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Experiences of integrated management of European Cherry Fruit Fly (*Rhagoletis cerasi*) and how to utilize this knowledge for Sea Buckthorn Fly (*Rhagoletis batava)*

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Abstract

The genus *Rhagoletis* Loew includes about 65 known species distributed throughout Europe, Asia and America. Most species are oligophagous, attacking only a few closely related host plants. The European cherry fruit fly *R. cerasi* is the economically most important pest species in Europe. *R. batava* and *R. alternata* can also cause economic damage in Europe. In addition to these species, the American cherry fruit fly species *R. cingulata*, *R. indifferens* and *R. fausta*, as well as the apple maggot *R. pomonella*, the blueberry maggot *R. mendax*, and the walnut infesting species *R. completa* and *R. suavis* are pest insects of high economic importance. *R. cingulata* and *R.completa* were recently introduced to Europe and are currently spreading in Central Europe. A lot of research was conducted on integrated control of the European cherry fruit fly *R. cerasi* during the past hundred years. For the <u>monitoring</u> of flight period of *R. cerasi* yellow sticky traps are used. This method was shown to give reliable results for the timing of application. However, an economic threshold cannot be determined with yellow sticky traps, because fruit infestation is also influenced by crop load and weather conditions during oviposition period of flies. Chemical control (<u>Insecticides</u>) of *R. cerasi* is currently impeded by the withdrawal of “old” organophoshporus compounds (Dimethoate) and the debate on side-effects of neonicotinoids. <u>Attract-and-kill strategies</u> are available or under development: food baits (based on yeast hydrolysate and sugar) are mixed with the organic insecticides Spinosad or Neem. The baits attract the flies, stimulate feeding and thus increase uptake of the insecticide. However, the efficacy of attract-and-kill strategies strongly depends on the attractiveness of the bait which is influenced by climate conditions. <u>Mass trapping</u> by yellow sticky traps combined with baits is used for cherry fruit fly control in home-gardens. However, due to the high number of traps needed to achieve good control, this strategy is too expensive for commercial production. The use of kaolin as <u>mechanical barrier on the fruit surface to prevent oviposition</u> was shown to be effective against *R. indifferens* and *R. mendax*. Because kaolin treatments leave white residues on fruit, this method is not used against cherry fruit fly. Recently, it was shown that oil products can also prevent oviposition by creating a slippery layer on the fruit surface. A <u>biocontrol</u> method using the entomopathogenic fungus *Beauveria bassiana* has been developed and is currently registered in serveral European countries (product Naturalis-L). This strategy is mainly used in organic production. Another biocontrol strategy could be the use of parasitoids. However, the use of larval parasitoids is hampered by the steadily increasing fruit size of cherries for fresh consumption: parasitoids are no longer able to reach the larvae in the center of the cherry fruit. The use of <u>crop netting</u> to protect trees is the currently most widely used method of cherry fruit fly control. With the increasing number of dwarf tree cherry orchards covered against rain to avoid fruit splitting, it has become a viable, cost-effective method of cherry fruit fly control. However, for high standard trees this method is not suitable. In this situation, the use of nets for <u>soil covering</u> (to avoid hatching of flies from overwintering pupae in the soil) can be used.

Key words
Rhagoletis cerasi, biocontrol, Beauveria bassiana, insecticide, crop netting

Introduction

The European cherry fruit fly, *Rhagoletis cerasi* (L.) (Diptera: Tephritidae) is the most important pest of sweet cherries in Europe. Without insecticide treatment up to 100% of fruits can be infested. *R. cerasi* poses a challenge to cherry growers because the tolerance level of the market for damaged fruit is relatively low, with maximum 2% of infested fruits. Because fruit fly infested fruit cannot be sorted out, the whole lot is rejected if tolerance levels are exceeded. The disqualification of table cherries to distillery quality considerably reduces the market price, which causes serious financial losses.

