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Raspberry cane midge (*Resseliella theobaldi* (Barnes)), biology, control methods and monitoring

by

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PREFACE

This is the result of a master thesis (30 ects) carried out within the horticultural programme at the Swedish University of Agricultural Sciences. The thesis consists of a field study of the raspberry cane midge and a literature study. Christer Tornéus, at the Swedish Board of Agriculture, was my supervisor and Birgitta Rämert, SLU, the examinator.

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SUMMARY

Raspberry cane midge is a serious pest of raspberries. The larvae feed in natural splits in the primocanes and these feeding wounds allow entry of infection by several fungi. The complex of larval feeding and fungal infection is termed midge blight. Midge blight leads to poor vigour of second-year canes with fewer fruit-bearing lateral shoots. Efficient control is difficult to achieve due to the sheltered place where the larval feeding and the short lifespan of adults. Monitoring of the male flight period is possible with sex pheromone traps.

This thesis includes trials conducted in the season of 2007 in a raspberry plantation situated in the south of Sweden. In 2006, the presence of the raspberry cane midge in the plantation was confirmed by large catches in the pheromone. The trials in 2007 included two pheromone traps that were deployed for monitoring of male midges in an unsprayed row of the raspberry cultivar Tulameen. In the same row the presence of larvae and eggs in primocanes were studied by making artificial splits, in which female midges laid their eggs. The results from the pheromone traps showed flight of male midges from late April until the beginning of October. The highest trap catches were recorded from the middle of July to late August with peak trap catches of 400-500 male midges per trap and week. The highest number of eggs and larvae in the artificial splits were found in July with 12 eggs and larvae per cm split. The increase of male midges trapped in pheromone traps in August was not followed by higher number of larvae and eggs in splits. This is results could be due to the presence of more natural splits later in the season leading to a dilution effect. Also predation of anthocorid bugs and predatory gall midges could have decreased populations of larvae in splits.

An additional study was conducted to investigate possible interference between pheromone traps. The results indicate that traps placed in close vicinity (7 and 20 metres apart) show a decrease in number of trapped midges, thus monitoring traps should be placed more than 20 metres apart to give representative data of the male flight pattern.

SAMMANFATTNING

Hallonbarkgallmyggan är en allvarlig skadegörare i hallon. Larverna äter på vävnaden i naturliga sprickor på förstaårsskotten och i såren kan flera olika sorters växtpatogena svampar infektera. Infektionen kan leda till svaga tvåårsskott som bildar få laterala fruktbärande skott. Det är svårt att effektivt bekämpa hallonbarkgallmyggan eftersom larverna lever så skyddat under barken och på grund av att vuxna kläcks kontinuerligt under säsongen. Förekomsten av vuxna gallmyggehannar kan följas under säsongen genom att hänga ut klisterfällor med sexferomonkapslar.

Flera försök gjordes under säsongen 2007 i en hallonodling i Sydsverige. Under 2006 bekräftades förekomsten av hallonbarkgallmyggor i den här odlingen med hjälp av stora fångster i feromonfällor. Försöken som gjordes under 2007 är beskrivna i det här examensarbetet och består bland annat av registrering av fällfångst i två feromonfällor upphängda i en obesprutad rad av sorten Tulameen. I samma rad studerades även larv och äggförekomsten igenom att artificiella sprickor gjordes i förstaårsskotten, i vilka honorna lade sina ägg. Fångsten i feromonfällorna visade på att hallonbarkgallmyggan förekom i odlingen från i början av maj till i början av oktober. De högsta fällfångsterna registrerades i mitten av juli till sen augusti med så mycket som 400-500 vuxna gallmyggehannar i en fälla på en vecka. Det högsta antalet ägg och larver i sprickorna observerades under juli månad med 12 ägg och larver per centimeter spricka. Ökningen av vuxna myggor som fångades i feromonfällor under augusti följdes inte av en ökning av ägg och larver i sprickorna. Det kan bero på att fler naturliga sprickor förekom i odlingen senare under säsongen vilket ledde till en utspädande effekt i de artificiella sprickorna. En ökad förekomst av rovlevande näbbskinnbaggar och gallmyggor observerades och bidrog till det minskade antalet larver i sprickorna.

Ytterligare ett försök gjordes med feromonfällor där eventuell interferens mellan feromonfällor studerades. Försöksresultatet visar på att fällor placerade i närheten av varandra (7 och 20 meter) leder till att färre gallmyggehannar fångas, alltså borde fällor som används i prognossyfte placeras mer än 20 meter ifrån varandra för att ge en representativ bild över antalet myggor som förekommer i odlingen under säsongen.

TABLE OF CONTENTS

1 INTRODUCTION

Raspberry cane midge, *Resseliella theobaldi* (Barnes), is a serious pest of raspberry. The midge belongs to the gall midge family, Cecidomyiidae. The raspberry cane midge causes damage to first-year canes (the primocanes) of raspberries by larval feeding under the epidermis of the canes. In these wounds several fungal infections can occur. This complex of larval feeding and fungal infection is called midge blight. Symptoms of midge blight are dark, sunken lesions on the canes and the following year heavily infested canes can die back or fail to produce lateral shoots. Efficient control is lacking due to the midges having a long emergence time in spring that would require several insecticidal treatments for full control. The protected feeding place for larvae under the epidermis of first-year canes is also a contributing factor to the difficulties of control.

This thesis includes a literature study of the raspberry cane midge and trials studying the flight dynamics by pheromone traps and larval development by artificial splits in primocanes. The hypotheses were that 1.) there is a correlation between adult male midges caught in pheromone traps with larval development in splits and 2.) that there is interference between pheromone traps located in a near vicinity of each other, resulting in fewer midges trapped in these due to confusion or compeition. The literature study and the results from the trials are the basis for a discussion on possible control measures.

2 BACKGROUND

2.1 Raspberries

2.1.1 Commercial raspberry plantations in Sweden

According to statistics gathered by the Swedish Board of Agriculture the number of raspberry growers in Sweden has increased marginally since 1999, but the total area of raspberry plantations has increased by one-third.

Table 1. Statistics on number of hectares of raspberries grown in Sweden, number of companies and the yield. The statistics are based on data collected by the Swedish Board of Agriculture (Jordbruksstatistisk årsbok, 2007).

	1999			2002			2005		
	Area Hectares	Harvest Tonnes	Number Companies	Area Hectares	Harvest Tonnes	Number Companies	Area Hectares	Harvest Tonnes	Number Companies
Raspberry	117	118	156	130	191	156	156	250	160
Total berries	3 358	-	949	2 909	-	811	3 191	-	767

2.1.2 Raspberry history and biology

Raspberry (*Rubus idaeus)* belongs to the *Rosaceae* family. It originates from forests in Europe and Asia and there are very old records of using raspberry flowers and berries for medicinal purposes. Records of domestication were not found until the 16th century and the varieties at that time were mainly sour-tasting. The sweet-tasting varieties grown now are the result of breeding programmes (Jennings, 1988).

Raspberries have perennial roots and biennial shoots. The shoots, also called canes, grow vegetatively the first year. In the autumn raspberries enter a winter dormancy that requires temperatures below 7°C. The dormancy time for raspberries is relatively short and buds react quickly to mild temperatures, thus varieties with a longer dormancy time and late breaking are preferable for growing in Scandinavia. During the dormancy the raspberry plants can survive very low temperatures, though frost damage is a threat after several days with mild temperatures followed by cold nights (Nes, 1998).

In springtime lateral branches are produced, which bear flowers and fruits in the summer. After fruiting the entire cane dies. First year canes are often referred to as primocanes and canes in their second year of growth as floricanes (Goulart, 1991). During the growing season the excessive amount of primocanes are often removed as a control strategy, as more open rows have a lower incidence of fungal attacks (Nes, 1998).

The harvesting season can be prolonged by growing autumn fruiting varieties, which bear fruit on their primocanes (Jennings, 1988).

2.1.3 Natural splits

In a transverse section of a young cane the typical vascular cylinder with pith, xylem, phloem and cambium becomes visible with a surrounding ring of pericycle fibre bundles. Outside the fibre bundles two layers of parenchyma and epidermis cells are found. With increasing age canes develop several layers of periderm cells. During the growth of the primocanes several natural splits can develop as the outer cortical layer often grows more slowly than the rate that the cane increases in thickness.

