Summerfruit Tortrix, *Adoxophyes orana:* Life Cycle, Warning System and Control[1]

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ABSTRACT

The summerfruit tortrix, *Adoxophyes orana* F.v.R., is a pest which has recently adapted to the intensive culture of apple and pear. The larvae develop primarily on the young leaves and shoots and occasionally feed on the surface of the fruit. Under Swiss conditions there are two flights per year though there are three in Greece with the second and third overlapping. The diapausing larvae hibernate in the third stage (L_3) and begin development again in the spring. There are three periods in which the larvae are active. The methods used to sample populations for making management decisions are: visual examination of flower clusters in spring, sex pheromone traps, and visual examination of shoots and fruit in summer. A model describing the life cycle as a function of temperature allows for the determination of the best time to sample damage and to apply treatments with regard to their particular mode of action. Some classical insecticides provide control curatively but efficiency is always reduced against older larvae. The best results are obtained at egg eclosion following the first flight. The insect growth regulator (IGR), fenoxycarb, is very effective when applied in the spring against the last stage larvae (L_5) of the overwintering generation. A specific virus also gives good control in the spring against overwintering larvae. The mating disruption technique and insect growth inhibitors (ICI), which prevent the formation of chitin, are currently being studied. For all the products used to control *A. orana*, the timing of the application is extremely important in order to obtain the best efficiency.

Introduction

The distribution of the tortricid, *Adoxophyes orana* F.v.R., encompasses all of northern Europe and Asia. This tortricid is very polyphagous, developing on more than 30 genera of host plants (Janssen 1958). It adapted later to *Rosaceae* and was not known as a pest of apple and pear in western Europe until 1939 in the Netherlands (De Jong 1951), 1944 in Belgium and the northwest of France (Soenen 1947), and later in Germany (Blunk and Janssen 1952), Switzerland (Geier 1953, Klinger 1956) and in northern Italy (Salvaterra 1953). In Greece, *A. orana* was mentioned for the first time as a pest of apple, peach and cherry in the region of Naoussa in Macedonia in 1985 (Savopoulou-Soultani et al. 1985). The introduction probably came from Yugoslavia.

Outbreaks of *A. orana* are closely linked with the quality of leaves available to the larvae. The population density can be very high in intensively managed orchards with strong shoot growth but is always lower in orchards with less intensive management where annual growth is reduced.

The intent of this article was to summarize the life history of *A. orana* in Switzerland and

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discusses techniques used to monitor and manage this pest. Obvious and potential differences between the life history and control of *A. orana* in Greece and Switzerland are emphasized. In addition, some useful information derived from two models is presented that associates important life history events of *A. orana* with degree day values.

Cycle of Development

A. orana overwinters (hibernates) in the third developmental stage (L_3). They leave their shelters around early April. The larvae start feeding on the flower buds when these have expanded and continue during and after the blossom period. In Switzerland, the most advanced individuals enter the pupal stage at the beginning of May (Fig. 1). The first flight of the overwintering generation begins during the last days of May but occurs for the greater part in June. The first eggs (egg masses) hatch in early June in early years but can continue until the end of the month. The young larvae web and feed between the veins of leaves at the extremities of shoots until they arrive at the third larval stage (L_3) when they begin to roll the leaves together with webbing. The infestations are then very easy to see. The larvae of the last stage (L_5) sometimes attack the surface of the fruit, most commonly when the fruits are touching each other. Feeding on the fruit sometimes covers an area of several cm^2. In Switzerland the second flight may begin at the end of July and continues occasionally through September. The young larvae feed on leaves and fruit where they make small circular holes. The third stage larvae (L_3) quit feeding in August, September or in early October and move to hibernating sites.

In the north of Greece, *A. orana* has 3 to 4 flights (Kyparissoudas 1988). The first flight is separate but those following overlap each other (Fig. 2). As a consequence there is a mixture of larvae of different developmental stages from