The European cherry fruit fly belongs to the family of Tephritidae, which has world-wide distribution with about 4000 described species in about 500 genera. The genus *Rhagoletis* Loew includes about 65 known species. Most species are oligophagous, attacking only a few closely related host plants. In addition to *R. cerasi*, the American cherry fruit fly species *R. cingulata*, *R. indifferens* and *R. fausta*, as well as the apple maggot *R. pomonella*, the blueberry maggot *R. mendax*, and the walnut infesting species *R. completa* and *R. suavis* are pest insects of economic importance. Host plants of *R. cerasi* include various different *Prunus sp*. (Rosaceae; *P. cerasus*, *P. avium*, *P. serotina*, *P. mahaleb*) as well as *Lonicera sp.* (Caprifoliaceae; *L. xylosteum* and *L. tatarica*).

Life history characteristics of *R. cerasi*, like of other oligophagous Tephritid species, are best suited for exploiting resources that are predictable in time and space but are only available during a short period of the year. A close adaptation of their biology to the fruiting pattern of the host and precision in seasonal synchronisation are more important than high reproductive potential and high mobility. Hibernation occurs in the soil in the immediate vicinity of the hosts. Thus there is no need for dispersal flights. Adult emergence and life span are closely correlated with host plant phenology. Pupal carryover for two or more winters is used for “spreading the risk” of failure of the host plants to fruit in a particular year. There is only one generation each year and a long obligatory winter diapause. Relatively unspecific visual and odour stimuli are used to identify oviposition sites. Competition in the larval stages (contest type) is largely avoided by oviposition of only a single egg in each fruit and by the application of a host marking pheromone after oviposition, which ensures an adjustment of larval density to the carrying capacity of the host and maximizes dispersion over available food resources. The mating system of these species is usually resource-based: the males control the oviposition substrates and mating is often initiated by forced copulation without elaborate courtship behaviour.

The following paper summarizes the knowledge on biology, research and control of *R. cerasi*, points out general traits of all *Rhagoletis* species and suggests possible methods of control for the sea buckthorn fly *R. batava*.

Emergence and monitoring of flight period

Pupal development and adult emergence *of R.cerasi* is influenced by soil temperature in spring by temperature conditions during winter diapause as well as by the host plants from which the pupae originated and geographic provenance. The earliest attempts to develop a forecasting model for the eclosion time of flies were made in the 1930s. This model was revised and improved in the 1960s [1, 2] and 1970s [3, 4]. Knowledge of first fly appearance is important for a proper timing of control measures. For *R. cerasi*, beginning of the flight period can be determined using forecasting models based on soil temperature measured at a depth of 5 cm. Emergence starts at 430 degree days above the temperature threshold of 5°C [1, 5].

At the moment, a forecasting model predicting the emergence of adult flies in different regions in Switzerland is available for the farmers on the internet platform www.sopra-acw.admin.ch/ [6]. As *R.batava* also overwinters in the soil, hatching of adult flies is most likely also dependent on soil temperatures.
In absence of a forcasting model, depots of pupae in the soil can be used for precise monitoring of emergence [7]: larvae are collected from infested fruit, and buried outside in the soil. In the following spring, small cages are installed over the depots and emergence is daily counted.
An easier method to monitor the flight period, is the use of yellow sticky traps. For *R. cerasi*, , one or two traps per cherry variety should be placed on the southeast side of the tree canopy in full sun in mid-May prior to fly emergence and are examined twice a week. However, not all yellow traps are equally effective. For *R. cerasi,* traps with an high reflectance at 485 to 500 nm (yellow green region) and a secondary peak of reflectance at 365 nm (ultraviolet region) were most efficient [8, 9, 10]. For *R. batava*, most efficient trap colour needs to be identified. However, traps are not good indicators of the fruit infestation level. Depending on yield, weather conditions during oviposition and trap position, the economic threshold ranges between two and ten flies per trap. Treatment decisions should therefore be based on the expected yield and the infestation level in the previous year.