Pitcher (1952) has characterized three different splits depending on the state of development of the outer cortical tissue. Type 1 splits develop early in the season and are the shallowest splits involving only the epidermis and the outer layer of the parenchyma cells. This layer dries up and curls back after about two weeks, but before that it provides the midge with a good place to oviposit. Type 2 splits also occur early in the season and are splits penetrating radially from epidermis to the pith. These splits develop into V-shaped splits filled with callus. As no cortical layers are separated this kind of split is not well suited for midge development. Type 3 splits are developed from the middle to late in the growing season. In these splits all parenchyma cells are involved in the splitting, resulting in a clear separation between the parenchyma and the periderm. Underlying tissue stays green longer than in type 1 splits, thus these splits are even more suitable for midge development. The first generation of midges oviposit primarily in type 1 splits and the second and third oviposits primarily in type 3 splits (Pitcher, 1952).

Fig. 1. Natural splitting of primocane in summertime with dark areas due to midge larvae infestation.

Accumulated length of naturally appearing splits and average extent of bark splitting of different raspberry cultivars were assessed by Vétek *et al.* (2006) in a one-year trial. The result showed that the cultivar Tulameen, used in experiments in this thesis, has primocanes that hardly splits. More natural splits mean more openings for larvae, which could lead to more fungal attack (Vétek *et al.*, 2006).

2.2 Raspberry cane midge

2.2.1 History

Raspberry cane midge was first recorded by Theobald in 1921, who gave it the generic name *Thomasia sp.,* which later became the genus name *Thomasiniana.* Barnes described the midge in 1926 and gave it the common name raspberry cane midge (Barnes, 1926). Gagné (1973) synonymised the genus *Thomasiniana* with *Resseliella* and the raspberry cane midge got its present name *Resseliella theobaldi* (Barnes). The raspberry cane midge is a member of the gall midge family, Cecidomyiidae, but does not form galls like some other members (Pitcher, 1952).

The raspberry cane midge was considered to be of little economic importance until 1946 when a high death rate of raspberry canes following damage of this species was reported. Pitcher (1952) consequently started to study the biology and control of the raspberry cane midge. In 1952 Sylvén reported observations of raspberry cane midge larvae found in raspberries in the southern part of Sweden and Denmark.

Woodford and Gordon (1978) reviewed information from researchers and advisors in Europe and stated that *R. theobaldi* had at that time spread to be widely distributed in Europe. As the midges are poor fliers the extensive spread would probably be due to transport of soil from cane nurseries. The increase of damage by the raspberry cane midge in Scotland in the 70s was hypothesized to be the result of warmer climate, resulting in earlier cane splitting that coincided with the emergence of the first generation of midges. Thus a higher number of females from the first generation that found splits for egg laying led to a larger second generation that could cause considerable damage (Woodford & Gordon, 1978).

2.2.2 Biology

The adult raspberry cane midge is reddish brown in colour and measures around 2 mm in length, with the females slightly larger than the males. Males have long beaded antennae that are characteristically curled back. Females have shorter antennae and their antennae are not as obviously beaded as the males. In the tip of the abdomen the males have a clasper and the females have a long ovipositor (Pitcher, 1952) (Fig. 2 a b).

Fig. 2. a. To the left a male raspberry cane midge with its long beaded antennae and clasper.
b. To the right a female raspberry cane midge with short antennae and an ovipositor.

Adult midges are short-lived and most often they do not live longer than three days. Adult midges do not feed and feeding damage is only caused by their larvae. Females have a tendency to live longer than males and their life span can be expanded if egg laying is delayed. Emergence of midges depends on weather conditions and at low temperatures fewer midges emerge (Pitcher, 1952). The observations of the time of the day when the majority of midges emerged have been contrasting. Pitcher (1952) suggests that it is evenly spread out during daytime and Barnes (1944) considered the evening to be the typical emergence time. Pheromone traps records at two hourly intervals over a two day period showed that emergence is in the evening (Cross, 2007). Raspberry cane midges are poor flyers and prefer to stay in the lower part of the host plant (Pitcher, 1952).

Normally males emerge first and mating occurs when the females emerge. Oviposition occurs, if conditions are favourable, mainly during the first 24 hours of life (Pitcher, 1952). Mated females primarily oviposit in splits of primocanes (Gordon & Williamson, 1991), although in Scandinavia evidence of ovipositing in splits of second-year shoots has been seen (Dalman & Malkki, 1986). Observations show that fresh splits are preferred over old and already occupied ones with larvae (Pitcher, 1952). Nijveldt (1963) observed in the laboratory that the scent from wounds and splits is the most important stimulus for oviposition. His studies involved a comparison of oviposition on twigs of *Salix* where half were sprayed with sap from

Fig. 3. A female raspberry cane midge has inserted her eggs under a flap of epidermis on a primocane.

young raspberry canes, resulting in immediate egg-laying on sprayed twigs and no egg-laying on unsprayed twigs (Nijveldt, 1963). Eggs are laid by females inserting their extended ovipositor under the flaps of wounds and splits in canes. The eggs are small, translucent and elongated (Gordon & Williamson, 1991) (Fig. 3). Females lay eggs that are predominantly either male or female (Barnes, 1944).

Larvae hatch after 7-10 days, depending on the temperature, and start feeding on the cortex of the canes (Gordon & Williamson, 1991). Larvae are able to degrade celluloses, which are constituents of the cell wall (Grünwald & Seemüller, 1979). Larvae are at first translucent but with age become more pink/salmon coloured (Gordon & Williamson, 1991). A portion of the larvae becomes more yellow/orange coloured instead, these larvae are identical to the pink coloured except for their colour (Fig. 4). Often larvae tend to crowd together in groups in the splits while feeding on the cortical cells. Tissues around the larvae's feeding place get discoloured and form a dark spot increasing in size to become a uniform brown/black area (Pitcher, 1952). Larvae are fully matured after 14-21 days then they fall to the ground to spin cocoons and pupate in the upper layer of the soil (Gordon & Williamson, 1991). Larvae of this species unlike other Cecidomyiid species, have not a well developed jumping habit and therefore fall to the ground or project themselves a very short distance only. Overcrowding in splits has lead to larvae leaving before fully matured (Pitcher, 1952).

Fig. 4. Primocane split with raspberry cane midge larvae. Notice the colour diversity (arrow) from yellow to pink/salmon.

On average 14-21 days are spent in the cocoon in the summer time. The cocoons are covered with soil particles and are therefore hard to find without washing away the soil. After completing the cocoon, the larvae either stay quiescent or start to pupate. Over-wintering larvae stay quiescent in the cocoon until spring. In spring the larvae pupate inside the cocoon and the pupae leave the cocoon to assume an upright position at the soil surface before emergence. Emergence of adults starts when the right weather conditions occur (Pitcher, 1952). In a summer trial made by Pitcher (1952), pupation occurred on the seventh day after the larvae had entered the soil and emergence occurred on the sixteenth. Emergence of midges

from their overwintering stage can be induced by two-three weeks of temperature over 20°C without a prior freezing period (Pitcher, 1952).

Stenseth (1972) made an extensive experiment on the development time of the raspberry cane midge under different temperature conditions. He found that the time required to complete the life cycle was 16-28 days at 30°C, 18-32 days at 24°C, 23-46 days at 21°C, 32-55 days at 18°C and 44-67 days at 15°C. From this he concluded that there could be several generations of midges per season and that these could be overlapping due to the variations between the maximum and the minimum time required for completion of the lifecycle at a given temperature.

Pitcher (1952) studied the number of generations of midges each year in the UK by examining larvae and eggs in canes. He found three generations with the first occurring in late May early June. The second generation of larvae he found to occur in July. The timing of the third generation varied a lot and depended to a great extent on the climatic conditions. Often only a portion of the population passes through a third generation as some go into diapause to over-winter. In years with warm weather a fourth population could also be found (Pitcher, 1952). Pitcher (1952) observed that the number of larvae in splits of the first generation seldom reached more than 100 individuals per cane. The second generation colonies were often larger and 200-300 individuals per cane could occur. The third generation varied greatly in size from few larvae up to 300 individuals per cane. Gordon & Williamson (1991) observed that the emergence of the second generation of adult midges often coincides with harvest. At this time the canes have developed many natural splits, thus there are a lot of potential oviposition places. In Finland the second generation supposedly occurred in late July at the same time as the start of the harvest, as after harvest third-instar larvae were observed in canes (Dalman & Malkki, 1986). In the Netherlands, Nijveldt (1963) observed three generation a year by using emergence cages.