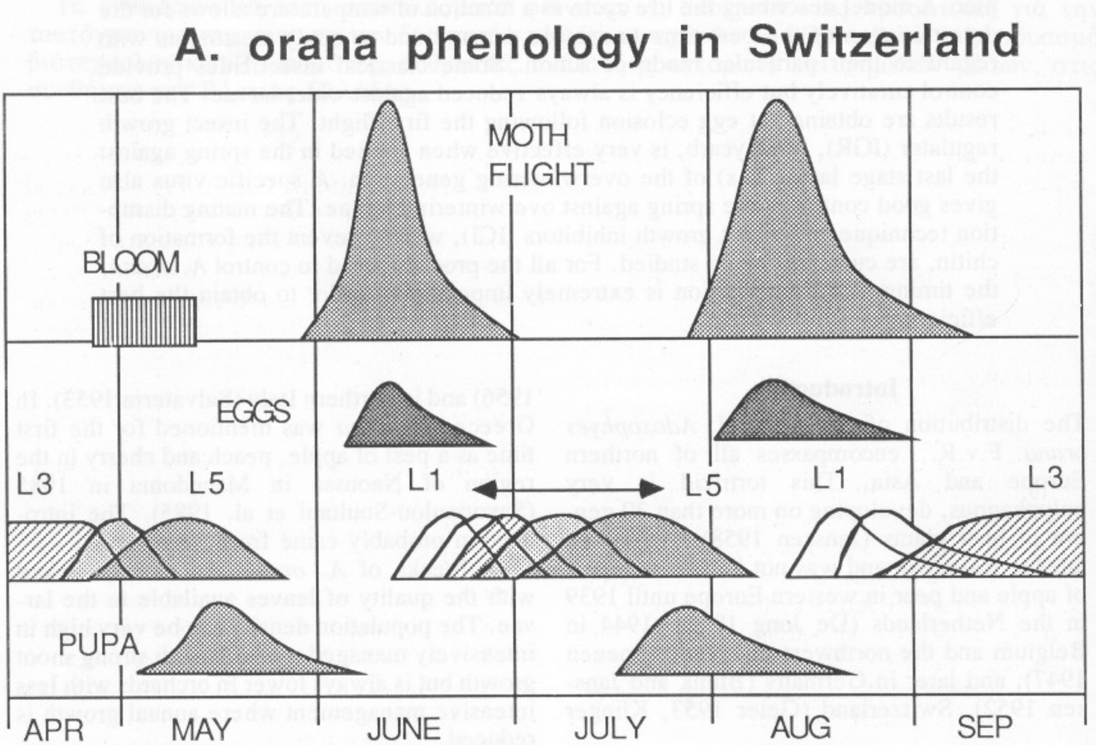

FIG. 1. Representation of the life history of the summerfruit tortrix, *Adoxophyes orana* F.v.R., under average conditions in Switzerland.