Pre-Oviposition period

Before oviposition, the adults go through a temperature-dependent maturation period of six to 13 days during which they need to feed on carbohydrates, proteins and water in order for the gonads to mature. Nutrients are obtained from bird droppings, honeydew, extrafloral nectaries, and bacterial colonies on leaf and fruit surfaces. This period is a suitable time span for most regulation methods.
Yellow sticky traps can be also used for mass trapping. However, in order for mass trapping strategies to be effective one to eight traps per tree (depending on tree size) are needed [11]. Traps are placed on the southeast side of the canopy. Because the traps should be hung in the upper part of the canopy, much labour is involved, thus making this strategy uneconomical for conventional cherry production. Nevertheless, mass trapping may still be the only option for controlling *R. cerasi* in home gardens, in which the application of insecticides is often impossible due to the lack of proper application equipment. Due to the lack of registered alternatives, yellow sticky traps are still widly used in organic cherry production throughout Europe. In addition to yellow surfaces, *Rhagoletis* flies also react to red or dark coloured spheres of approximately the same size as the host fruit [12]. For the apple maggot (*R. pomonella*) sticky spheres are used as traps. For cherry fruit fly, however, this strategy is unsuitable due to too small fruit/trap size.
As the flies are looking for food sources during the pre-oviposition period, food baits are an option to attract the flies. Food baits usually consist of yeast hydrolysate, and an ammonia releasing source (e.g. ammonium acetate). Trimethylamine (smell of long dead fish) and diaminobutane (rotting meat smell) were also shown to be effective. Food baits could either be used in combination with a yellow sticky trap, or in combination with an insecticide. Although some of the food baits tested in combination with yellow sticky traps were able to double the number of captured flies [13], none of the baits tested showed economic potential. However, the use of food baits in combination with insecticides showed promising results. The spinosad Product GF120 (Dow AgroSciences) is used in US and in dryer areas of Europe [14]. In regions with moist summer climate, the efficacy of GF120 was insufficient. Recently another bait (CombiProtec, Dedetec, Germany) was developed which shows better results in humid conditions. For *R. batava*, the application of insecticide-bait applications might be an option.

Insecticide applications are also applied during the pre-oviposition period. Until recently, one application of Dimethoate has been the standard for controlling *R. cerasi* in Swiss sweet cherry production, because it is by far the most cost-efficient method. Since 2011, however, this product is no longer registered for use in fruit production in Switzerland because of problems of ecotoxicity and residues on harvested cherries. Two applications of Acetamiprid are currently recommended for cherry fruit fly control in Switzerland. The situation in many other European countries is comparable. However, implementation and transition periods differ between the countries. Mainly Neonicotinoids are currently used to control *R. cerasi.*
The life span of flies under field conditions is difficult to estimate and may range between four to seven weeks, which leads to a total flight period of seven to 11 weeks.

Mating
Mating of *R. cerasi* occurs on sunny days with temperatures above 15°C. Host fruit on sunny parts of the trees is used as a mating site. Mating is initiated when a female in search of an oviposition site lands on a fruit occupied by a male. It was shown that the males produce a highly species-specific pheromone which attracts females. However, contrary to the pheromones of many Lepidoptera, this pheromone seems not to have a long-range attraction [15]. Besides the pheromone, fly behaviour plays a major role in locating mating partners: due to their preference for host fruits in full sun, the flies aggregate in certain parts of the trees. In these circumstances, an elaborate long-range pheromone might be of minor importance [16]. It was even hypothesized that the pheromone might function primarily as an aphrodisiac [17]. Until now this pheromone is not fully identified and neither monitoring tools nor management strategies based on this pheromone are available for *R. cerasi* control. Same is true for other *Rhagoletis species*: pheromones are either not identified or not available for commercial use. Thus, the use of e pheromone does not seem an good option for control of *R.batava*. One to three copulations during a female's life span are considered to be necessary to maintain high egg fertility.
Another strategy to prevent offspring is the sterile insect technique. For cherry fruit fly control it was developed between 1960 and 1980 [18, 19, 20, 21, 22]. The major bottle-neck of this technique is the artificial rearing of the fly [23, 24, 25, 26]. Several points in the insect's biology complicate rearing: *R. cerasi* is univoltine, has an obligatory diapause of at least 150 days, and *R. cerasi* is monophagous with a strongly selective host choice. The lack of a suitable rearing method for producing enough sterile insects for mass releases prevented this strategy from being commercially introduced.

