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Effect of trap type and height in monitoring the orange wheat blossom midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae) and its parasitoid, *Macroglenes penetrans* (Kirby) (Hymenoptera: Pteromalidae)

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ABSTRACT

The orange wheat blossom midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae), is a common pest of wheat that is frequently parasitized by *Macroglenes penetrans* (Kirby) (Hymenoptera: Pteromalidae). Both species need to be detected and quantified using a reliable monitoring system to assess the risk for wheat crops and, if necessary, determine the timing of insecticide treatments in order to ensure their efficiency against the pest and prevent adverse side-effects on beneficial insects. Four trap types, placed at 0.6 m above ground level, were compared for their efficiency in catching *S. mosellana* and *M. penetrans*: yellow sticky traps, white sticky traps, yellow water traps and pheromone-baited traps. For the pheromone-baited and yellow water traps, three heights (0.2, 0.6 and 1 m above ground level) were tested. For *S. mosellana*, the pheromone-baited trap was the most efficient and 0.2 m was the best height. In non-source fields with important flights of immigrant female midges, however, yellow water traps could be more efficient than pheromone-baited traps, capturing males almost exclusively. For *M. penetrans*, the most efficient traps were the sticky and yellow water traps and the best height was 0.6 m. These relative efficiencies of traps and height positions were clearly related to differences in flight behavior between the species and between the sexes.

1. Introduction

The orange wheat blossom midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae), is a common pest of wheat (*Triticum aestivum* L.) throughout the northern hemisphere. This univoltine species overwinters in the soil as cocooned larvae and, each spring, a proportion of these larvae pupate, after which the adults emerge and mate at the emergence site (Barnes, 1956; Pivnick and Labbé, 1992). The mated females fly in search of host plants at susceptible growth stages (i.e., from ear emergence until the end of flowering) in order to lay their eggs on the spikes (Ding and Lamb, 1999; Oakley et al., 1998). The eggs hatch a few days later and the larvae feed on the developing kernels, causing damage and shriveled grain (Reeher, 1945). After the feeding period, the larvae drop to the ground, burrow into the soil, spin a cocoon and enter into diapause (Barnes, 1956).

Populations of *S. mosellana* are commonly parasitized by an ovo-larval endoparasitoid, *Macroglenes penetrans* (Kirby) (Hymenoptera: Pteromalidae), which is an important natural control agent of this pest (Affolter, 1990; Doane et al., 1989). Several studies have shown the beneficial action of *M. penetrans* to regulate *S. mosellana* populations (Affolter, 1990; Barnes, 1956). This parasitic wasp emerges at the same time as its host, or a few days later (Affolter, 1990; Chavalle et al., 2015a; Doane and Olfert, 2008; Elliott et al., 2011; Ellis et al., 2009). The female wasp lays an egg inside the egg of its host. Despite the presence of this parasitoid, the midge larva completes its development and overwinters in the soil. In spring, *M. penetrans* completes its development in the midge larva, consumes its host and emerges as an adult wasp (Affolter, 1990; Doane et al., 1989).

Attacks by *S. mosellana* can significantly reduce wheat yield (Chavalle et al., 2015b) and the quality of harvested grains (Dexter et al., 1987), but they also facilitate secondary fungal infections (Oakley, 1994). In Europe, important outbreaks causing significant damage have been reported in the United Kingdom (Oakley, 1994; Oakley et al., 2005), Germany (Gaafar et al., 2011), France (Rouillon et al., 2006) and Belgium (Chavalle et al., 2015b). Several studies have estimated the yield loss at about 100 kg/ha for a density of one larva

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per ear (Kurppa and Husberg, 1989; Oakley et al., 1998; Olfert et al., 1985; Rouillon et al., 2006). In the United Kingdom, crop losses exceeded £30 million in 1993 (Oakley, 1994) and £60 million in 2004 (Oakley et al., 2005). Damage due to this pest is not observed every year because it depends on the coincidence between flights and susceptible growth stages of wheat, but also on weather conditions conducive to adult midge flight and egg laying. The damage level is often underestimated because the adult midges are small and remain hidden in the crop canopy during the day and the larvae are covered by the wheat ear's envelopes (Lamb et al., 2002; Pivnick and Labbé, 1993). The difficulties in detecting *S. mosellana* complicate decisions on when to apply insecticide treatments against this pest. For farmers, it is necessary to use a reliable monitoring system for assessing the risk to their wheat crops in order to determine the timing of insecticide treatments and to avoid applying useless insecticide treatments (no coincidence between flights and susceptible growth stages of wheat, low infestation level). A reliable monitoring system would also help to preserve the parasitoids that act as biological control agents on the *S. mosellana* populations.