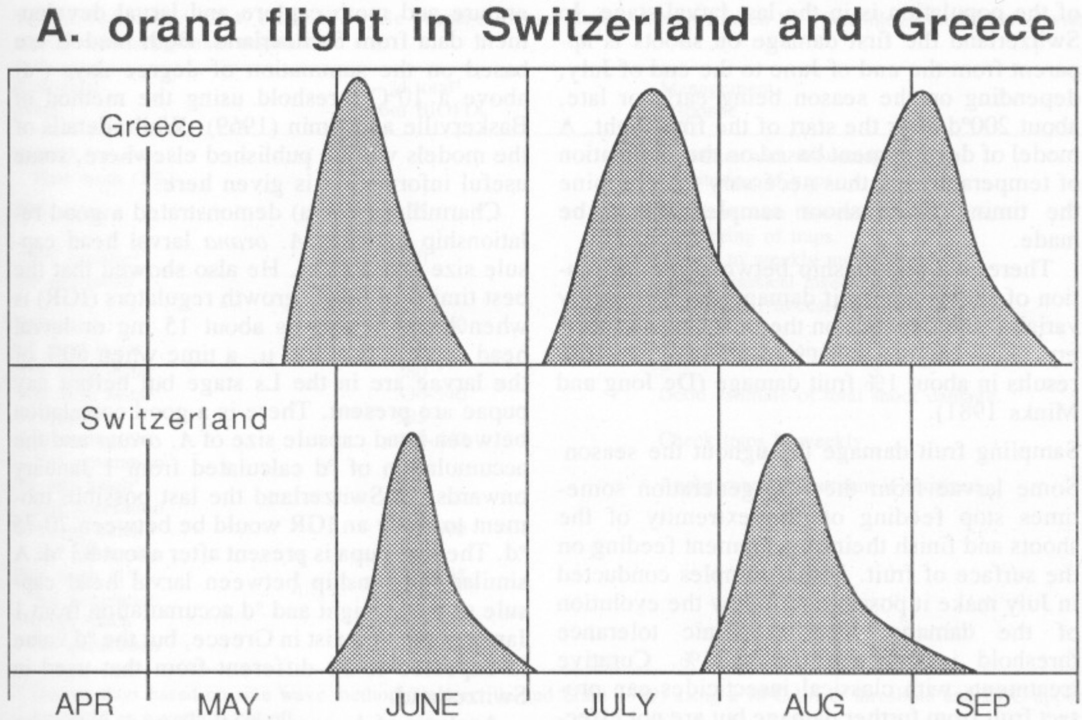

FIG. 2. Comparison of the flight activity of the summerfruit tortrix, *Adoxophyes orana* F.v.R., under average conditions in Greece and Switzerland. (in part based on information from Savopoulou-Soultani, M., et al. 1985 and unpublished flight curves).

the end of July through to September, which makes curative control later in the season more difficult.

Methods of Sampling and Warning

Estimation of larval populations in spring

In Switzerland, estimation of the population in spring is made by sampling flower clusters at the end of April just before the bloom of apple. This sampling is labour intensive because it is necessary to examine a large number of clusters and because the identification of the larvae is often difficult. It allows the detection of plots (orchards) where the population potential is sufficiently high (>0.5%) to justify a treatment in summer, but it does not permit the discrimination between moderate and low populations. Probably in Greece this sampling can be done better after the blossom period because blossom occurrence in the Mediterranean region is earlier than in central Europe.

Sex pheromone traps

For *A. orana* there is a poor relationship between the captures in pheromone traps and the subsequent damage. The trap catches cannot be used as the only information for making control decisions. Under Swiss conditions, if the weekly captures do not exceed 20 to 40 moths, control is usually not required. By contrast, exceeding this threshold does not always represent a strong threat. If control is necessary, pheromone trap captures allow the precise determination of the beginning of egg hatch which is the optimal timing for treatment with classical insecticides (e.g. organo-phosphates or synthetic pyrethroids). The first hatch begins after the accumulation of about 100 degree-days (°d) above a threshold of 10°C following the rapid increase in moth captures.

Sampling shoot damage in summer

Sampling the attack of the summer generation at the extremity of shoots is easy to execute because the damage is easily visible when the L_3 larvae and older begin to roll the leaves. However, when the first attacks are detectable the rate of attack increases rapidly, often doubling in 3 to 5 days, before stabilizing when most of the population is in the last larval stage. In Switzerland the first damage on shoots is apparent from the end of June to the end of July, depending on the season being early or late, about 200°d after the start of the first flight. A model of development based on the summation of temperatures is thus necessary to determine the timing when shoot samples should be made.

There is a relationship between the infestation of shoots and fruit damage but it is highly variable and depends on the fruit load and variety. On average, a shoot infestation of 5 to 10% results in about 1% fruit damage (De Jong and Minks 1981).

Sampling fruit damage throughout the season

Some larvae from the first generation sometimes stop feeding on the extremity of the shoots and finish their development feeding on the surface of fruit. Visual samples conducted in July make it possible to follow the evolution of the damage. The economic tolerance threshold is between 0.5 to 1%. Curative treatments with classical insecticides can protect fruit from further damage but are not effective against older larvae which are protected in rolled leaves.

The small larvae of the last generation generally develop as far as the L_3 larva before entering diapause. They feed on leaves and fruit in August and September, making small holes. If the tolerance threshold is passed it is possible to intervene with a curative treatment but the choice of insecticides is more limited due to pre-harvest interval restrictions.

Sampling fruit at harvest

A visual examination of about 2,000 fruits per orchard plot at harvest always gives much information. Fruit injuries caused by the first and second generation of *A. orana* differ in appearance thus allowing the discrimination of when control failures occurred. In addition, the small feeding holes at the end of the season show the presence of overwintering larvae and indicate that control measures may be needed in the following year.

Phenology Model of *A. orana* Development

Two models of *A. orana* development, a regression model and a simulation model based on the PETE (Welch et al. 1978) system, have been developed using information from the literature and moth capture and larval development data from Switzerland. Both models are based on the summation of degree days (°d) above a 10°C threshold using the method of Baskerville and Emin (1969). While details of the models will be published elsewhere, some useful information is given here.

