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Review

Integrating parasitoids into management of pollen beetle on oilseed rape

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Abstract. Hymenopterous parasitoids can exert substantial natural control on oilseed rape pest populations. This paper reviews recent work at Rothamsted Research on integrating parasitoids into the management of rape pests. It focuses on the pollen beetle, *Meligethes aeneus*, and its two larval endoparasitoids, *Phradis interstitialis* and *Tersilochus heterocerus.* Strategic research on the behavioural ecology of the parasitoids is described. *Phradis interstitialis* was shown to use upwind anemotaxis to locate the crop. Within-field spatio-temporal distributions of *M. aeneus* adults and larvae were complex with irregular patterns of aggregation. Whereas *P. interstitialis* was closely associated temporally and spatially with the distribution of its host, *T. heterocerus* larvae were as abundant outside dense host patches as within them and showed little pattern. Both parasitoid species overwinter in the soil of the rape field and emerge the following spring. Post-harvest soil cultivations, particularly ploughing, can reduce their survival, whereas non-inversion tillage is less harmful. Phenological studies show that pyrethroid applications during flowering threaten parasitoid populations. Implications of the research for conservation biological control and the development of more environmentally-friendly crop protection is discussed.

Key words: *Meligethes aeneus*, parasitoids, conservation biological control

INTRODUCTION

Meligethes aeneus, the pollen beetle, is a major pest of oilseed rape throughout Europe (Alford et al., 2003). The recent development of resistance to pyrethroids in *M. aeneus* (Hansen, 2003) has made more urgent the need for control strategies that minimise insecticide use and optimise biological control (Williams, 2004; Williams et al., 2005). This paper reviews recent work at Rothamsted Research, undertaken within the EU-funded project MASTER (Williams et al., 2005), on integrating parasitoids into the management of *M. aeneus*. It focuses on two parasitoid species: *Phradis interstitialis* and *Tersilochus heterocerus*. These are the most widespread and abundant of the nine species that attack *M. aeneus* in Europe (Nilsson, 2003; Williams et al., 2005). Both are ichneumonid larval endoparasitoids and, like their host, are univoltine. Strategic research on their behavioural ecology and how crop husbandry practices can be modified to enhance conservation biological control is described.

Phenology of spring emergence

Both *P. interstitialis* and *T. heterocerus* overwinter as diapausing adults within host cocoons in the soil of the field of the former oilseed rape crop. They emerge in the spring.

To monitor the phenology of spring emergence, emergence traps (each 0.5 m^2) were placed on winter wheat, established after winter rape and the numbers of parasitoids caught weekly were recorded.

In both years, first and last emergence dates for *P. interstitialis* were earlier than those for *T. heterocerus* (Table 1); *P. interstitialis* emerged during the second half of April in 2004 but from early April to late May in 2005, whereas *T. heterocerus* emerged during the second and third weeks of May in 2004 but from late April to early June in 2005. The more extended emergence in 2005 compared with 2004 probably reflected the more intensive sampling and a greater population of parasitoids in 2005.

Table 1. Total numbers and dates of first and last *P. interstitialis* and *T. heterocerus* adults to emerge into emergence traps placed on winter wheat (following winter rape) at Rothamsted Research in 2004 and 2005.

		P. interstitialis			*T. heterocerus*		
	No. of traps	First caught	Last caught	Total no. caught	First caught	Last caught	Total no. caught
2004	10	16 April	30 April	120	7 May	21 May	17
2005	30	6 April	25 May	1739	27 April	1 June	1005

Crop location

Oilseed rape is grown in rotation with cereals, usually in a different field each year. Consequently, on emergence in the spring, the parasitoids must locate a new crop of oilseed rape to find their host larvae.

To investigate how the parasitoids locate the crop and how wind direction influences the direction of their flight, a circular plot (20 m diameter) of winter rape was encircled, 5 m from its circumference and in different compass directions, by eight double-sided Malaise traps (Williams et al., 2006). A meteorological station close to the plot measured wind direction and wind speed. The parasitoids trapped in the outer halves of the traps, relative to the crop, from mid-April to late May, were counted. The traps were ranked in order of decreasing numbers of parasitoids caught per day and again in order of decreasing air flow per day, and the ranks compared using Spearman's Rank Correlation.

Numbers of *P. interstitialis* caught in the traps (totals of 20–167 per day) were sufficient for Spearman's Rank Correlation analyses on six days. On these days, maximum air flow was into the SE, S or SW traps, whereas maximum parasitoid catch was into the NW, NE, N, E or W traps. All correlations were negative (r_s = -0.56 to 0.95), significantly so ($P < 0.01$) on 3 of the 6 days.