To detect and monitor *S. mosellana* flight patterns in order to evaluate the potential risk for wheat crops, a reliable monitoring system must use traps with highest sensitivity. Until the early 2000s, the traps used as warning system to detect *S. mosellana* and monitor its flights were unbaited traps, such as emergence traps (Affolter, 1990; Elliott et al., 2009; Ellis et al., 2009), yellow water traps (EPPO, 2007; Rouillon et al., 2006) and colored sticky traps (mainly yellow) (Affolter, 1990; Ellis et al., 2009; Knodel and Ganehiarachchi, 2008; Lamb et al., 2002; Oakley and Smart, 2002). In the early 2000s, the identification of the sex pheromone of *S. mosellana* as (2*S*, 7*S*)-nonadiyl dibutyrate (Gries et al., 2000) led to the development and commercialization of a pheromone trap (Bruce et al., 2007; Mircioiu, 2004). This pheromone-baited trap was a precise tool for flight monitoring and has been used in several studies on *S. mosellana* throughout the world (Ellis et al., 2009; Gaafar and Volkmar, 2010; Jacquemin et al., 2014; Knodel and Ganehiarachchi, 2008; Liatukas et al., 2009; Li et al., 2011). For monitoring *M. penetrans*, the main parasitoid of *S. mosellana*, only unbaited traps were available. In wheat fields, emergence traps (Affolter, 1990; Elliott et al., 2011; Ellis et al., 2009) and sticky traps (Affolter, 1990; Oakley and Smart, 2002) were used.

In our study, flights of *S. mosellana* and *M. penetrans* were monitored in a winter wheat field in order to compare (i) the capture efficiency of four trap types (yellow sticky, white sticky, yellow water and pheromone-baited traps) at 0.6 m above ground level, (ii) the capture efficiency of pheromone-baited traps and yellow water traps at three heights (0.2, 0.6 or 1 m above ground level) and (iii) the ability of the pheromone-baited trap and yellow water traps to capture males and females at three heights.

2. Materials and methods

2.1. Field trapping experiments

The experiments were conducted in 2011 and 2013 at Gembloux (50°34′29″N, 4°44′29″E) in Belgium. Gembloux is in an important cereal-growing region with deep loamy soils. Each year, the traps were placed in a winter wheat field (2.2 ha) cropped with a susceptible variety: Popstart in 2011 and Sahara in 2013 (Jacquemin, 2014). This field was a source field and the infestation level by *S. mosellana* and the parasitism by *M. penetrans* were evaluated by extraction of larvae and insects reared from soil samples: 560 larvae/m^2 in 2011 (19% parasitized by *M. penetrans*) and 410 larvae/m^2 in 2013 (25% parasitized by *M. penetrans*). The traps were placed in the field using a randomized complete block design (three blocks). Each block was separated from the next one by at least 20 m and the traps were spaced 10 m apart within a block. Four trap types were compared: yellow sticky trap, white sticky trap, yellow water trap and pheromone-baited trap. Eight traps were placed in each block: one of each colored sticky traps at 0.6 m above ground level and one pheromone and yellow water trap, each at 3 different heights (0.2, 0.6 and 1 m above ground level).

The yellow sticky trap was made in our laboratory and consisted of a yellow sticky insert (Bug-Scan® - Biobest, Westerlo, Belgium) in a square shape (10 × 10 cm) arranged in a CD case for easy transport. This case was perforated and fixed on a stake so that the yellow sticky insert was 0.6 m above ground level (i.e., at the height of wheat ears). The yellow sticky trap was chosen because it has been used in many studies (Affolter, 1990; Ellis et al., 2009; Lamb et al., 2002; Oakley and Smart, 2002).

The white sticky trap was also made in our laboratory. It consisted of white silicone paper in a square shape (10 × 10 cm), which was sprayed with insect glue (Soveurode®) and arranged in a CD case for easy transport. This case was perforated and fixed on a stake so that the white sticky insert was 0.6 m above ground level (i.e., at the height of wheat ears). The white sticky trap was chosen because our visual field observations showed some *M. penetrans* adults on Apiaceae with white flowers.