Charmillot (1989a) demonstrated a good relationship between *A. orana* larval head capsule size and weight. He also showed that the best timing of insect growth regulators (IGR) is when larval weight is about 15 mg or larval head capsule is 1,100 μ, a time when 60% of the larvae are in the L_5 stage but before any pupae are present. There is a good correlation between head capsule size of *A. orana* and the accumulation of °d calculated from 1 January onwards. In Switzerland the last possible moment to apply an IGR would be between 70-75 °d. The first pupa is present after about 83 °d. A similar relationship between larval head capsule size or weight and °d accumulation from 1 January should exist in Greece, but the °d value is expected to be different from that used in Switzerland.

Analysis of *A. orana* moth capture data from 1976 to 1989 showed that activity in Switzerland was highly variable from year to year. The first moth of the overwintering generation was detected as early as 17 May (1976) or as late as 12 June (1980). Average detection of the first moth over the period was 3 June (±9.4 days) and the average percent of total capture on that date was 8%. The average for 50% emergence was 9 June (±6.7 days). Using a lower threshold temperature of 10°C and the sine-wave method of calculating degree days (Baskerville and Emin 1969), the average degree day accumulation on 3 and 9 June was 168 (±23 °d) and 210 (±23 °d), respectively, calculated from 1 January. The flight of overwintering moths and those of the summer generation was distinctly separate. The first moth of the summer generation was detected as early as 14 July (1976) and as late as 14 August (1980). Average detection of the first moth of the summer generation was 29 July (±11 days), and the average percent of total emergence on that date was 8%. The average for 50% emergence was 8 August (±9.5 days). The average °d accumulation on 29 July and 8 August was 616 (±65 °d) and 693 (±38 °d), respectively.

Using first moth capture as a biological fix

TABLE 1. Summary of *A. orana* life cycle events in degree days (°d) as predicted by a phenology model along with appropriate management responses if any.

Biological event	°d total[1] from BIOFIX	Management response
BIOFIX[2] First moth (1%)	0	Continue with bi-weekly monitoring of traps.
50% capture	65	Continue with bi-weekly monitoring of traps.
100% capture[3]	240	Switch to weekly monitoring.
5% egg hatch	135	Apply classical insecticide treatment if necessary.
50% hatch	185-190	
1% third instar	210	Check shoots for larval feeding.
50% third instar	280	
90% third instar	330-340	Good estimate of total shoot damage.
5% pupae	395	
First moth (1%) 2nd generation	430-440	Check traps bi-weekly.
5% egg hatch[4] 2nd generation	590	Apply control treatment if required.
50% egg hatch 2nd generation	685-690	
First moth (1%) 3rd generation	885-895	
5% egg hatch 3rd generation	1045	

[1] Degree days based on sine wave method (Baskerville and Emin 1969) using a 10°C lower threshold and 29°C upper threshold as a vertical cut-off.

[2] BIOFIX="biological fix point" which is the biological event used to initialize the model, in this case it is the capture of the first moth in pheromone traps.

[3] This is a conservative estimate for 100% capture. Under most situations last moths of the overwintering generation would be captured earlier than this.

[4] This timing with classical insecticides will for some pear and apple varieties be near harvest in Switzerland so product choice will be limited by pre-harvest interval restrictions.

point (BIOFIX) is useful for initializing the °d accumulation and provides a more accurate prediction of life history events in the summer generation. Table 1 summarizes the predictions of critical life cycle events derived from the °d model along with appropriate management responses.

Methods to Control *A. orana*

Control using classical insecticides

A number of classical insecticides in the organo-phosphate and synthetic pyrethroid groups are registered for control of *A. orana* larvae. All of these products are more effective in controlling the neonate or very young larvae than the older larvae, L_4 and L_5. The timing of the treatment is essential for the efficacy of the control. Under Swiss conditions there are three periods of larval activity (Fig. 1). Control with classical insecticides usually is not very effective in spring because of the presence of older larvae. When the larval population is high, however, spring treatments may help reduce populations thus making control in summer easier (Fig. 3).

In June, timing of application is most effective at the first egg hatch. However, even if the insecticide used has a long residual period it is necessary to repeat the treatment after 12-15 days because the young larvae feed at the tip of the shoots where new leaves that were not hit by the first spray develop very rapidly.

A curative control is possible in July when the damage on the shoots is visible. This allows protection of the fruit but the impact on the population dynamics is poor because many larvae are protected by the rolled leaves and webbing. Also at this time the choice of insecticides is more restricted because some of them are not effective against older larvae.