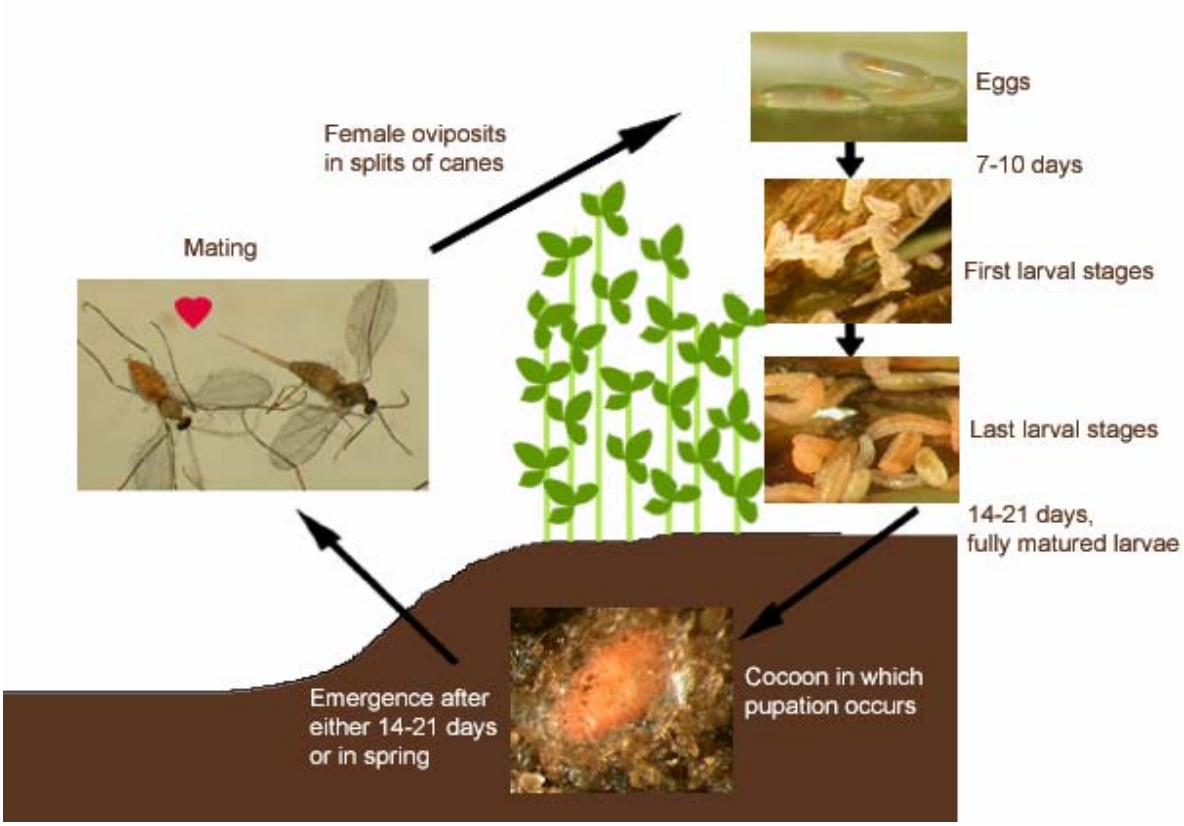

Fig. 5. Schematic figure over the raspberry cane midge life-cycle.

2.2.3 Damage

2.2.3.a Damage by larval feeding

Damage by larval feeding to the canes is mostly superficial, but becomes serious as the wounds act as infection sites for fungi (Gordon & Williamson, 1991). Fungal infection of the internal tissues of the canes is possible due to the degradation of cellulose by the midge larvae. The cellulose degradation leads to the destruction of the protective properties of the periderm (Grünwald & Seemüller, 1979).

Damage from the first generation larvae are deeply penetrating lesions which often give rise to cankers. Cankered canes can survive to the following year, but are weakened and break very easily. Damage from the later generations is often more severe, as these generations are larger and as fungal infections damage the cork layer which cannot be repaired in this growth stage (Gordon & Williamson, 1991). Pitcher (1952) observed the second generation to be responsible for a greater total area damage than the other generations put together. Typical symptoms of damage from the later generations are irregular brown lesions developing during late autumn and early winter. The following year damaged canes often show symptoms, like failure to produce enough lateral shoots or that shoots wilt and die before harvest.

The severity of the symptoms depends primarily on the area and extent of vascular tissue destroyed by the fungal infection. As symptoms on the primocanes b first ecome visible the following year when they become floricanes, the growers often save these for next year's harvest as they seem healthy and vigorous. Williamson and Hargreaves (1979a) observed a correlation between increase of midge damage and cane girth. This could be due to the higher growth rate of large primocanes which could result in more splitting, thus more oviposition sites. Yield losses up to 90 % have been recorded, although the production of primocanes the following spring is not affected (Gordon & Williamson, 1991). Stenseth (1977) proved that larval infestation on primocanes significantly reduced the yield the following year and the higher yield on undamaged plots was due to more healthy and long-lasting second-year canes. Investigations on scoring of midge damage by Williamson and Hargreaves (1979a) revealed that 20 % of the lower 30 cm of the cane could be covered in midge lesions before yield was affected.

Fig. 6. Brown lesions on a primocane caused by raspberry cane midge larvae.

2.2.3.b Damage by fungal infection

Midge blight is a term used to describe fungal infection following midge injury to primocanes. The superficial damage to the periderm caused by midge larvae becomes after fungal infection more penetrating and fungal fructifications can be seen in the damaged area (Pitcher & Webb, 1952). The fungi grow into the woody part of the raspberry cane and thereby the phloem and xylem are damaged, thus the flow of nutrients and water is decreased (Labruyère & Engels, 1963). Observations by Pitcher and Webb (1952) showed that in one field almost every case of fungal infections on canes was preceded by midge damage. Joäng and Zakrisson (1996) showed in their thesis work that there was a strong correlation between occurrence of fungal infections in canes and occurrence of larvae infestation.

By scraping off the outer layer of cork and epidermis the following year, symptoms of midge blight appear as brown irregular but clearly defined patches. Several fungal species have been isolated from lesions within the feeding area of midge larvae. Pitcher and Webb (1952) found primarily *Didymella applanata* (Niessl.) Sacc., *Leptosphaeria coniothyrium* (Fckl.) Sacc. and *Fusarium culmorum* (W. G. Smith) Sacc. Williamson and Hargreaves

(1979a) found principally *Fusarium avenaceum*, but also *Phoma* sp. and *Alternaria* sp. in lesions caused by larval feeding.

D. applanata is also known to cause the disease spur blight, but though the same fungus is involved in both spur blight and midge blight the symptoms are not alike. Symptoms of spur blight include brown, V-shaped lesions and the infections are spread from an infected leaf through the petiole and into the node. Infected leaves are often shed prematurely (Williamson, 1991). When *D. applanata* infects wounds caused by midge infestation the infection goes deeper and the damage becomes more severe (Pitcher & Webb, 1952).

Some of the scraped canes with midge infestation may also show striped brown lesions and these are caused by the infection of *Leptosphaeria coniothyrium* (Fig. 7). This fungus is also involved in the disease cane blight, which is often associated with mechanical injuries (Gordon & Williamson, 1991). Pitcher and Webb (1952) stated that though *L. coniothyrium* was the least common fungal species found in midge wounds it caused the most serious damage. Williamson and Hargreaves (1979b) considered the role of *L. coniothyrium* in the midge blight complex to be unclear as it is also responsible for cane blight and then mainly infects through wounds made by abrasion to canes by old stubs, or by frost damage (Labruyère & Engels, 1963). A spraying programme with an insecticide targeting the raspberry cane midge significantly reduced symptoms of striped lesions, which indicates that *L. coniothyrium* is involved in midge blight (Williamson, 1987).

Fig. 7. Primocane likely with a *Leptosphaeria coniothyrium* (cane blight) infection, because of the typical striped symptoms.

2.2.4 Control

2.2.4.a Monitoring

Occurrence of midges in fields can be monitored by several methods, by observing egg-laying in artificial splits in primocanes (Stenseth, 1977), by a temperature model based on accumulated soil temperatures (Gordon *et al.*, 1989), by deploying emergence cages in field (Pitcher, 1952) and by monitoring mature male midges by using pheromone traps (Cross & Hall, 2005).