The yellow water trap was a Flora® yellow trap of 26 cm in diameter (Signe Nature, La Chapelle d'Armentières, France), a well-known trap widely used by farmers and scientists for detecting insects in crops and chosen for these reasons. It was fixed on a stake at 0.2, 0.6 or 1 m above ground level and filled with 1 L of water, with a drop of surfactant (washing up liquid) added; this mixture was renewed twice a week.

The pheromone-baited trap used in our study was described by Bruce et al. (2007). It consisted of a delta trap with a removable sticky insert and a rubber septum lure that released the *S. mosellana* sex pheromone. Traps and lures were obtained from Suterra® (Suterra Europe Biocontrol Espana SL, Gavà, Barcelona, Spain). In each pheromone trap, the same rubber septum lure remained in place for the full season. The delta trap was fixed on a stake at 0.2, 0.6 or 1 m above ground level.

During the entire flight period (23 April to 15 June 2011 and 1 June to 12 July 2013), every day in the early afternoon the sticky inserts were replaced and the insects caught in the yellow water traps were collected. The insects were then identified, sexed and counted using a stereomicroscope. *Sitodiplosis mosellana* was determined using the identification key for the Cecidomyiidae family (Skuhravá, 1997). *Macroglenes penetrans* was determined using the identification key for Pteromalidae (Graham, 1969) and the description given by Johansson (1936).

2.2. Statistical analysis

Statistical analyses were performed using R 3.4.4 (R Development Core Team, 2018). All R codes, detailed analyses output and raw data are available as supplementary material in a public repository: https://doi.org/10.6084/m9.figshare.5702764. The flight patterns were compared between years and between *S. mosellana* and *M. penetrans* within each year according to the methodology proposed by Murtaugh et al. (2012). The average Julian day of emergence for each individual was compared between the two groups with a student *t*-test.

Two series of analyses were conducted to compare the different traps where the data were analyzed separately for each species. An initial series of analyses was conducted to compare the capture efficiency of the four trap types at 0.6 m above ground level, using linear mixed models with a Gaussian distribution. The trap type, the year and their interaction were defined as fixed explanatory variables, whereas the blocks were defined as a random effect. A $\log_{10}(x+1)$ transformation was applied to the total number of insects caught across all sampling dates, defined as the dependent variable, in order to limit heteroscedasticity problems. The conditions of application were checked using residual plots. For all the models, the significance of differences among trap types was tested using likelihood ratio (LR) tests (analysis of deviance). When the LR test was significant, post-hoc comparisons were performed using the multcomp package (Bretz et al., 2011). We compared the different traps within each year and also the average of the two years of captures among the different trap types using an appropriate contrasts matrix.

A second series of analyses was conducted to compare the capture efficiency of yellow water traps and pheromone-baited traps at three heights (0.2, 0.6 and 1 m above ground level) and to compare the difference in their ability to trap males and females at three heights. Linear mixed models with a Gaussian distribution were used with four fixed effects (and all interactions: sex, trap height, trap type and year), whereas the blocks were defined as a random effect. A $\log_{10}(x+1)$ transformation was applied to the total number of insects caught across all sampling date, defined as a dependent variable, in order to limit heteroscedasticity problems. The conditions of application were checked using residual plots. For all the models, the main effects and interactions were tested using likelihood ratio tests. When the LR test for the effects including trap height were significant, only relevant post-hoc pairs of comparisons were conducted (with p-value correction for multiple comparison): we compared the number of individuals captured between all pairs of trap heights for a given trap type, a given year and for males, females and both sexes pooled.

3. Results

3.1. *Sitodiplosis mosellana*

3.1.1. Flight pattern and trap type

The flight patterns (Fig. 1) and the number of *S. mosellana* midges caught (Table 1) varied from year to year, depending on trap type and meteorological conditions. The flights occurred 6 weeks earlier in 2011 than in 2013: the first *S. mosellana* adults were caught on 23 April 2011 and on 5 June 2013 and the average difference of Julian day was 44.6 days ($t = -525.46$, $df = 22241$, $p < 0.0001$). This strong difference in phenology was due to a hotter spring in 2011 as confirmed by the meteorological data and the very accurate emergence models known for this species (Jacquemin et al., 2014). In 2013, the pheromone traps had caught the first *S. mosellana* adults 7 days before the yellow water traps. In 2011, only 1 *S. mosellana* adult was caught by yellow water trap (at 0.60 m) 1 day before the first *S. mosellana* adults caught by pheromone traps.