Finally, control with classical insecticides is still possible in August and early September when timed at the egg hatch of the second generation but it is necessary to take into account

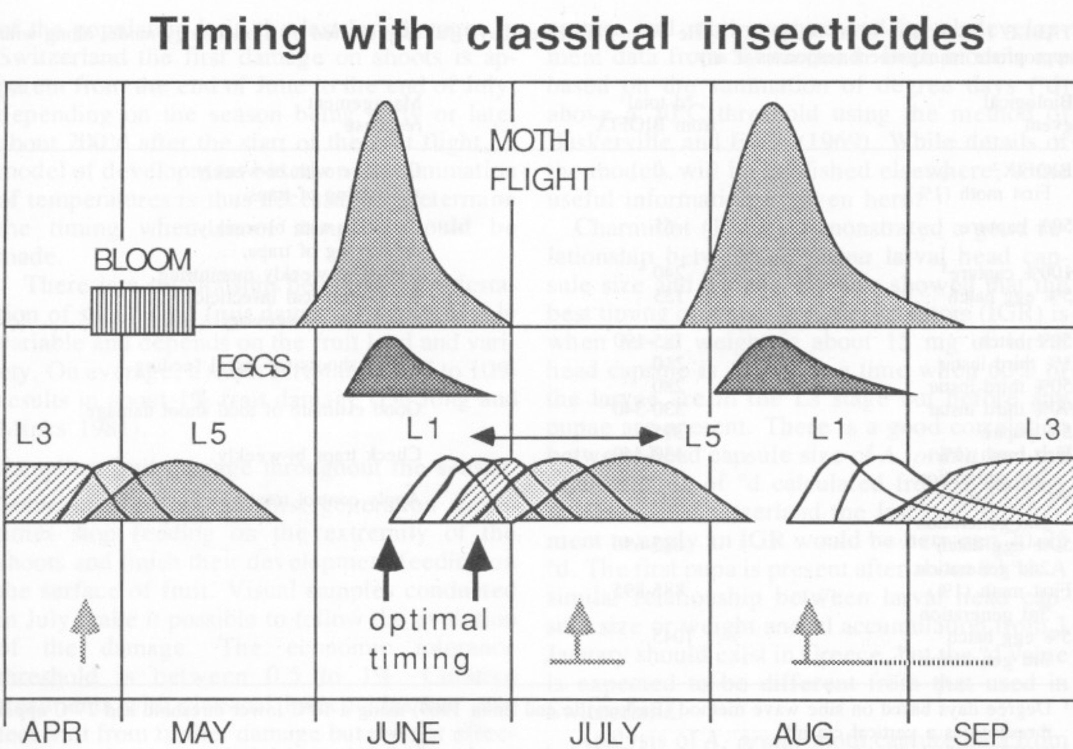

FIG. 3. Timing of classical insecticides in relation to the occurence of sensitive life stages of *Adoxophyes orana* in Switzerland. The optimal timing is represented by the black arrows while alternative timings are shown as shaded arrows.

the pre-harvest interval. Generally this treatment is not advised, in part because the egg hatch period is more lengthy than during the first generation and in part because control of *A. orana* should be done earlier in the season to avoid damage on fruit at the end of the first generation.

In principle, the above remarks also apply to conditions in Greece where the timing of treatments will be earlier because of the more rapid development of *A. orana*. Late in the season, however, control will always be more difficult because of the overlapping of generations giving a mixture of larvae of different developmental stages.

Finally it should be remembered that the majority of the classical insecticides, especially the synthetic pyrethroids, are very toxic to natural enemies of pests, in particular to the predatory mites.

Control with insect growth regulators (IGR)

Metamorphosis in insects is regulated by a complex system of hormones of which juvenile hormone (JH) plays a dominant role. An IGR, for example fenoxycarb, is an analog or mimic of JH. When fenoxycarb is applied against the young larvae of *A. orana* which produces JH it has no effect. However, when it is applied on L_5 larvae which do not produce JH it disrupts development of the pupa. An IGR cannot be applied curatively since the death of the insect occurs in the pupal stage, after the larval feeding period. Therefore, it must be applied against the generation preceding the one causing economic damage. This occurs in the spring against the last stage of the overwintering generation (Fig. 4). The timing of an IGR treatment clearly must be precise. There are two means to determine when this will occur in a certain region. It is enough to regularly sample in the spring 20 to 30 larvae from a representative orchard within a region and weigh the larvae or measure the size of the head capsules. The first fenoxycarb treatment is applied when the average head capsule size is 1,100 μ or when the average weight is about 15 mg. At that time 60% of the population is in the L_5

