the

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control of pests, particularly of leafrollers, in this orchard can be found in Gruys (1982), De Reede et al. (1985) and Blommers et al. (1987).

From 1979 onward, caterpillars of the autumn leafroller were collected regularly, either from trees in July/August or from picked apples at inspection after harvest. These larvae were kept individually in cotton wool stoppered 5 × 1 cm glass tubes with artificial diet (Ankersmit et al., 1977) in an outdoor insectary through autumn and winter. The species of parasitoids emerging were identified according to Evenhuis and Vlug (1983). The moths emerging in spring were brought together with potted apple seedlings in small wooden rearing cages in the insectary to produce eggs. Larvae procured this way in the summer of 1984 were reared through another two generations (through 1985 and 1986) on apple seedlings (young caterpillars) and artificial diet (older larvae) under outdoor conditions. Specimens from these rearings were used to establish the duration of both the pupal and the egg stage at various temperatures. This was done by daily inspection of individual larvae and egg batches in constant-temperature cabinets under 16.5 h fluorescent light per 24 h. Minor daily temperature fluctuations in these cabinets were calculated from thermograph recordings and are mentioned with the results. Elevated humidity levels were maintained by placing the trays with rearing tubes into polythene bags containing a moistened cotton wick.

Three series of experiments were run to establish pupal duration, in one (1985) the larvae had spent the winter outdoors, in two (both in 1986) the diapausing larvae had been kept till early January in a refrigerator.

The duration of egg development was determined with egg batches laid by moths in polythene bags, provided with some diluted honey.

Sex-pheromone traps (S. Voerman, Institute of Pesticide Research, Wageningen) containing 1 mg 1 : 9 Z-11-Tetradecen-1-ol acetate + E-11-Tetradecen-1-ol acetate (Persoons et al., 1984) were used to establish the flight curve of this species from 1983 to 1986. Only two traps were used in 1983. Two traps were placed in each of seven blocks, of about 0.5 ha, in both 1984 and 1985, and one trap in each of five blocks in 1986. Traps were inspected twice per week, but in 1986 daily.

Daily minimum and maximum temperatures were taken from a Stevenson screen, at 1.5 m, at the meteorological station at Wageningen. The daily increase of the temperature sum in day degrees (DD) was computed as a sinusoidal curve in 2 h steps through the daily maximum and minimum temperature (Rabbinge, 1976).

Results

Phenology of larvae in winter. The overwintered caterpillars start to pupate as soon as temperature rises in spring. In the insectary the very first pupations were observed in the first decade of March; in 1980 and 1984. Most pupations occurred in April: in the first decade in 1985, in the second in 1980, and in the third in 1984. A few caterpillars collected at harvest 1983 pupated earlier next spring than those gathered from trees in July.

Most of the larvae kept in the refrigerator till 6 January 1986, pupated outdoors in the last decade of March. The pupation of those placed in rearing cabinets at 10, 12.7 and 16 °C took on average 16.4, 11.9 and 7 days, respectively, indicating a temperature threshold of 6.0 °C. The relation between this post-diapause development rate (V_{pd}) and temperature (T in °C) calculated from these data by least-square linear regression

Table 1. Average duration of the pupal stage of *S. musculana* at various constant temperatures in the laboratory. N = number of pupae. Daylength 16.5 h.

Year (Series)	Temp (°C)	Duration (days)	N
1986 (1)	10.0	48.9	15
1986 (2)	10.7	43.9	12
1986 (1)	12.7	29.6	16
1985	13.1	26.2	23
1985	14.5	20.2	30
1986 (2)	15.2	21.5	11
1986 (1)	16.0	19.8	20
1985	17.5	16.1	26
1985	20.0	11.1	29
1986 (2)	20.0	11.9	12

is: $V_{pd} = 0.0138\ T - 0.082$ (determination coefficient $r^2 = 0.96$).

Pupae and temperature. The duration of the pupal stage at various constant temperatures is presented in Table 1. The daily variation of the temperature in the cabinets, mainly caused by the heat of the lighting, was higher at the lowest temperatures (± 1.6° at 10° and 10.7 °C) than at the highest (± 0.8° at 20 °C). The standard deviation of the average duration varies between 3.6 and 8.8%.

The relation between developmental rate (V_{pupa}) and temperature can be described from these data by linear regression as: $V_{pupa} = 0.0066\ T - 0.049$ ($r^2 = 0.97$). Assuming a throughout linear relationship, the developmental threshold should be 7.4 °C. The estimated heat sum is 151 DD.

Phenology of moths. Fig. 1 shows the cumulative flight curves as established by traps with the specific sex attractant at De Schuilenburg from 1983 to 1986. The first moths were always observed in the first week of May. The major flight period is very fixed and short; most moths are caught between 13 and 18 May. The very last specimen was always trapped in the first week of June.