The capture efficiency of the four trap types at 0.6 m above the ground level was significantly different (see Fig. 2 with Post-Hoc results and Table 2A for Likelihood Ratio Tests). The pheromone-baited traps caught 100 to 1000 times more *S. mosellana* than any of the traps that had no pheromone. Only a few individuals were caught with the yellow water traps and the sticky traps (yellow or white).

3.1.2. Trap height and sex ratio

The vast majority of *S. mosellana* caught with the pheromone-baited traps were males, thanks to the strong attraction of the sex pheromone for males (Table 1). The sex ratios were more balanced with the traps that had no pheromone.

For the traps tested at three heights, the number of males caught decreased drastically from 0.2 m to 1 m above the ground (Fig. 3, Table 2B). The effect of height on the number of females caught was not so clear: a slight effect was observed with the yellow water traps in the lowest position, but there was no effect with the pheromone-baited traps. The sex ratio increased, however, with trap height in favor of the female (Table 1).

3.2. *Macroglenes penetrans*

3.2.1. Flight pattern and trap type

Like its host, the flight patterns (Fig. 4) and number of *M. penetrans* caught (Table 1) varied from year to year, depending on the meteorological conditions. The first *M. penetrans* adults were caught on 8 May 2011 and on 11 June 2013 and the average difference of Julian day was 40.2 days ($t = -430.71$, $df = 5870.6$, $p < 0.0001$). The *M. penetrans* flights started 2 weeks later than *S. mosellana* flights in 2011 and 1 week later in 2013. The flights occurred on average 8.0 days later than *S. mosellana* flights in 2011 ($t = -110.36$, $df = 17982$, $p < 0.0001$) and 3.5 days later in 2013 ($t = -34.347$, $df = 8298$, $p < 0.0001$). Unlike its host, greater numbers of *M. penetrans* were caught with the sticky traps (yellow or white) and yellow water traps than with the pheromone-baited traps (Fig. 2, Table 2A).

3.2.2. Trap height and sex ratio

Regardless of trap type, males caught always outnumbered females caught (Table 1). For both traps tested at three heights, the *M. penetrans* catches were consistently more numerous at 0.6 m than at 0.2 m above the ground (Fig. 5, Table 2B). Between the heights of 0.6 and 1 m above the ground, the results depended on trap type: the yellow water traps always caught more *M. penetrans* at 0.6 m than at 1 m. The pheromone-baited traps at 0.6 or 1 m, however, caught similar numbers of *M. penetrans*. From year to year, the male catch distribution across the heights varied: male catches at 0.2 m with the water traps were far lower than at the two other heights in 2013, but at more similar levels in 2011.

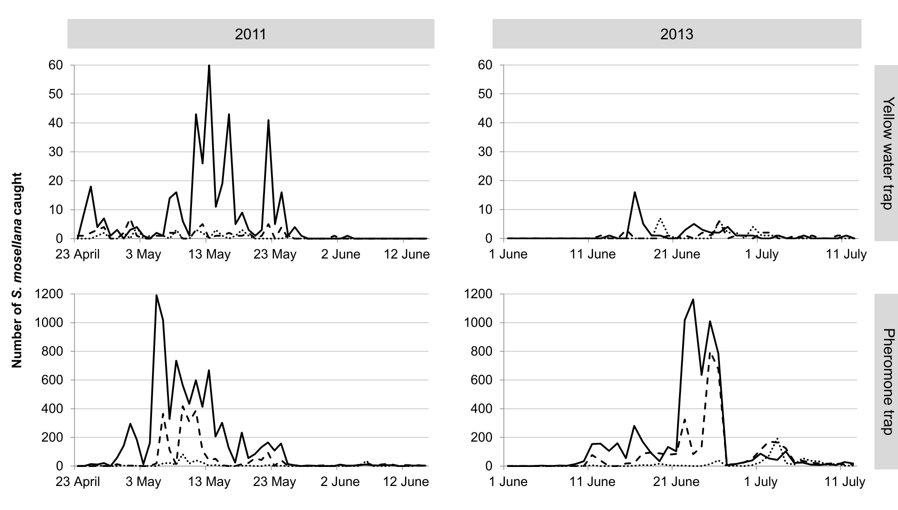

Fig. 1. *Sitodiplosis mosellana* flight patterns with yellow water traps and pheromone-baited traps at 0.2, 0.6 and 1 m above ground level during the entire flight season in 2011 and 2013. Total number of *S. mosellana* caught for each trap (3 repetitions/trap).