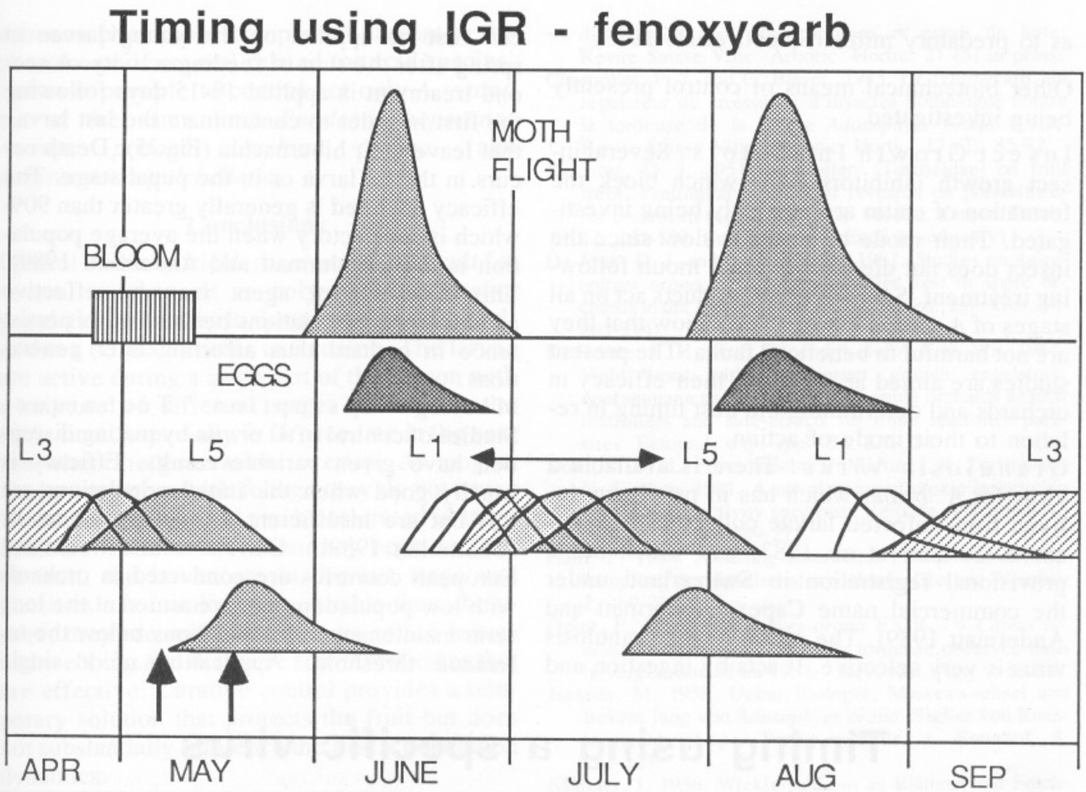

FIG. 4. The optimum timing of IGR products, for example fenoxycarb, in relation to the occurence of sensitive life stages of *Adoxophyes orana* F.v.R. under conditions in Switzerland.

larva but none have pupated (Charmillot 1989a). When the populations are high a second application 10-15 days after the first will control the later developing larvae.

Under conditions in Switzerland, the optimum timing of the first application against *A. orana* coincides with the phenological stage "G" of the apple variety Golden Delicious, that is a few days after full bloom. However, some damage to the brood of bees has been observed when larvae are fed with pollen contaminated by IGR within a day of the treatment. In 1989, fenoxycarb was therefore not permitted during blossom time (Anonymous 1989). North of the Alps the treatment can be effective when applied just before the bloom period though there is a reduction in efficacy because the timing is not optimal. In the Upper Rhone Valley, on the other hand, the treatment can be made immediately after the blossom period because in this region there are not yet any pupae present at that time. In other regions including the Mediterranean, for example, the Italian Trentino, the larvae of *A. orana* attain the stage sensitive to an IGR only after the blossom period because of the difference in phenology between the host plant and the insect. Probably a similar situation exists in Greece.

When applied in the spring against the last larval stage of the overwintering generation, fenoxycarb has always shown a good effect and could keep pest densities of the first and second generation below the tolerance threshold (De Reede et al. 1984, Galli 1984, Charmillot and Blaser 1985). However, there is a risk of immigration during the first flight period if the orchard treated with an IGR is located less than 20 meters from orchards inhabited by high *A. orana* populations, that are treated with a classical insecticide in summer. After the second year of fenoxycarb use it is often possible to apply only a single treatment.