Eggs and temperature. After a preoviposition period of about 2 days at 20 °C, captive females start to lay egg batches, apparently in preference on wood; on a piece of bark or on the wooden parts of a cage. In the orchard, some egg batches were found on tree trunks. The batches contain about 40 eggs in average (Table 2). Young eggs are yellowish white. Later they turn via orange-yellow to black.

The duration of egg development at various constant temperatures is given in Table 2. In all, 188 egg batches were observed, 17 of which appeared not fertilized and were left out of consideration. Egg mortality was rather elevated at all temperatures. It was mainly due to the failure of caterpillars to emerge from the eggs after apparently normal embryonic development. Egg mortality was extremely high at 10.7 °C. These egg batches were also markedly smaller, indicating that the temperature was less favourable for oviposition, too.

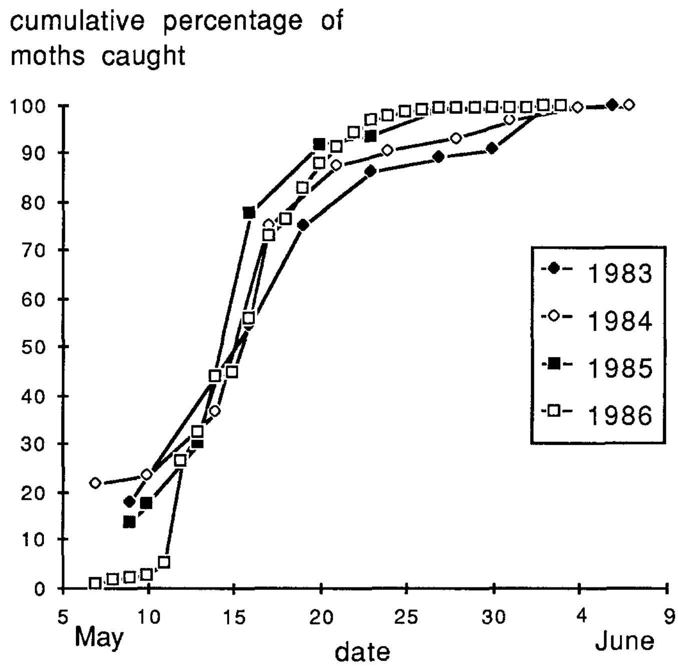

Fig. 1. Cumulative percentages of male moths caught in sex-pheromone traps. Total numbers of moths caught: 1984 174 (in 2 traps), 465 (14), 514 (14), 444 (5).

Table 2. Average duration of the egg stage of *S. musculana* at various constant temperatures in the laboratory.

Temp.	Duration (days)	Number of eggs[1]	% Mortality[2]	Eggs/batch[3]
10.7	39.8	344	65	28.5
12.7	29.3	1397	32	40.3
15.0	20.2	1093	25	39.4
20.0	10.9	1235	26	37.1

[1] Number of eggs eclosed.
[2] Percentage of eggs not eclosed.
[3] Average number of eggs per batch.

Least square linear regression yields the following relationship between development rate (V_{egg}) and temperature: $V_{egg} = 0.0073\ T - 0.057$ ($r^2 = 0.99$). Development should take 135 DD above 7.8 °C, if the relationship would be linear at the lowest end too.

Using this estimate and local temperature readings, Table 3 was calculated as an indication of the time of natural egg emergence in the years 1983-1986. Starting with three dates of the flight period: 6, 16 and 26 May, chosen as representative points of respectively the early, the major and the last period of oviposition, the time of egg emergence

Table 3. Time of average eclosion of autumn leafroller eggs, laid on three dates, as calculated from the daily temperature readings of 4 years, assuming that egg eclosion is 135 DD above 7.8 °C after egg deposition.

Year	Flight period		
	early (6 May)	peak (16 May)	late (26 May)
	Calculated time of egg emergence		
1983	6 June	10 June	15 June
1984	12 June	16 June	20 June
1985	27 May	4 June	18 June
1986	1 June	11 June	18 June

was calculated. The first larvae should emerge in the last week of May, or after a cooler spring in the first week of June. The date of peak emergence does not vary more than two weeks. And one may be fairly sure that each year the vast majority of eggs will have eclosed by the third week of June. By then the oldest larvae are 3 weeks old at the most.

Observations on the development of the caterpillars on apple seedlings in the insectary in 1980 and 1983, showed that eggs laid from mid-May onward began to eclose in the second week of June. At the start of July, most of the larvae were still in the second stage. They were found at the underside of the leaves, each in a small web spun to the main vein. By the end of July, most of larvae were in the third stage. From this stage onward, they started to spin leaves together. A month later, larvae were in the third till fifth stage. All caterpillars were full grown by the end of September. Fig. 2 summarizes the life cycle of the autumn leafroller.