This study confirmed that *P. interstitialis* uses upwind anemotaxis to locate the rape crop within the arable landscape. The upwind flight is probably in response to odour cues released from the rape plants. Understanding the effect of wind direction on the flight of parasitoids to winter rape holds potential for improving the precision of forecasting their arrival and their spatial distributions on the crop. It also holds potential for manipulating and enhancing their populations for integrated pest management strategies that aim to incorporate conservation biological control. Parasitoid populations on a crop may be increased if the new crop is sited close to and downwind of that of the previous year, to encourage upwind immigration flights by parasitoids towards it.

Phenology on the crop

Insect sampling in winter rape crops over three consecutive years, by yellow water traps emptied three times per week, showed that *M. aeneus* and its two parasitoids arrive on the crop in succession (Table 2).

Table 2. Date, with crop growth stage (according to Lancashire et al., 1991) in parentheses, of first and peak capture of *M. aeneus* and its parasitoids, *P. interstitialis* and *T. heterocerus* in yellow water traps on winter rape at Rothamsted Research in 2003-5.

Year	*M. aeneus*		*P. interstitialis*		*T. heterocerus*	
	First caught	Peak catch	First caught	Peak catch	First caught	Peak catch
2003	17 March (42)	26 March (52)	18 April (61)	05 May (66)	28 April (64)	05 May (67)
2004	16 March (16)	23 April (63)	16 April (60)	23 April (63)	03 May (65)	07 May (67)
2005	21 March (54)	04 April (61)	30 March (59)	25 April (67)	25 April (67)	09 May (70)

First capture of *M. aeneus* was during the second half of March at green bud (GS 51-54), that of *P. interstitialis* was from late March to mid-April at yellow bud/first flower (GS 59-61) while that of *T. heterocerus* was from late April to early May at mid-flower of the main raceme (GS 64-67). Peak numbers of *M. aeneus* were from mid-March to early April at late green bud to early flower (GS 52-63), of *P. interstitialis* from late April to early May at mid-flower of the main raceme, and of *T. heterocerus* in early May at late flower of the main raceme (GS 67-70). Both pest and its parasitoids continued to be caught throughout the flowering period of the crop.

Dates of first recorded emergence from overwintering sites (Table 1) and first recorded arrival on crops in 2004 and 2005 (Table 2) were within 0–7 days of each other, that is, almost simultaneously taking into account sampling frequency. The sequential arrival of the two parasitoid species and their phased activity on the crop accords with their known biology and that of their host. *Meligethes aeneus* feeds and lays its eggs in the buds; its larvae have two instars that feed on pollen in the flowers (Alford et al., 2003). *Phradis interstitialis* oviposits into the eggs and first instar larvae of *M. aeneus* and thus searches for its hosts in the buds of oilseed rape. By contrast, *T. heterocerus* oviposits into second instar larvae and searches for its hosts in open flowers (Nilsson, 2003).

Spatial distributions on the crop

The spatial distributions of oilseed rape pests, including *M. aeneus* and its parasitoids (Ferguson et al. 2003), on a crop of winter rape at Rothamsted Research have recently been described. Insects were sampled from 40 spatially- referenced points within the field. Spatial Analysis by Distance IndicEs and a randomisation procedure were used to describe and compare the patterns of distribution across time and between species.

The distributions of both *M. aeneus* adults and larvae were found to be complex with irregular patterns of aggregation. Both were clustered in the north-eastern half of the field and were significantly associated. The distribution of *P. interstitialis* larvae was closely associated with that of its host larvae, whereas, by contrast, that of *T. heterocerus* eggs showed little pattern, being spread evenly across the field.

Knowledge of the spatial patterns of insect distribution within crops could help optimise the integration of insecticides and parasitoids into IPM strategies for the crop. Insecticides can seriously reduce parasitoid survival. Disparities in the within-crop spatial distributions of a pest and its parasitoid enable treatments to be targeted at pest populations, minimising impact on the parasitoid. In this case, spatial targeting of insecticides against patches of *M. aeneus* would help conserve the more evenly distributed *T. heterocerus* but not the more closely associated *P. interstitialis.*

Parasitisation rates

Mature *M. aeneus* larvae, whether parasitized or not, drop from the flowering canopy to the soil below to pupate. Densities of larvae dropping from the canopy of crops not treated with insecticide, can be high but variable from year to year (Table 3).

Table 3. Numbers and percentage parasitism of mature *M. aeneus* larvae from winter rape at Rothamsted Research, not treated with insecticide.

Year	No. of *M. aeneus* larvae/m^2	% parasitized (*n*)	% parasitized by	
			P. interstitialis	*T. heterocerus*
1999	1597	24 (4875)	24	11
2003	2374	62 (500)	61	38
2004	-	97(300)	95	20
2005	1222	26 (300)	17	5

Both *P.interstitialis* and *T. heterocerus* are koinobionts, so their host larva continues to develop with the parasitoid inside. The percentage of mature larvae that are parasitized can be determined by dissecting them to find the black eggs of *T. heterocerus* or the small larvae of *P. interstitialis* (Nilsson, 2003). Their relative importance varies with season, but can be very high in some years, for example, 97% in 2004 (Table 3). Multiparasitism, that is, host larvae with more that one species of parasitoid is common but only one parasitoid develops to adult within each larva. So, *P. interstitialis* and *T. heterocerus* are essentially competitors. Superparasitism, that is, host larvae with > 1 egg or larva of the same species is common with *T. heterocerus* but not with *P. interstitialis.* Together, *P. interstitialis* and *T. heterocerus* can exert substantial natural control on *M. aeneus*.