Table 1
Total number of *Sitodiplosis mosellana* and *Macroglenes penetrans* caught with the four trap types (pheromone, yellow water, white sticky and yellow sticky; 3 repetitions/trap) at each height in 2011 and 2013.

Trap types	Height (m)	*Sitodiplosis mosellana*						*Macroglenes penetrans*					
		2011			2013			2011			2013		
		Total	♂	♀	Total	♂	♀	Total	♂	♀	Total	♂	♀
Pheromone	0.2	8538	8523	15	6605	6592	13	13	9	4	36	21	15
Pheromone	0.6	2235	2218	17	3452	3431	21	73	56	17	128	93	35
Pheromone	1	310	279	33	587	563	24	57	35	22	152	107	45
Yellow water	0.2	382	316	66	49	29	20	1345	1284	61	92	59	33
Yellow water	0.6	54	30	24	25	6	19	2153	2067	86	1261	1155	106
Yellow water	1	30	12	18	25	7	18	385	348	37	637	565	72
White sticky	0.6	8	1	7	17	3	14	3781	3646	135	366	352	14
Yellow sticky	0.6	56	46	10	49	14	37	4775	4560	215	1744	1720	24

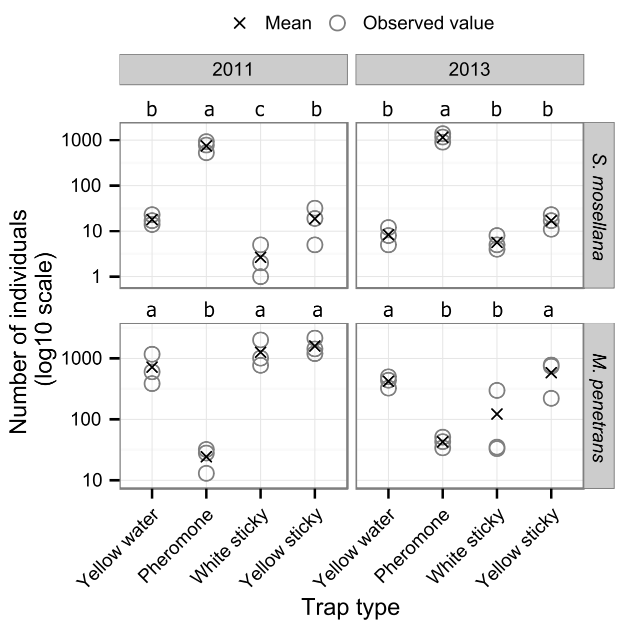

Fig. 2. Number of *Sitodiplosis mosellana* and *Macroglenes penetrans* ($\log_{10}$ scale at Y-axis) caught with the four trap types (yellow water, pheromone, white and yellow sticky) at 0.6 m above ground level during the entire flight season, in 2011 and 2013. The data were analyzed separately for each species. Observed value is the total number of insects caught for each trap (3 repetitions/trap type). Means with at least one common letter (within a year and a species) are not significantly different based on the post-hoc tests ($\alpha = 0.05$). See the figshare public repository for details about the post-hoc tests.

4. Discussion

Our study compared the relative efficiency of different trapping systems (trap types and trap heights) species by species and sex by sex for *S. mosellana* and its parasitoid, *M. penetrans*. In any one year, the flight patterns obtained with the four trapping systems differed, especially in the case of *S. mosellana* when pheromone-baited traps were used. As demonstrated by Ellis et al. (2009) and Jacquemin (2014), understanding and interpreting pheromone-baited trap catches depends on the field in which the traps are placed: source field or non-source field for *S. mosellana*. For our study, both wheat fields were infested by *S. mosellana* and *M. penetrans* as a result of wheat cropping in the previous years. The relative abundance of catches for each species and each sex would have been different in a non-source wheat field because of the specific behavior of each sex of each species. In a non-source wheat field, immigrant female midges can be numerous, whereas male midges are generally rare because they tend to stay close to their emergence site in order to fertilize newly emerged females (Ellis et al., 2009; Jacquemin, 2014; Pivnick and Labbé, 1993). For this reason, in non-source fields, pheromone-baited traps might not catch more midges than the other trap types because the sex pheromone released by the lure attracts male midges only. The choice of trapping system should be made according to what information is being sought.