Damage. Larvae of the fourth stage and older may attack apples, causing superficial damage (Fig. 3). The blemishes are generally more extensive than those by most other leafrollers. In all but the latest apple varieties, larvae get into the crates together with the picked fruits. In that way, one caterpillar often affects several fruits. Table 4 indicates the average damage due to this species at harvest since its discovery in 1979. Minor blemishes of this sort were not included as they are caused also by other leafrollers. The damage levels do not show large changes during these years, although we did not

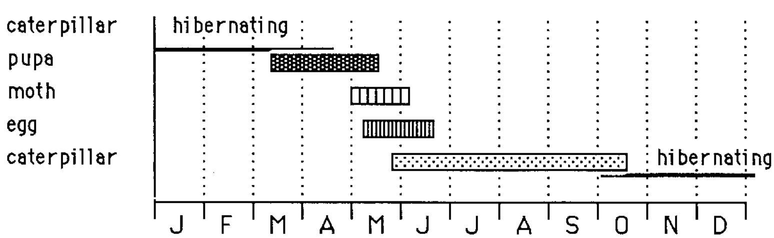

Fig. 2. Life cycle of *S. musculana*.

Fig. 3. Apples (cv. Belle de Boskoop) with damage by autumn leafroller.

Table 4. Average percentage of damage due to *S. musculana* on apples at harvest of four varieties at De Schuilenburg. Sample size: 1000-2000 apples per variety from each of 12 blocks.

Year	Variety			
	J. Grieve	Cox's O.P.	Boskoop	G. Delicious
1980	—	—	0.36	0.12
1982	—	—	0.69	0.28
1983	0.18	0.62	0.83	0.27
1984	0.08	0.29	0.49	0.13
1985	0.18	0.30	—	0.12

spray deliberately against the pest. Moreover, none of the limited number of insecticides applied against other pests (cf. Blommers et al., 1987) seems to have had an effect. The application of diflubenzuron (Dimilin 25%WP) in some blocks against caterpillars after bloom (300 g a.i. ha^{-1} at the end of May) or against codling moth (150 g a.i. at the end of June) should have been most suited with regard to timing, but this compound (0.02% a.i.) proved ineffective on young caterpillars on apple seedlings (L. Blommers, unpubl.).

The differences in attack between varieties appear to be rather consistent. In three out of four years, damage on cv. Belle de Boskoop was more than three times (3.1-3.8) that on cv. Golden Delicious. Only in 1982 it was 2.5×. These figures were between 2.2 and 2.6 for cv. Cox's Orange Pippin.

Parasitoids. Forty seven, or about 40% of the half grown caterpillars (N = 121) collected from trees in July or August in 1981, 1983 and 1985 appeared to be parasitized. The ichneumonid *Glypta varicoxa* Thomson was the most numerous parasitoid, accounting for about one third of the number over the years. This species is also the only one which appeared to emerge both before overwintering (7 specimens) and after (9). Most other species emerged only before.

The other parasitoids observed were 7 *Tranosema arenicola* (Thomson), 3 *Mesochorus* sp., 1 *Diadegma praerogator* (L.), 1 *D. apostata* (Gravenhorst) and 1 *Teleutaea striata* (Gravenhorst) (all Ichneumonidae), 8 *Meteorus ictericus* (Nees), 1 *Apanteles xanthostigma* (Haliday), 1 *Apanteles* sp. and 1 *Macrocentrus thoracicus* (Nees) (Braconidae), and 6 *Colpoclypeus florus* (Walker) (Eulophidae). Specimens of one species were nearly always reared from one sample. For example, all eight *M. ictericus* were reared from 43 caterpillars in 1981.

Discussion

S. musculana was observed only once on apple outside 'De Schuilenburg' (P. Alkema, pers. comm. 1981). It is also rare in orchards in England (Alford, 1984). At the experimental orchard, its density is stationary.

The autumn leafroller hibernates as full-grown caterpillar in leaf litter and on tree trunks (Glen, 1982; F. Vaal, unpubl.). Initially, it was contemplated to try to forecast the emergence of moths. Three sets of data would have been needed: the climatic conditions determining the end of diapause, plus those governing post-diapause development and pupation. The latter two were studied, indeed. The period up to pupation took 75 DD above 6 °C under experimental conditions, and should have been similar to the actual post-diapause period because the caterpillars were held at 4 °C till the start of the experiment. Because of this low threshold, post-diapause development may occur at any time during a mild winter (if diapause is over). On the other hand, it may be assumed that cold conditions (of unknown length and intensity) have to be met to end diapause in both mild and severe winters. As, moreover, the microclimatic conditions in the various hibernation sites – trunks and fallen leaves – are different, forecasting the phenological development of this species in late winter and early spring was deemed rather impractical, eventually. Calculated moth emergence periods, using the determined thresholds and temperature sums for post-diapause and pupal development together with daily maximum and minimum temperatures from the Stephenson-screen, and starting at the 1th of January, varied more than the real flight curves over the years (Helsen, unpubl.).