Stenseth (1977) monitored egg laying in a raspberry field by making artificial splits in primocanes, the splits were examined one week later and eggs were counted. A temperature

model was designed to predict emergence time in spring and it was based on temperature data recorded at a soil depth of 10 cm. The first oviposition of *R. theobaldi* was estimated to occur when the daily accumulated soil temperature reached 339°C days above a base of 4°C. The temperature model is believed to be accurate to ± 5 days (Gordon *et al*., 1989). Monitoring with pheromone traps is now also a possibility as the sex pheromone has been identified and synthesized, though the sex pheromone is only attractive to males (Cross and Hall, 2006).

In 2006 the Swedish Board of Agriculture participated in a ring test organized by Dr. Jerry Cross at the East Malling Research and Prof. David Hall at the Natural Resources Institute, England. The ring test included monitoring with sex pheromone traps and correlating the number of males caught with the number of larvae in artificial splits in primocanes. Monitoring started in the beginning of May and continued to the end of August and artificial splits were made from the middle of June to the end of August (Nilsson, 2007). In 2006 the result from the ring test showed that the population recorded from pheromone traps was substantially smaller than the population of 2007 (Fig. 20). The number of larvae and eggs in artificial splits was also lower and the late recording in 2006 with artificial splits probably missed the first generation.

2.2.4.b Cultural control measures

Removal of the primocanes at the end of May prevented egg-laying of the gall midges during their first flight period and according to Nijveldt (1963), this lead to an important reduction of the gall midge population. Damage by late night frosts were also avoided by removal of the first primocanes. Damage by frost can lead to excessive branching of canes and the development of splits (Nijveldt, 1963). Dalman and Malkki (1986) found that the removal of young canes (15-20 cm) reduced the number of larvae and the amount of fungal lesions.

Fig. 8. Old stubs of canes cause abrasion on primocanes, thus providing infection sites for fungi and oviposition sites for the raspberry cane midge.

2.2.4.c Chemical control

Insecticide control strategies are most commonly confined to target the first generation as the later generations often coincide with harvest (Gordon & Williamson, 1991). Pre-harvest spraying programmes in 1987 with fenitrothion (organophosphorous insecticide) reduced the

number of patch lesions found in sprayed plots compared to unsprayed plots (Williamson, 1987). The use of fungicides to control midge blight has not been successful, probably as numerous fungi are involved and could be responsible for midge blight (Williamson, 1987).

In Sweden, Gusathion (azinphosmethyl, an organophosphorous insecticide) has been used to control the raspberry cane midge, although from 2009 its use will not be allowed anymore. Registered alternatives are different pyrethroid products (Swedish Board of Agriculture, 2007). In Norway the neonicotinoid thiacloprid, called Calypso, is registered. Calypso is effective in June against eggs and small larvae of the raspberry cane midge, according to spraying trials done by Bioforsk, Norwegian Institute for Agricultural and Environmental Research (Jaastad, 2007).

2.2.4.d Natural enemies

2.2.4.d.i Parasitoids

Barnes (1944) observed that some parasitized midge larvae stay in the canes during winter instead of overwintering in the soil. The parasitic wasp found by Barnes (1944) was identified later by Pitcher (1952) as *Tetrastichus inunctus*, which is now thought to be synonymous to *Aprostechus epicharmus* (Vétek *et al.* 2006). This species attacks mainly the first generation of midges. Parasitized midge larva become bloated and black with the parasitoid larva developing inside.

Vétek *et al.* (2006) assessed the parasitisation rate on raspberry cane midge larvae by collecting second-year shoots from May to July. They found that the degree of parasitism ranged from 15 % to 33 % during the growing season. Shoots were examined under a stereomicroscope for the skins of dead larvae, in which some fully fed parasitoid larvae could be observed. *Aprostechus epicharmus*, a chalcidoid species of parasitoid, was proven by Vétek *et al.* to be the principal parasitoid of *R. theobaldi. A. epicharmus* is a widespread species in Europe and is also present in Sweden (Hedqvist, 2003).

A large population of parasitoids can be maintained by avoiding insecticidal sprays during their emergence period, in Hungary this occurred from June to August. By leaving many primocanes uncut over the winter more overwintering locations are provided for the parasitoids, thus a larger starting population in spring time could be possible and lead to a higher parasitisation degree (Vétek *et al.*, 2006).

2.2.4.d.ii Predators

Nymphs of the anthocorid species *Anthocoris nemorum* have been seen feeding on midge larvae in canes, although no noticeable effect on the midge population has been reported (Pitcher, 1952). Barnes (1944) reported a predaceous gall midge belonging to the genus *Lestodiplosis* in canes with raspberry cane midge, but noted that their control effect was small.

2.2.4.d.iii Pathogens

A formulation based on *Bacillus thuringiensis* (var. *israeliensis*), which is pathogenic to dipteran insects, was used by Shternshis *et al*. (2002) to control the raspberry cane midge. Their results indicated that midge blight severity is significantly reduced by applying BT. Antonin *et al*. (1998) did not get an efficient control when applying BT (var. *israeliensis)* against raspberry cane midge larvae in September and they argued that the ineffective control could be due to too low temperature.

Shternshis *et al.* (2002) also used a formulation based on the metabolites of *Streptomyces avermitilis* to control the raspberry cane midge. This formulation also gave a significant reduction in midge blight compared to the control. It had, besides a controlling effect on the raspberry cane midge, a reducing effect on *D. applanata,* a fungus involved both in midge and spur blight.

3 MATERIALS & METHODS

The flight dynamics of the raspberry cane midge was studied during the season of 2007, by deploying pheromone traps in an unsprayed row. The egg and larval development in canes was studied by making artificial splits in primocanes. With the aim to look for a correlation between adult male midges caught in pheromone traps with larval development in splits. Interference between pheromone traps was also studied by deploying traps at a set distance from eachother.

3.1 Raspberry plantation

Trials were conducted in a raspberry plantation situated in the southern part of Sweden, close to Trelleborg. In the plantation four different raspberry cultivars were present, Algonquine, Tulameen, Glen Prosen and Glen Ample. In total about 6 km of raspberries rows were grown and the plantation is divided into four fields. Two wind-breaking nets were placed in the western border and between field 3 and 4. Hedges of an *Alnus sp.* are grown at the borders, between field 2 and 3 and between field 3 and 4. The plantation had problems with wilting of second-year before fruit set. A schematic figure of the plantation is given in Fig. 13.

Fig. 9. Picture showing the raspberry plantation with windbreakers and hedges. The row in the lower left is the Tulameen row in which the artificial splits and the monitoring was made**.**

A weather station (µMetos) was setup in the hedge between field 3 and 4 (O in Fig. 13). The weather station registered temperature and precipitation on an hourly basis. Data was transferred by the MetLink software and the data of the daily average minimum and maximum temperature was used in this thesis.

3.2 Sex pheromone traps

The components of the female sex pheromone have been identified and synthesized by the East Malling Research (EMR) and the Natural Resources Institute (NRI). The racemate of

the major pheromone component 2-acetoxy-5-undecanone are used. A racemate is a mixture of equal amounts of two enantiomers, substances whose molecular structures are mirror images of one another. In this experiment white rubber septa containing 10 μg of the racemate were used. The efficiency of the lures is considered to last in field environment for a month, thus the lures in the trials were replaced at one-month intervals. Lures were placed in white delta traps which measured 20 x 20 cm (Fig. 10). White sticky bases were placed in the bottom of the traps and replaced weekly in the monitoring experiment and twice a week in the interference experiment. Lures with the sex pheromone component were provided by the Natural Resources Institute. Delta traps were provided by AgriSense-BCS Ltd.

3.3 Monitoring with pheromone traps

In a row of the cultivar Tulameen two pheromone traps were mounted ("M" in Fig. 13). The row chosen was not sprayed with insecticides and a protected zone was maintained by keeping neighbouring rows unsprayed also, thus avoiding spray drift. In this row the first primocanes were not eradicated. The two traps were placed in the row 45 metres apart at a height of 0.5 m above the ground. The traps were deployed in the middle of April and the monitoring continued to the beginning of October. The sticky bases of the traps were replaced weekly and the males counted under a stereomicroscope.

An additional trap was hung in the northwestern corner of field 4, where newly established raspberry plants are grown. The trap was hung in a row with Glen Ample and the field was sprayed twice with Gusathion in May.

Fig. 10. Delta trap with rubber septa lure situated in the middle of the sticky base.

3.4 Interference between pheromone traps

Interference between pheromone traps was studied by mounting of five delta traps in a square with a middle trap, i.e. making a dice pattern. Two different sizes of squares were used, one with the outer traps 20 metres apart and one with the outer traps seven metres apart (Fig. 11). Between the two squares there was a control distance of approximately 60 metres.