Dispersal flights
With the relative stability of the system, i.e. pests that overwinter beneath perennial hosts, there appears to be little impetus for adults to move long distances. Dispersal flights occur only in situations in which flies are deprived of suitable fruits for oviposition: when cherries are destroyed by frost or early harvest or when all fruits are already infested [27]. Driven by high oviposition pressure, the females leave their original tree [28], and the males follow a little later [27, 29]. The flies move from tree to tree until they find a suitable host [30]. Maximum distances of dispersal flights are difficult to evaluate experimentally and might range between 100 and 500 m [2, 30], in exceptional cases as far as 3 km [20]. Flight studies in the laboratory showed that flies are capable of flying several kilometres in 24 hours if no landing platforms were available. However, within orchards, 95% of the flies move only to neighbouring trees of later ripening varieties [2, 31], and from there on to *Lonicera sp*. bushes [27].
In order to prevent immigration of flies into orchards, net covering can be an option. Especially with the increasing number of dwarf tree orchards shielded from rain to prevent the large sized

cherry varieties (>24 mm fruit diameter) from splitting, crop netting is a viable, cost-efficient strategy for protecting cherries from infestation [32]. Experiments using netting to cover the trees were conducted at the Palatinate Agricultural Service Centre (DLR Rheinpfalz, Germany [33]), at the Bavarian State Research Centre for Agriculture (LfL Bayern, Germany [34]) and at the Research Institute of Organic Agriculture (FiBL, Switzerland, Häseli, personal communication). The “Rantai K” net-type with a mesh size of 1.3 mm was used in all experiments. Netting should be installed before the beginning of the flight period and the netting should remain in place until the latest ripening cherry varieties are harvested.

Oviposition

Oviposition occurs around noon and during early afternoon on sunny days when temperatures rise above 16°C. Weather conditions during the oviposition period are considered to be crucial for the regulation of population densities: the high oviposition activity during long-lasting periods of fine weather can lead to extreme outbreaks of this pest. Both olfactory and visual cues are involved in the choice of suitable fruits for oviposition. However, the visual component appears to dominate. Females recognize the fruit by visual cues based on shape (spherical or hemispherical), size (2.5 to 10.3 mm diameter) and contrast-colour against the background (dark shape in front of lighter background) [17, 35]. Once a suitable fruit has been located, the female explores the surface structure (smoothness, softness and shape) by walking in circles on the surface and decides whether or not to oviposit [35]. The female pierces the fruit with its ovipositor and inserts a single egg just below the skin. After oviposition the females deposit a water-soluble host-marking pheromone by dragging the ovipositor around the fruit surface [36]. This pheromone prevents further ovipositions into the same fruit [37, 38]. The use of this pheromone was investigated in the 1970s [36, 38, 39]. In field experiments using naturally derived pheromone, an efficacy of 63 to 90% was observed [39]. High synthesis costs, however, prevented the use of this pheromone in commercial cherry growing. In addition, efficacy was low at high infestation levels and under rainy conditions. Moreover, about 10% of the trees had to remain untreated in order to provide unmarked fruits for oviposition [37]. Mechanical barriers are another option to prevent oviposition: Oviposition behaviour of cherry fruit flies is influenced by host fruit characteristics, such as texture [36], surface structure [35], and chemosensory stimuli [36]. Watching the flies during oviposition, gives the impression that flies need a lot of force to penetrate fruit skin. Altering physical properties of fruit surface can therefore prevent oviposition: It was shown that oil treatments prevent oviposition of *R. cerasi,* because the flies were not able to penetrate the slippery, oily skin with the ovipositor [13, 40]. For Apple maggot, *R. pomonella,* Kaolin clay is used as physical barrier with good success.Drawback of kaolin applications are the residues on harvested fruit. Therefore it is not an option for cherry fruit fly control. However, following up the idea of mechanical barriers seems promising also for *R. batava* especially for fruit needed for processing.