It is important to note here that fenoxycarb appears to be harmless to many hymenopteran parasites (Dorn et al. 1981) and also to predators such as syrphids and coccinellids as well as to predatory mites (Stäubli et al. 1983).

Other biotechnical means of control presently being investigated

Insect Growth Inhibitors. Several insect growth inhibitors (IGI) which block the formation of chitin are presently being investigated. Their mode of action is slow since the insect does not die until the first moult following treatment. Some of these products act on all stages of *A. orana* larvae. Tests show that they are not harmful to beneficial fauna. The present studies are aimed at verifying their efficacy in orchards and determining the best timing in relation to their mode of action.

Granulosis Virus. There is available a virus for *A. orana* which has in part been derived from infected larvae collected in an orchard (Schmid et al. 1983) and which has a provisional registration in Switzerland under the commercial name Capex (Andermatt and Andermatt 1989). The action of the granulosis virus is very selective. It acts by ingestion and can first be applied on the young larvae in spring after the start of feeding activity. A second treatment is applied 10-15 days following the first in order to contaminate the last larvae that leave their hibernacula (Fig. 5). Death occurs in the Ls larva or in the pupal stage. The efficacy obtained is generally greater than 90% which is satisfactory when the average population is low (Andermatt and Andermatt 1989). This new control agent may be effective against larger populations because of its persistence in orchard thus affecting later generations.

Mating Disruption Technique. Studies of control of *A. orana* by mating disruption have given variable results. Efficacy is usually good when the initial populations are low but are insufficient against higher levels (Charmillot 1989b). Current studies in several European countries are conducted in orchards with low populations and are aimed at the long term maintenance of populations below the tolerance threshold. Application of a single

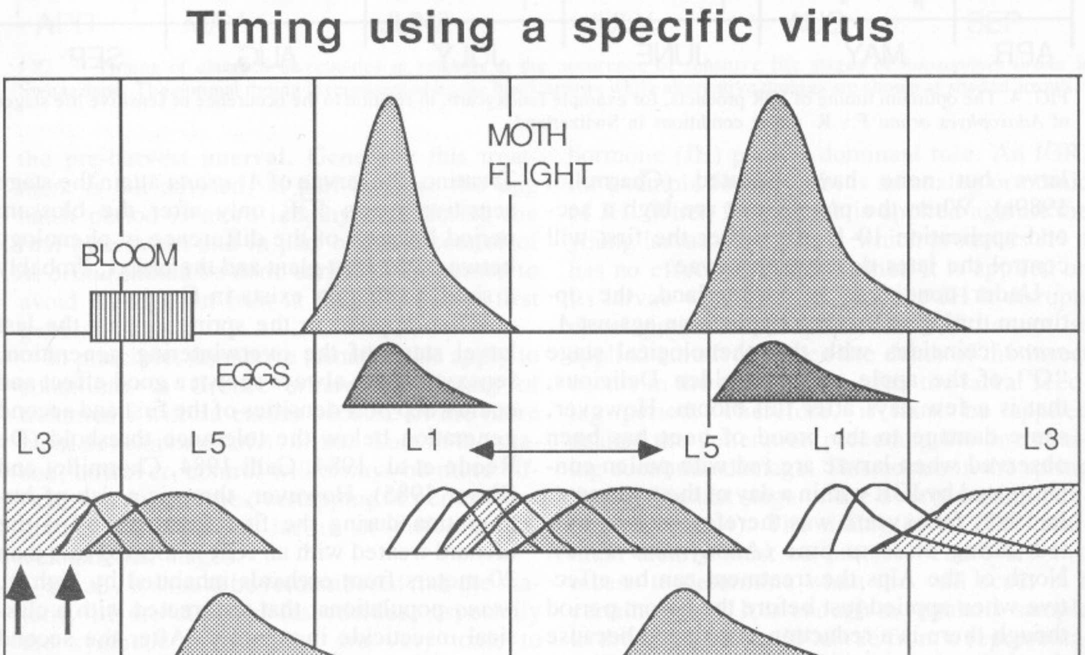

FIG. 5. The optimum timing of a specific granulosis virus, Capex, in relation to the occurence of sensitive life stages of *Adoxophyes orana* F.v.R. under conditions in Switzerland.

common pheromone component present in the pheromone of several related tortricid species, makes it possible to control not only *A. orana* but at the same time *Pandemis heperana, Archips podana, Archips rosana,* and *Argyrotaenia pulchellana*.