In addition a single trap was deployed as a control an additional 60 metres from the closest trap. Two sprays of the organophosphorous insecticide, Gusathion, were applied twice before flowering. The overview of the plantation (Fig. 13) shows the distribution of the traps. The interference experiment was started on May the 7th in connection with the sightings of the first generation. The sticky bases were changed if needed in connection to the observations conducted twice a week. Insects were counted by using hand lens or under a stereomicroscope.

A repetition of the interference experiment was conducted when repression of catches were seen in the small square compared to the large square and the control trap. The repetition experiment was set-up in field 3 on the 17th of July. The first interference trial was ended on the 27th of July when some rows were eradicated. The second trial continued until the 20th of September. In total 24 readings of trap catches from the first repetition were made and 17 readings were made from the second repetition.

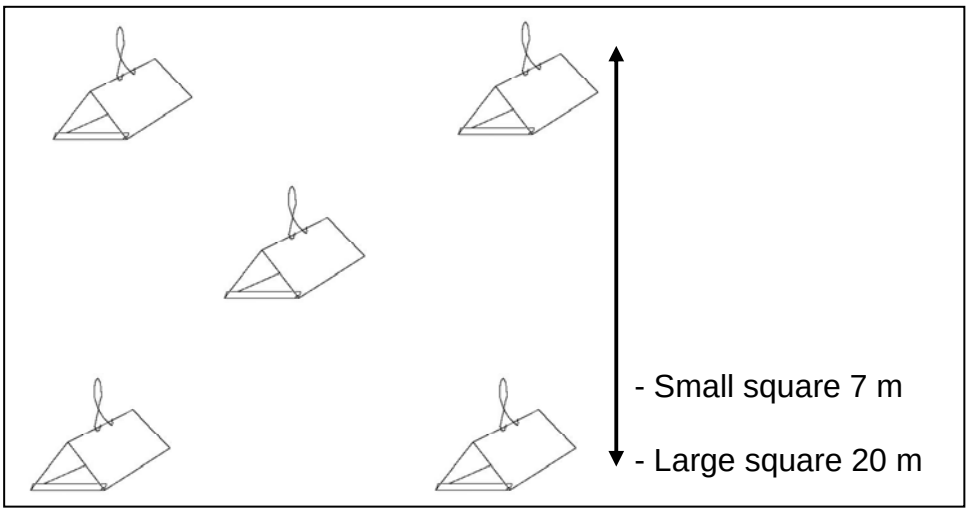

Fig. 11. Set-up of traps for interference trial. Traps were hung in a square, a small one with a 7 metres side and a larger one with 20 metres side.

3.5 Infestations in artificial splits in primocanes

Weekly from the end of May to the middle of September, artificial splits were made in 20 primocanes in the unsprayed row of the variety Tulameen. The trial with artificial splits was not started until enough primocanes of 30-40 cm length were present in the row, which occurred on the 22 of May. Artificial splits of approximately 10 cm were made in the basal part of the canes, by using a sharp needle (Fig. 12). A flap of epidermal tissue was made by holding the needle tangentially. Each week 10 primocanes with one week-old splits and 10 primocanes with two week-old splits were collected and the number of larvae and eggs

counted. Larvae were separated during counting as either being small, translucent turning slightly pinkish or larger, opaque and orange/yellow coloured. The length of each split was recorded subsequently and as a result the number of larvae and eggs per centimetre could be calculated. Counting of eggs and larvae in artificial splits were carried out until egg-laying ceased in September.

Fig. 12. Picture showing an artificial split made on a primocane, dark areas next to the split are evidence of midge infestation

3.6 Statistical analyses

Data from the interference experiment was analysed using a Friedman test to test whether the different traps had given statistical differences in trap catches. The Friedman is a non-parametric analysis of a randomized block experiment. The statistical analyses were conducted in Minitab 14.

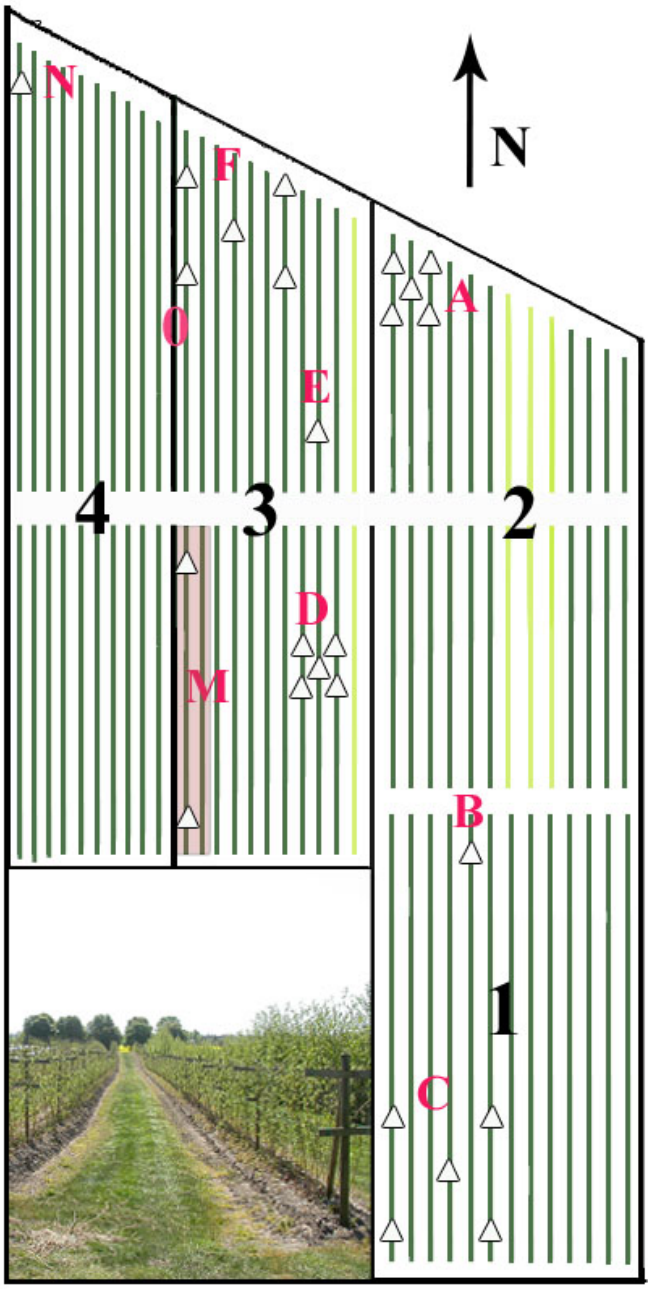

Fig. 13. Schematic figure on the raspberry plantation and the trap placement. The plantation is divided into 4 parts (field 1-4) and dark green lines represent rows with raspberries and light green represent rows with gooseberries. The letters stand for:

A: Interference exp. Small square. Rep.1
B: Interference exp. Single control trap. Rep. 1
C: Interference exp. Large square. Rep.1
D: Interference exp. Small square. Rep. 2
E: Interference exp. Single control trap. Rep.2
F: Interference exp. Large square. Rep.2
M: Row with Tulameen where two traps were hung for monitoring, Pink area = unsprayed area. In this row the artificial splits are also made.
N: Single control trap in field 4 which is newly established.
O: Weather station (µMetos)

4 RESULTS

4.1 Monitoring with pheromone traps

Trap catches from the two pheromone traps in the unsprayed row ("M" in Fig. 13) were monitored throughout the season. One pheromone trap was hung in field 4 in a row with the newly established raspberry plants to monitor the presence of midges. The number of trapped midges was about one-fourth of the amount caught in the unsprayed row in field 3 (Fig. 14). The maximum and minimum temperatures registered on a daily basis from the entire monitoring period are presented to see if the temperature affected the flight of males (Fig. 15). When the temperature peaked in the beginning of June the number of trapped midges decreased simultaneously.

The first male midges were trapped in the end of April in the two monitoring traps and the first males in the newly established field were caught two weeks later. Flight of male midges occurred throughout the season and peaked in the middle of August with over 500 male midges trapped in one trap in one week. Several peaks of trap catches could be seen from the two monitoring traps and three in the trap of the newly established field. In the newly established field the trap catches were one-fourth of the mean trap catches from the two traps in the older and unsprayed row.