Egg and larval developement

The duration of embryonic development mainly depends on temperature and ranges between two to ten days. After eclosion, the larvae immediately move towards the cherry pit in order to find protection from parasitoids and predators. Larval development lasts between 17 and 30 days, depending on the temperature and the maturity stage of the cherries. The larvae go through three instars, reaching a final size of approximately 6 mm. During their development, the larvae tunnel in the fruit, macerate the tissue and ingest the broken down pulp. Larvae develop better and faster in fruits with higher sugar content and lower acidity [41]. High populations of *R. cerasi* can be therefore observed in sweet cherry orchards, whereas sour cherries usually remain free from high infestations. The infestation level can be estimated using the salt solution test [42]: 100 randomly picked cherries of each cherry variety are crushed until the pits are separated from the pulp. A saturated salt solution (350 g salt per litre water) is added. Floating larvae can be counted after 10 minutes. Control of larvae is only possible with systemic insecticides (Dimethoate), which are no longer registered in most European countries.

Pupation and overwintering

Around harvest, mature larvae bore exit holes through the fruit skin. Under field conditions, pupation usually occurs within three hours after entering the soil [29]. Most pupae are therefore found directly under the tree canopy, especially under the south and southeast parts of the tree, which is also where the highest fruit infestation levels are observed. Pupation depth is mainly influenced by soil type and usually ranges from 2 to 5 cm. The cherry fruit fly is an univoltine species: the pupae remain in the soil until the following spring. Overwintering pupae enter diapause and require a chilling period before development can continue. Approximately 180 days at temperatures below 5°C are required for maximum emergence [2, 3, 43]. Pupal mortality during the nine to 10 months of diapause is high and is mainly attributed to unfavourable climatic conditions, predation and parasitation: usually only 5% to 15% [41] of the pupae emerge in the following year. A few individuals remain in diapause for an additional year or sometimes for several years [28, 29, 43]. This pupal carryover is a highly adaptive trait, ensuring that the population will not perish on account of failure of host plants to fruit in some years.

Because *R. cerasi* pupae spend more than 10 months per year in the soil and because the area of pupation is strictly limited to the surface directly under the canopy of infested trees [29], the possibility of soil treatments was appealing [44]. Covering the soil under the tree canopy with netting to prevent the hatching flies from reaching the fruit is another efficient management strategy. The netting can reduce fruit infestation by 91% [31, 45]. Because the flies can survive for a long time under the netting, it is advisable to bury the edges of the netting completely. This, however, leads to high labour costs. Moreover, expensive, fine-mesh netting (0.8 mm mesh width) is considered to be necessary, because young flies after emergence can easily get through nets with mesh widths of 1.3 mm. Nevertheless, this method could be an option for controlling *R. cerasi* in extensively managed standard tree orchards. This strategy could be also tested against *R. batava*.

Mortality and antagonists

In cherry production, harvest (and the consequent removal of larvae from the orchard) is considered to be one of the main mortality factors [41]. In addition, temperature and rain have a major impact on mortality. No literature is available on the effects of **viruses** or **bacteria** on *Rhagoletis sp.*.