Conclusions

Control of the tortricid, *A. orana,* is difficult for several reasons. It is polyvoltine, allowing population increases to occur two (Switzerland) or three (Greece) times in a season. The larvae are active during a large part of the season with a mixture of different stages present at the same time, especially in Greece late in the season when the generations overlap. As long as the larvae only attack foliage they do not cause economic damage and can be tolerated in large numbers. In summer, when they begin to feed on fruit, the larvae are in the last stage and densities are usually high. At this time, however, they are well protected by rolled leaves and webbing and there are few insecticides that are effective. Curative control provides a temporary solution that protects the fruit but does not substantially influence the pest's population dynamics.

Good management of *A. orana* can be obtained with a single preventative treatment. However, success of this strategy depends on good knowledge of the pest's life cycle, a reliable estimation of pest density and optimal timing of the control agent in relation to its mode of action and to plant growth. Preventive control is possible with classical insecticides applied at the time of first egg hatch and with an IGR applied against the L_5 larvae of the spring population.

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KEY WORDS: Tortricidae, *Adoxophyes orana*, Summerfruit tortrix

Το Λεπιδόπτερο *Adoxophyes orana* F.v.R.: Βιολογικός Κύκλος, Σύστημα Προειδοποίησης και Καταπολέμηση

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ΠΕΡΙΛΗΨΗ

Το Λεπιδόπτερο *Adoxophyes orana* F.v.R., είναι ένας εχθρός που προσαρμόσθηκε πρόσφατα στις εντατικές καλλιέργειες μηλιάς και αχλαδιάς. Οι προνύμφες αναπτύσσονται αρχικά επάνω σε νεαρά φύλλα και βλαστούς και ευκαιριακά προσβάλλουν την επιφάνεια του καρπού. Στην Ελβετία υπάρχουν δύο πτήσεις το χρόνο, ενώ στην Ελλάδα υπάρχουν τρεις πτήσεις με τη δεύτερη και τρίτη να επικαλύπτονται. Οι διαπαύουσες προνύμφες διαχειμάζουν όταν είναι στο τρίτο στάδιο (L_3) και αρχίζουν πάλι να αναπτύσσονται την άνοιξη. Υπάρχουν τρεις περίοδοι που οι προνύμφες είναι δραστήριες. Οι μέθοδοι προειδοποίησης είναι: η οπτική εξέταση των λουλουδιών την άνοιξη, οι παγίδες με φορομόνες φύλου και η οπτική εξέταση των βλαστών και καρπών το καλοκαίρι. Ένα μοντέλο, που περιγράφει το βιολογικό κύκλο σε συνάρτηση με τη θερμοκρασία, επιτρέπει τον καθορισμό του καλύτερου χρόνου δειγματοληψίας ζημιών και εφαρμογής φαρμάκων σε σχέση με τον τρόπο δράσης τους. Μερικά κλασικά εντομοκτόνα προσφέρουν θεραπευτική καταπολέμηση αλλά η αποτελεσματικότητά τους πάντοτε μειώνεται εναντίον προνυμφών προχωρημένης ηλικίας. Τα καλύτερα αποτελέσματα επιτυγχάνονται κατά την εκκόλαψη των ωών της πρώτης γενεάς. Ο ρυθμιστής ανάπτυξης των εντόμων (IGR), fenoxycarb, είναι πολύ αποτελεσματικός όταν εφαρμόζεται την άνοιξη εναντίον του τελευταίου προνυμφικού σταδίου (L_5) της διαχειμάζουσας γενεάς. Ένας ειδικός ιός επίσης δίνει καλά αποτελέσματα εναντίον των διαχειμαζουσών προνυμφών. Τον καιρό αυτό μελετώνται η τεχνική της παρεμπόδισης των συζεύξεων και οι παρεμποδιστές ανάπτυξης των εντόμων (IGI) που εμποδίζουν τον σχηματισμό της χιτίνης. Για όλα τα προϊόντα που χρησιμοποιήθηκαν για την καταπολέμηση του *A. orana* ο χρόνος που μεσολαβεί είναι πολύ σημαντικός για τη μέγιστη αποτελεσματικότητα.