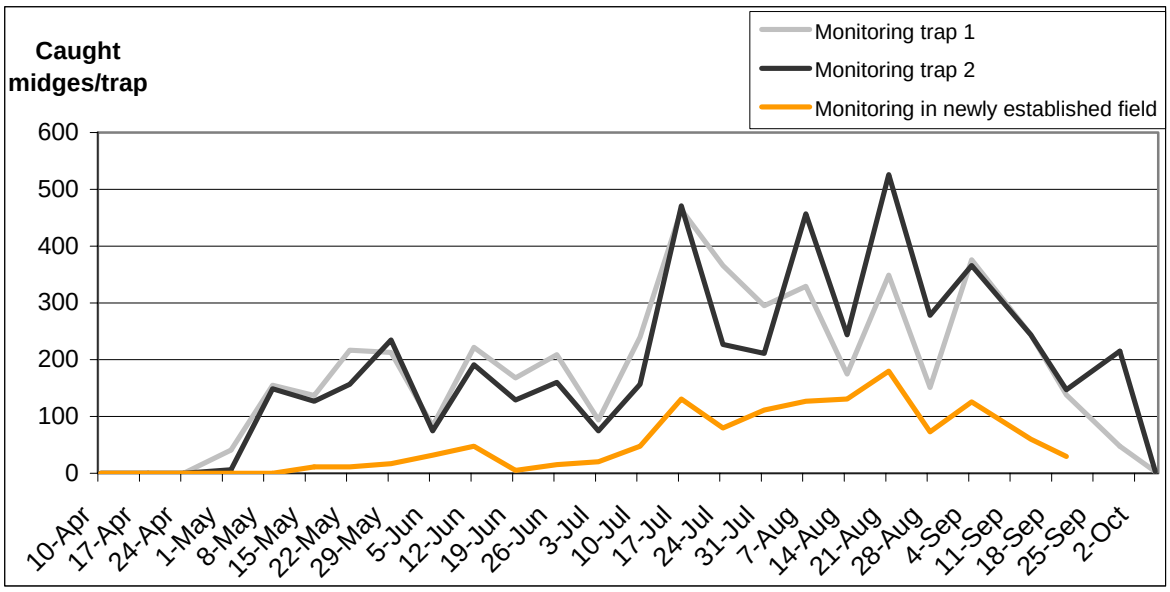

Fig. 14. Graph showing recorded trap catches from April until October from the two monitoring traps in the unsprayed row and the one in the field with newly established raspberry plants**.**

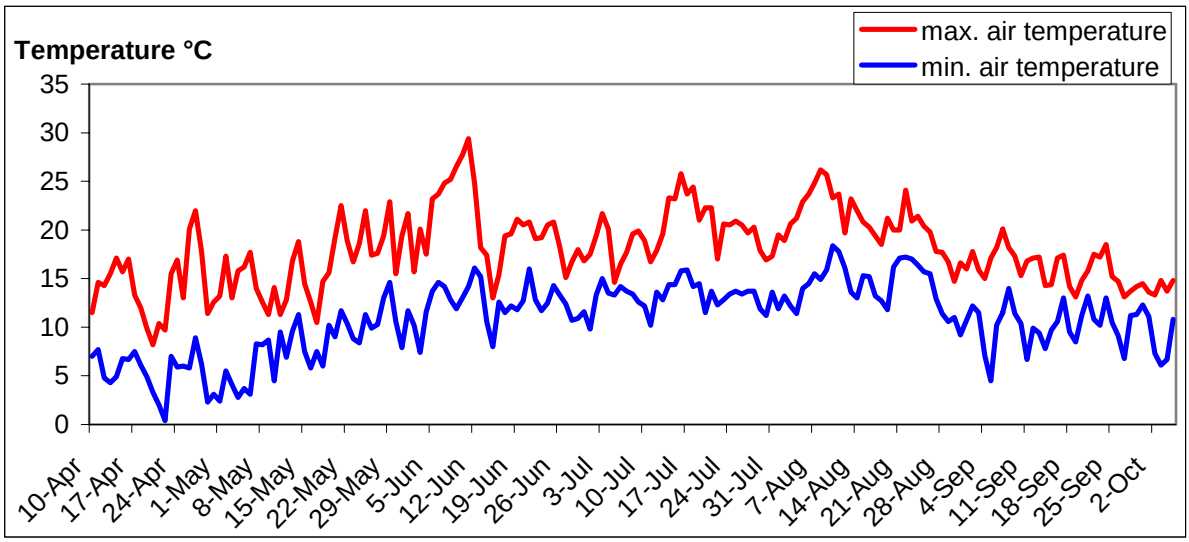

Fig. 15. Daily maximum and minimum temperature registered during the season.

4.2 Interference experiment

Interference between traps in the square pattern was analysed by the non-parametric Friedman test. The test results indicate that there were statistical differences between the number of caught midges in the middle traps of the two square sizes and the single control traps in both replicates (rep.1: p=0.002, rep.2: p=0.018). Fig. 16 shows the mean number of trapped midges in the control trap and the two middle traps in a graph.

The differences between trap catches of the four outer traps in each square were also analysed with the Friedman test to see if the trap catches differed significantly (Table 2). The results from the test showed that trap catches all differed significantly except in square F, which was the large square in the second repetition.

Table 2. The results from the statistical test where the differences in trap catches of the outer traps in the squares are analysed. All gave significance difference in trap catches except for square F.

Treatment	**Small square (A) (rep. 1)**	**Large square (C) (rep. 1)**	**Small square (D) (rep. 2)**	**Large square (F) (rep. 2)**
Mean, outer traps	- 13,6 - 19,3 - 8,8 - 25,1	- 8,4 - 10,5 - 30,1 - 37	- 42,9 - 53,5 - 72,1 - 59,3	- 55 - 63,8 - 73,8 - 55,3
Statistical difference	p= 0.001	p= 0.000	p= 0.011	p= 0.508

In the rows where the first replication of the interference experiment was conducted it could be observed that traps with low trap catches were hung in plants that showed symptoms of virus or were of poor vigour. When these effects became clear the square of traps were moved a few meters to healthier plants. This was the case for square A and C, as these traps were placed early in the season before symptoms had occurred.

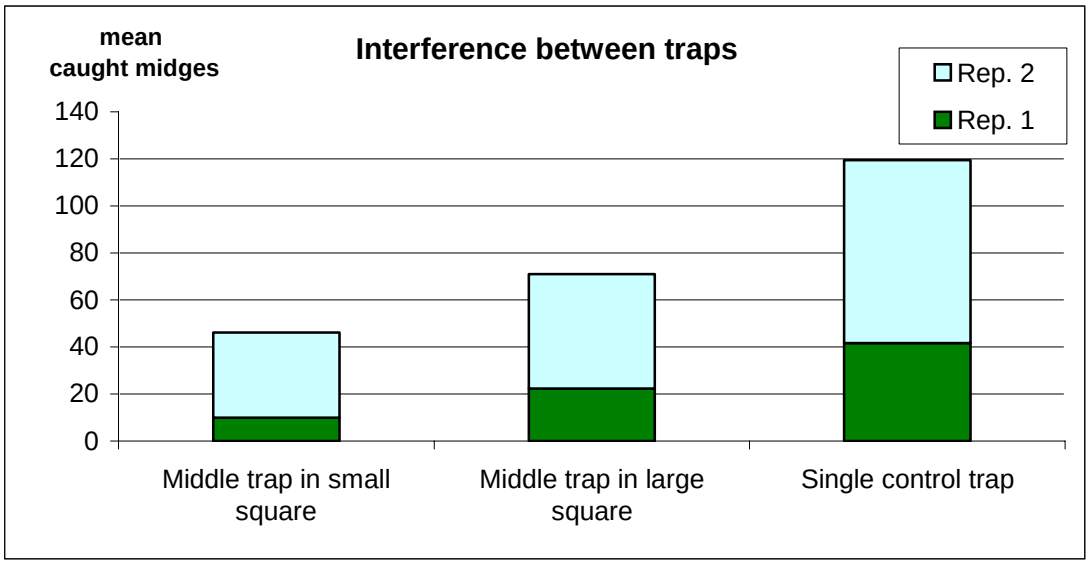

Fig. 16. The mean caught midges from the middle trap in the two squares are significantly lower than the trap catch from the single control trap. The middle trap in the small square caught the least number of midges.

The trap catches from the traps in the interference experiment were recorded twice a week and the recordings show three periods that could correspond to three generations: the first from late May to mid June, the second from mid July to the end of July, the third occurring in August (Fig. 17, Fig. 18).