The pathogenicity and virulence of different **entomopathogenic fungi** on different life stages of *R. cerasi* were also first evaluated in laboratory experiments. Adult flies were found to be the only life stage susceptible to fungus infection. *B. bassiana* ATCC 74040 showed a high virulence, the flies died during the pre-oviposition period. These results were the first evidence of the susceptibility of *R. cerasi* to infection with hyphomycetous fungi [46]. Field application strategies were therefore focused on adult flies using the fungus isolate *B. bassiana* ATCC 74040, which is formulated in the commercial product Naturalis-L (Intrachem Bio Italia). Repeated applications of Naturalis-L during the flight period of *R. cerasi* were shown to reduce the infestation level of fruits by 60-70% [47]. However, the application of Naturalis-L is considerably more expensive than the application of Dimethoate or Acetamiprid. The higher prices obtained for organically grown cherries might justify the higher input for pest control [13]. For good efficacy, four treatments of 0.25% Naturalis-L ($5x10^4$ CFU ml^{-1}) with

1000 l water per hectare should be applied at seven to ten day intervals. The first application should be made five to ten days after the beginning of the flight period. The time period between the last application and harvest should not exceed seven days. Other phytosanitary measures (early and complete harvest; removal of infested cherries) can further enhance the efficacy of Naturalis-L treatments. Because the use of fungicides can interfere with entomopathogenic fungi, close attention has to be paid to the whole pest management programme. The use of entomopathogenic fungi might also be a possibility for control for *R. batava.*

Laboratory studies have indicated promising results of **entomopathogenic nematodes** to control the third instar larvae of *R. cerasi* [48]. However, results of laboratory experiments conducted in the scope of the European COST 850 project were disappointing: in a screening of 18 different nematode strains, the highest mortality rates in third instar larvae were below 30% (observed after application of *Steinernema feltiae* at a concentration of $2x10^6$ infective juveniles per m^2 on soil, Grunder et al., data not published). Due to the limited time frame and the different spatial activity, the potential for entomopathogenic nematodes for controlling *R. cerasi* under field conditions was considered to be rather small.

Most Tephritid species are attacked by a complex of native **parasitoids** [49, 50]. For *R. cerasi*, 21 species of parasitoids (larval ectoparasitoids, larval endoparasitoids and puparium parasitoids) have been described [51]. No egg parasitoids of *R. cerasi* are mentioned in literature. In cherry production, however, the effectiveness of larval parasitoids is greatly impaired by the short ovipositor of parasitoid females, which cannot reach *R. cerasi* larvae in large cultivated cherries. Monaco [52] observed that 10 to 30% of *R. cerasi* larvae in wild cherries (*Prunus mahaleb*) are parasitized by *Opius magnus* Fischer (Hymenoptera: Braconidae), whereas no parasitization was observed in cultivated cherries. Similar observations were made by Haisch et al. [53] and Hoffmeister [15], who noted that *R. cerasi* individuals from *Lonicera sp.* generally show higher levels of parasitization than individuals from cultivated cherries: *O. magnus* [15] and *Halticoptera laevigata* Thoms. (Hymenoptera: Pteromalidae) [15, 54] have only been observed in individuals from *Lonicera sp*., whereas *Opius rhagleticolus* Sachtl. [15, 44] was also found in individuals from cherries – although in lower numbers. Contrary to these observations, Leski [2] showed *O. rhagleticolus* to be the principal parasitoid of cherry fruit flies in Poland. However, with parasitization rates of 22 to 32%, *O. rhagleticolus* could not control *R. cerasi* populations [2]. Pupal parasitation seems to be more important. *Phygadeuon wiesmanni* Sachtl. (Hymenoptera: Ichneumonidae) occurs throughout Central Europe [41, 55] and has been shown to be responsible for a pupal mortality rate as high as 72% [41]. Under bushes of *Lonicera sp*., however, the parasitation rates of pupae were found to be higher than under cherry trees [43]. A mass rearing and release of this parasitoid might lead to an effective control of *R. cerasi*. Until now only little effort was made towards this strategy. Other puparium parasitoids, such as *Phygadeuon elegans* Förster [55], *Gelis bremeri* Haberm. (Hymenoptera: Ichneumonidae) [2, 15, 43], *Polypeza försteri* Kieff. (Hymenoptera: Diapriidae) [56], and *Spilomicrus hemipterus* Marshall (Hymenoptera: Diapriidae) [15], were observed in lower numbers. Until now, no biocontrol strategies based on parasitoids of *R. cerasi* were evaluated under field conditions. Different parasitoids might attack *R. batava*. A monitoring of natural occurring larval and pupal parasitiods is necessary to select possible candidates for a biocontrol strategy.