Whereas the moment of pupation in early spring appears to be rather variable, the emergence of moths seems highly predictable, as the moment of 50% cumulative catch in pheromone traps fell on 15 May plus minus one day in all four observation years. As the main flight period is also short, it seems well suited as calendar-based biofix to mark the peak period of egg deposition and the start of embryonic development. More observations are needed to sustain this apparent predictability.

The rate of embryonic development was determined in view of forecasting egg eclosion in the field. The results indicate that most larvae emerge every year in the first half of June. As larval development is slow, chemical treatment by the end of June should always be in time to prevent damage.

The life cycle of *S. musculana* is exceptional among leaf feeding leafrollers in Western Europe in that the full grown caterpillar hibernates and the moths fly early in spring.

However, as the larval development is slower, a second generation does not arise, even not in warm summers. Even a mass rearing started with emerging pupae in spring and kept permanently at 20 °C and 16.5 h daylength failed as the caterpillars of the next generation went into diapause (Vaal, unpubl.). In contrast to the statement of Graaf Bentinck and Diakonoff (1968), the autumn leafroller has only one generation per year, at least in Dutch orchards.

Probably none of the more selective insecticides applied in this orchard was offensive to this species. But *S. musculana* is susceptible to various broad-spectrum insecticides (Alford, 1984). As 0.05% a.i. carbaryl proved very effective against young caterpillars on apple seedlings (Blommers, unpubl.), the use of this compound for fruit thinning in the first half of June might have some effect.

Analysis of the differences in damage levels (not shown here) between differently treated blocks (cf. Blommers et al., in press) was not successful. Evidently, the fact that a single caterpillar may cause damage to several picked apples, makes analysis at low damage levels difficult.

The fact that cv. Belle de Boskoop is harvested later than cvs James Grieve and Cox's Orange Pippin, may explain the greater vulnerability of the former cultivar. Especially cv. James Grieve seems escape damage because it is harvested by the end of August as many caterpillars are still half grown, although it can not be excluded that some minor blemishes by these younger larvae were not recognized as such. On the other hand, cv. Golden Delicious is the variety harvested last of all, but it escapes attack because most larvae are in hibernation by the time it is picked. Among freshly picked apples of this variety caterpillars of the autumn leafroller are rarely encountered.

The parasitoids reared are known already from other leafroller species (Evenhuis & Vlug, 1983). It is noteworthy that most wasps emerged before winter, at a rather unsuitable period (as it seems) for further propagation. In contrast, it might be of interest that the autumn leafroller is a host to *Colpoclypeus florus*. This ectoparasitic species is common on summer fruit tortrix (*Adoxophyes orana* F.v.R) in summer, but supposedly lacks larger caterpillars in the orchard in autumn to pass its last generation before hibernation (Evenhuis, 1974; Gruys & Vaal, 1984). The presence of the autumn leafroller helps perhaps to explain the great abundance of *C. florus* at the experimental orchard (Blommers et al., 1987).

Acknowledgements

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Samenvatting

Fenologie, schade en parasieten van de herfstbladroller in een Nederlandse boomgaard

De fenologie van de herfstbladroller (*Syndemis musculana* Hübner), een incidentele plaag op appel, werd nader bepaald met het doel het uitkomen van de eieren te kunnen voorspellen. In 1983-1986 viel de piekvlucht, bepaald met behulp van feromoonvallen, steeds tussen 13 en 18 mei.

De ontwikkelingsduur van de eieren bij verschillende constante temperaturen werd gebruikt om de periode van uitkomen te schatten. De meeste eieren zullen ieder jaar in de eerste helft van juni uitkomen.

Geconstateerde verschillen in schade tussen appelrassen blijken goeddeels terug te voeren op verschillen in pluktijdstip. De rupsen van de herfstbladroller zijn pas halfwas als de eerste appels eind augustus geplukt worden, terwijl tegen het einde van de oogst begin oktober de meeste al in winterslaap zijn. Met name tussentijdse rassen, als Cox's Orange Pippin and Schone van Boskoop, lopen extra schade op doordat grotere rupsen met de geplukte vruchten in de kist terecht komen.

Uit de rupsen werden negen, al van andere boomgaardbladrollers bekende, sluipwespen gekweekt, Omdat deze bladrollersoort, als enige in de boomgaard, als volgroeide rups overwintert, lijkt zij bij uitstek geschikt als winterwaard.

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