Crop husbandry for conservation biological control

Research suggests that there is potential to enhance conservation biological control by modifying some current crop husbandry practices to promote the survival of natural populations of key parasitoids.

Standard management of pests on winter rape throughout Europe still relies heavily on the application of insecticides. Application is often prophylactic without regard to pest incidence. It can involve at least three pyrethroid treatments targeted against different pests: firstly against *P. chrysocephala* in the autumn, secondly against *M. aeneus/C.*

pallidactylus at green bud, and thirdly against *C. assimilis/D. brassicae* at the end of flowering of the main raceme. As phenological studies have shown, application of insecticide against *M. aeneus* at green bud is before the main arrival of *P. interstitialis* (at yellow bud) or *T. heterocerus* (at mid-flower of the main raceme). However, any applied at the end of flowering of the main raceme coincides with peak incidence of both parasitoids on the crop, when they are still actively ovipositing into host larvae in buds and flowers and are most vulnerable to insecticide. Application of insecticides also risks development of insecticide resistance in target pests, already a problem on mainland Europe (Hansen, 2003).

In current best practice, insecticide is applied only when threshold values of pest numbers on the crop have been exceeded (Williams, 2004). In the UK, for example, the threshold for application of insecticide against *M. aeneus* is five beetles per plant on conventional cultivars and one per five plants on composite hybrid cultivars. However, this threshold considers only the number of pests present and not the numbers of parasitoids able to exert control. Where parasitoids are abundant, there is potential to raise the thresholds as the crop should be able to tolerate more pests before sustaining economic damage and requiring insecticide treatment. Temporal and spatial targeting of insecticides also have potential to minimize parasitoid mortality (Ferguson et al. 2003). Ideally, if only part of the *M. aeneus* population were killed by insecticide application without harming the parasitoid population, the parasitoid to host ratio would be increased, enhancing biological control of the pest.

Soil cultivations following harvest of the winter rape crop, can affect the survival of parasitoids that overwinter in the soil (Nilsson, 2003). Overwintering survival following ploughing can be poor. For example, in one study, although 24% of *M. aeneus* larvae were parasitized by *P. interstitialis* and *T. heterocerus*, fewer than 2% of either parasitoid survived overwinter to emerge as adults the following spring (Ferguson et al., 2003).

Table 4. Numbers of parasitoids/2.5 m^2 that emerged in 2004 and in 2005 after overwintering in plots at Rothamsted Research that had received different insecticide treatments to the oilseed rape and different tillage post-harvest. (i0 no insecticides, ie insecticides to pest economic thresholds, ii insecticides prophylactically).

	2004		2005					
	Ploughed	Minimum tillage	Ploughed			Minimum tillage		
	ii	i0	i0	ie	ii	i0	ie	ii
P. interstitialis	1	119	213	556	58	179	682	51
T. heterocerus	3	14	193	251	71	169	285	36
Totals	4	133	406	807	129	348	967	87

Recent work to develop pest management strategies incorporating parasitoids has compared the overwintering survival of parasitoids under different inputs of insecticide to the winter rape and different soil cultivation practices post-harvest (Williams et al., 2005; Nilsson et al., 2006). Results from two experiments at Rothamsted Research are given in Table 4. Winter rape plots received either no insecticide, insecticide only when pest economic thresholds were exceeded or insecticide prophylactically (three treatments). Winter wheat was established following the winter rape, either by ploughing, harrowing and drilling or by minimum non-inversion tillage at drilling only. The spring emergence of the *P. interstitialis* and *T. heterocerus* was monitored using emergence traps.

In 2004, 33 times more parasitoids emerged from the plot that received no insecticide and minimum tillage than from the plot that received three insecticide treatments and was ploughed post-harvest (Table 4). In 2005, parasitoid emergence was reduced 3- fold on the ploughed plot and 4-fold on the min-till plot by three insecticide applications compared to none. However, in 2005, overall survival on min-till plots was only 4% greater than on ploughed plots. Further replicated trials on the effects of soil tillage are under way at Rothamsted Research.

CONCLUSIONS

Phradis interstitialis and *T. heterocerus* are important parasitoids of *M. aeneus*. There is potential to enhance their effectiveness in conservation biological control by crop siting to encourage immigration, spatio-temporal targeting of insecticides and soil cultivation post-harvest.

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