Two sprays of the insecticide Gusathion (azinphosmethyl) were made on the 16th and 28th of May with the result of a fast decrease in the amount of caught male midges after the second application, see Fig. 17.

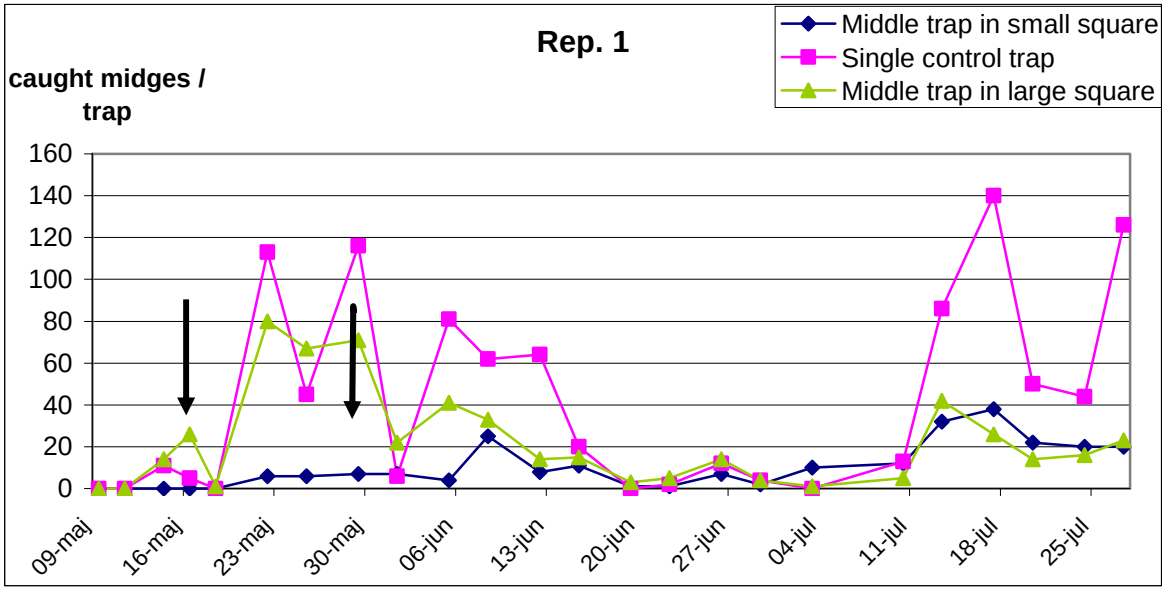

Fig. 17. Trap catches from the interference experiment repetition 1 that was carried out from May until end of July. The two arrows indicate the two applications of Gusathion.

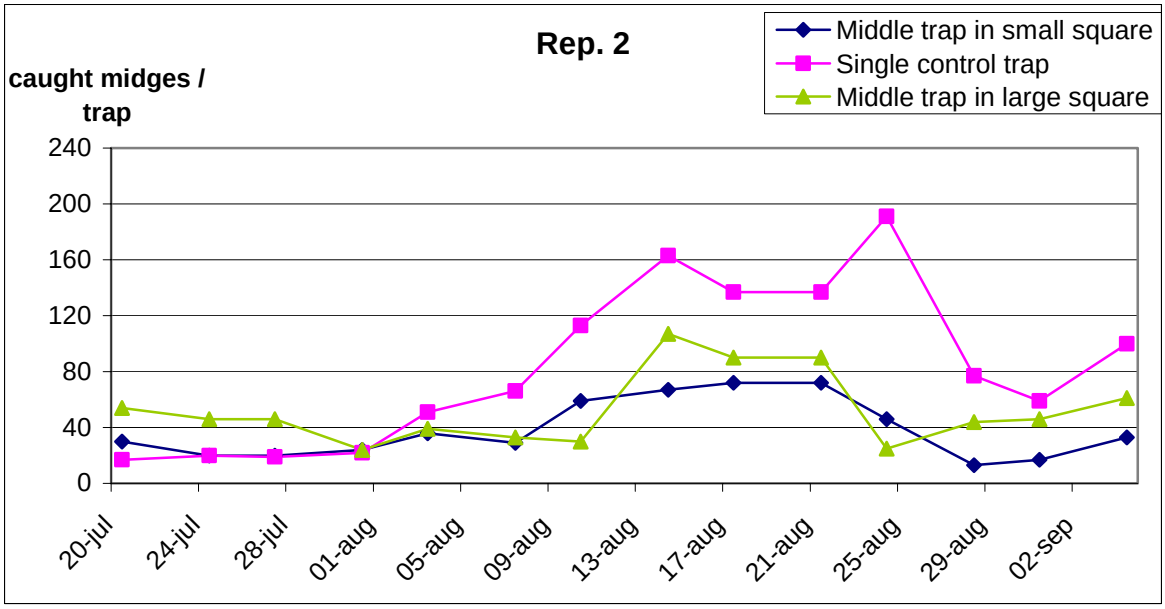

Fig. 18. Trap catches from the second repetition of the interference experiment, which was carried out from July until September.

4.3 Artificial splits in primocanes

Most infestations in splits were found in the middle of the summer in June and July. The cultivar Tulameen developed primocanes slowly in the spring, thus the oviposition places for the midges emerging in May are few. The number of larvae and eggs in splits peaked in July with 12 eggs and larvae per cm split.

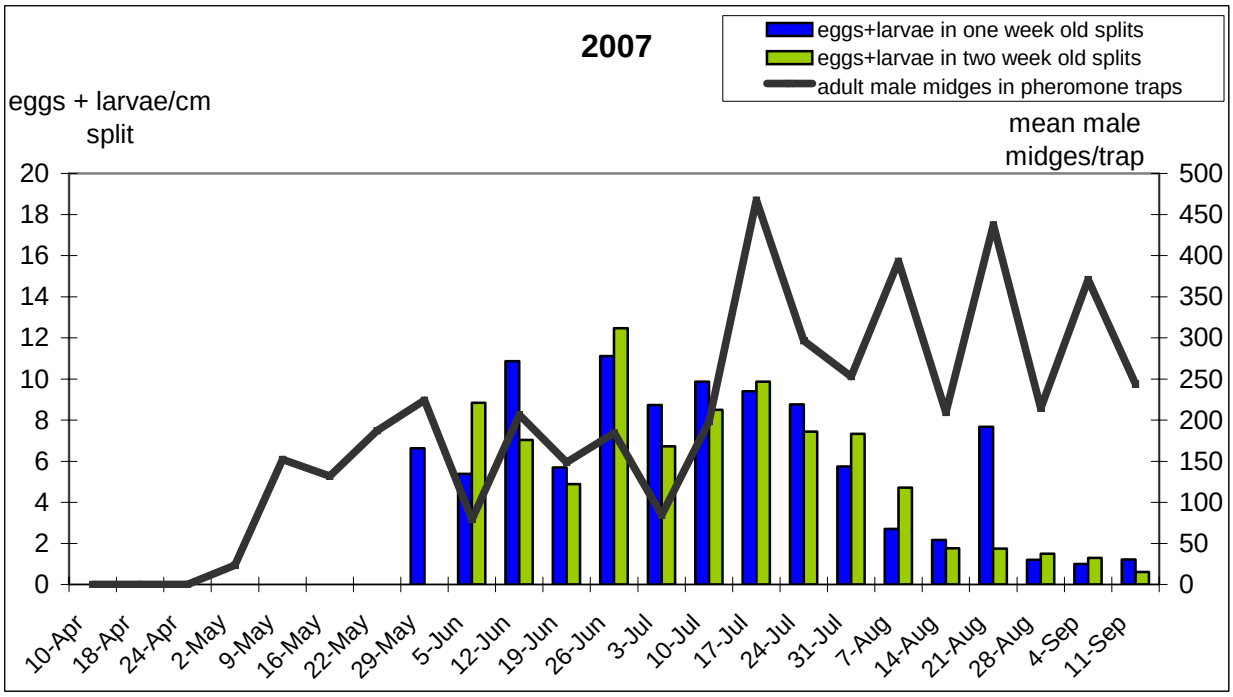

Fig. 19. A plotted graph with bars representing the number of larvae and eggs found in one and two week old splits in the experiment done in 2007. The line represents the mean trap catch during the season from the two monitoring traps.

The number of larvae found in the artificial splits was compared with the number of trapped male midges (Fig. 19). One interesting observation is that the high number of trapped male midges in August did not lead to a large amount of larvae and eggs in splits.