R. cerasi is most likely to be attacked by **predators** only during the short time span after leaving the fruit and pupation or immediately after emergence. Ants (*Myrmica laevinodis*, Hymenoptera: Formicidae), carabid beetles (*Anisodactylus binotatus*, Coleoptera: Carabidae) or staphylinid beetles (*Paedrus litoralis,* Coleoptera: Staphylinidae) are of particular

importance [41]. Boller [41] noted that up to 80% of larvae were destroyed by predators before pupation, and that ants seemed to be the most important enemy.
R. cerasi is not only associated with pathogenic microorganisms, but also with **symbiontic microorganisms**. Infestations by different strains of the endosymbiotic bacterium *Wolbachia* lead to an unidirectional cytoplasmatic incompatibility in *R. cerasi* [19, 57]. Because *Wolbachia* infestations can profoundly alter host reproduction, research on this topic might lead to new biocontrol approaches of *R. cerasi*.

Recommendation for cherry fruit fly control

Well-managed orchards are a prerequisite for the effective control of *R. cerasi*:

- Trees should be regularly pruned and trees height should be limited to 10 m to allow good coverage of spray applications and to facilitate an early and complete harvest of fruit.
- For new plantings of extensively managed standard trees, varieties suitable for mechanical harvest should be chosen to enable a quick harvest. Harvesting the cherries early and completely reduces the population level of *R. cerasi* by removing the larvae from the orchards before pupation.
- Infested fruits should not be dropped on the ground.
- If possible, early ripening cherry varieties should be chosen, because they are maturing before the majority of the flies are ready to oviposit.
- It is recommended not to cut the grass under the tree canopies until shortly before harvest. With a higher plant cover the soil temperatures remain low, which can delay fly emergence for about ten days .

Based on economic considerations, the following strategies for cherry fruit fly control are recommended.

- If still registered, one application if Dimethoate at the stage of colour change (green to yellow) of cherries is by far the most cost-efficient method.
- Alternatively, Neonicotinoid-products provide a good efficacy with reasonable costs.
- Crop netting with fine-mesh insect net (1.3 mm) to avoid immigration of flies into the orchard provides efficient control in intensively managed dwarf tree orchards covered by plastic or hail net.
- In organic cherry production in orchards without plastic cover or hail net, foliar applications of Naturalis-L (*B. bassiana*) are most suitable.
- The use of Spinosad-bait formulations (Spinosad GF120 or CombiProtec) is an option for control in areas with dry climate
- The use of yellow sticky traps is very expensive and only reasonable if no other regulation method is available.

Research options for *R. batava*

Research on *R. batava* is needed concerning several points:

- Testing and comparing different types of yellow traps, maybe in combination with baits
- Monitoring of flight period by yellow sticky traps (emergence time, duration) and development of a temperature based forecasting system
- Screening of host plant susceptibility (which varieties are less infested, which are the host plant traits responsible for infestation: sugar and acid content? ripening time? Colour?)

- Spinosad or neem-bait-applications: field efficacy trials using existing products and economic calculations
- Entomopathogenic fungi: field efficacy trials using existing products and economic calculations
- Netting over crop canopies or on the soil: field efficacy trials and economic calculations
- Mechanical barriers on fruit surface using oil or kaolin products: field efficacy trials using existing products: influence on infestation levels and on processing quality of berries
- Parasitoids: A monitoring of natural occurring larval and pupal parasitiods is necessary to select possible candidates for a biocontrol strategy.

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