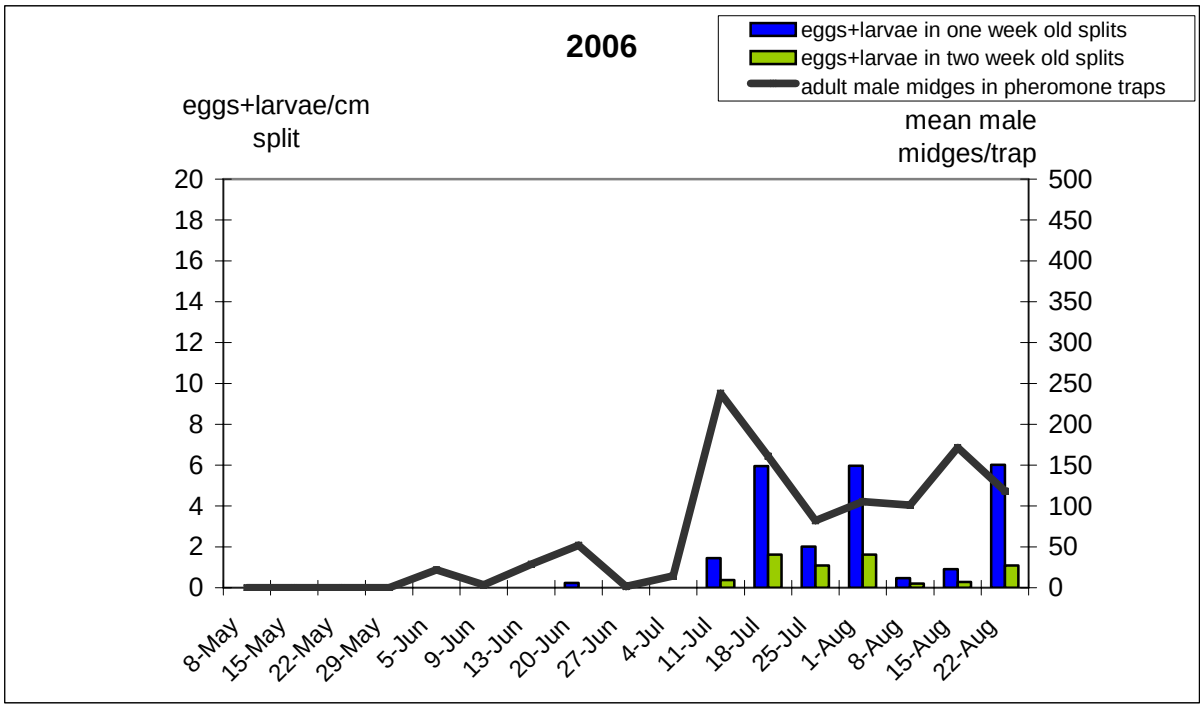

Fig. 20. The result from the ring test in 2006 (Nilsson, 2007). The line represents the mean trap catch in pheromone traps and the bars the number of eggs and larvae in artificial splits.

Fig. 22. Anthocorid nymph feeding on raspberry cane midge larva.

Fig. 21. Predatory gall midge feeding on a raspberry cane midge larva**.**

In July predatory gall midge larvae were found in splits with raspberry cane midge larvae (Fig. 21). Predating anthocorid nymphs were also found in splits from the beginning of August and forward (Fig. 22).

5 DISCUSSION

5.1 Midge monitoring and artificial splits

The number of trapped midges in the monitoring pheromone traps did not show evidence of clearly separated generations during the season. Stenseth (1977) noted that midges emerging from overwintering showed an asymmetrical and a prolonged emergence period, which could be the reason why the first generation is hard to distinguish from the second. By comparing the result from the monitoring traps 2006 and 2007 and the trap catches from the interference experiment three generations could be distinguished. The difficulties with distinguishing the different generations could be explained by another experiment done by Stenseth (1972) where he showed that a lower temperature increased the time frame of emergence. Traps deployed in tunnels or in warmer climate could give trap catches that show more distinctive generations and thereby a good timing of insecticidal control would be easier to achieve.

The presence of larvae and eggs in artificial splits did not increase with the male midge population in the pheromone traps from July and onwards. Therefore it could be argued that artificial splits are not a reliable measure of the magnitude of the population present in a plantation. Gunn and Foster (1978) discussed that the first artificial splits could make out the majority of splits present in spring. Therefore the number of larvae in these will not be representative for the population distribution in the plantation. They also discussed that a small number of larvae later in the season could be a result of dilution as more natural splits are available and not represent a smaller population present in the plantation. I think the dilution effect of a higher presence of splits is very likely causing the smaller number of larvae and eggs found in artificial splits later in the season.

In the splits predatory gall midge larvae and anthocorid nymph were found from August and onwards. This predation is also a contributing factor to the lower amount of larvae present in late season splits.

5.2 Pheromone trap interference

From the interference experiment it could be seen that traps situated in near vicinity of each other affect the number of caught male midges. The reason to the low trap catches could be mating disruption or more likely competition between traps. Cross (2007) has made several

experiments on mating disruption and raspberry cane midge with the result that the number of males trapped was minimized but still larvae were found in splits.

5.3 Control methods

Control of the raspberry cane midge is difficult due to the sheltered place in which larvae feed and the long emergence time of adult in spring time, which makes correct timing of insecticides harder. The short life span of adults (ca. 3 days) is another difficulty to the correct timing of control. Raspberry cane midge larvae have the ability to survive seasons with poor weather by going into diapause in the soil. The increase in temperature in Sweden by global warming could lead to a prolonged season and thus an increase of midge generations per year. There are few insecticides available in Sweden that efficiently can control the raspberry cane midge. Calypso, a neonicotinoid, could be an option if it gets registered in Sweden

Both artificial splits and pheromone traps are methods that could successfully be used to establish if the raspberry cane midge is present in a plantation or not. Damage of raspberry cane midge is most obvious the year after the larval feeding when the plant vigour is declining. These symptoms could be difficult to correlate to the presence of raspberry cane midge if not methods of detection like artificial splits and pheromone traps are used.

The use of eradication of the first flush of primocanes in spring is a control method used to decrease the number of oviposition places for the first midge generation. A complete eradication of first-year canes would force oviposition on second-year canes, on which Stenseth (1977) noted the number of larvae maturing to be few. Achieving a complete eradication of primocane is very hard and would require a very efficient herbicide and good application technique. The consequence of a failed eradication would be damaged primocanes with more wounds for midges to oviposit in.

Williamson and Hargreaves (1979a) stated that large canes are often more infested by midge larvae and the avoidance of saving these canes for harvest next year could lower the amount of damaged canes the subsequent season.

I think the most useful cultural control method is to use varieties that stand the Swedish climate well and that develop few natural splits. Tulameen is a variety in my opinion that is not suitable to be grown in open field in Sweden as it is sensitive to wind and has a low frost tolerance, which leads to more damaged primocanes and more possible feeding places for raspberry cane midge larvae.

5.4 Suggestions on continued research

- An investigation on soil coverage in spring time could be conducted with a material that will hinder the midge from emerging or by changing the upper soil environment to unfavourable conditions for the midge.
- The first generation of midges could be controlled by reducing the number of splits early in the season by designing methods that would make the primocane eradication in spring time more efficient.
- Mating disruption as a control could perhaps prove to be more successful when conducted closer to the soil surface as the midges appear to stay very close to the ground.
- It would be interesting to compare flight patterns of male midges in tunnels to open field by recording trap catches in pheromone traps. With the hypothesis that the first generation will emerge under a shorter period of time in protected conditions, thus making the control easier.

6 CONCLUSION

Raspberry cane midge is a serious pest of raspberries as an efficient control is difficult to achieve due to the protected feeding place of larvae, the short life span of adults and the long emergence time in spring. From the trials made in 2007 it could be concluded that flight activity of male raspberry cane midges occur from early May until October and three generation could be seen. The largest trap catches were observed in August with almost 500 midges trapped in one trap in one week. Pheromone traps situated in the near vicinity of each other affect the result of the trap catches. In this thesis it was shown that a reduction of trap catches took place when traps were hung at a distance of 7 and 20 metres apart compared to using a single control trap.

The highest amount of eggs and larvae in artificial splits were seen in July. The reduction of larvae in the artificial splits in August is probably due to the higher amount of natural splits present in the field and the increased predation by natural enemies. No correlation between trap catches in monitoring traps and the number of eggs and larvae found in artificial splits could be seen.

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