If the aim is to detect the beginning and intensity of *S. mosellana* flights in source fields, pheromone-baited traps are clearly the best choice (Chavalle et al., 2017; Ellis et al., 2009; Jacquemin, 2014) and they must be at 0.2 m above ground level. They are the most sensitive system for monitoring *S. mosellana* flight patterns, thus providing greater advantage in the early detection of midge infestation. A supplementary advantage of the pheromone-baited traps is that they catch few insects other than *S. mosellana*. This higher selectivity decreases the “noise” in the system and facilitates the counting and the management of the material collected in the traps. The particularly high efficiency of this trap at the lowest height can be explained by the behavior of adult midges that prefer to remain hidden close to the ground in the crop canopy during the day so as to protect themselves against wind and low air humidity (Pivnick and Labbé, 1993, 1992). This best efficiency of pheromone traps at low height was already observed in a previous study, where Li et al. (2011) reported a greater efficiency of pheromone traps at 0.4 m than those at 0.7 m and 1 m.

If the aim of trapping midges is to assess the risk of attack on wheat crops in fields where soil infestation is low (non-source field) or unknown, pheromone traps are not relevant: low capture levels with this trap cannot exclude the risk for the crop because it catches males, whereas it is the females that cause the risk of damage (Ellis et al., 2009; Jacquemin, 2014; Mircioiu, 2004). A non-source field with no catches of males in pheromone-baited traps can therefore be strongly attacked by female midges that have emerged from neighboring fields. In this case, the yellow water trap placed at 0.2 m above the ground appears to be the most reliable tool. As in the case of the pheromone trap, the lowest height gave the greatest efficiency, for the same behavioral reasons.

Sticky traps (white or yellow) did not provide more information than the yellow water traps about the presence of female midges and thus about the risk for the crop. These traps can be used to monitor adult midges, as observed by Lamb et al. (2002), but they are less easy to use. The greater efficiency of yellow sticky traps than white sticky traps has been demonstrated in previous studies (Li et al., 2011; Oakley and Smart, 2002). Sticky traps at 0.6 m above ground level (i.e., at the height of wheat ears) have proved to be efficient in catching *M. penetrans*, but not better than water traps. Regardless of trap type or height, a higher number of males was caught although the sex ratio at emergence of *M. penetrans* is about 1:1 (Affolter, 1990; Chavalle et al., 2015a). This high number of males caught by sticky traps was also observed by Affolter (1990), who showed that they have very intense aerial activity during day. Our visual field observations showed that

Table 2
Likelihood Ratio (LR) tests for the Gaussian mixed models. In all models the response is the log(x + 1) transformed total number of individuals across all sampling dates (for a given year). The bloc has been added as random effect in all models. We performed type II tests: the marginality rules are respected (each effect is tested after ignoring higher level interactions containing this effect). Selected pairwise post-hoc comparisons for these models are presented with compact letter display in Figures 2, 3 and 5.

A - Comparison of total number of individuals between 4 trap types

	Sitodiplosis mosellana			*Macroglenes penetrans*		
	LR	df	p (> χ^2)	LR	df	p (> χ^2)
Trap type	72.53	3	< 0.0001	30.34	3	< 0.0001
Year	0.39	1	0.5330	7.22	1	0.0072
Trap type x Year	10.24	3	0.0166	22.14	3	< 0.0001

B - Comparison of total number of individuals between sexes and trap heights for 2 trap types

	Sitodiplosis mosellana			*Macroglenes penetrans*		
	LR	df	p (> χ^2)	LR	df	p (> χ^2)
Height	29.41	2	< 0.0001	37.55	2	< 0.0001
Sex	37.74	1	< 0.0001	58.01	1	< 0.0001
Year	10.01	1	0.0016	0.99	1	0.3200
Trap type	36.80	1	< 0.0001	66.30	1	< 0.0001
Height x Sex	53.89	2	< 0.0001	10.76	2	0.0046
Height x Year	13.12	2	0.0014	12.46	2	0.0002
Sex x Year	d	1	0.3410	4.74	1	0.0294
Height x Trap type	7.69	2	0.0213	17.06	2	0.0002
Sex x Trap type	128.30	1	< 0.0001	41.26	1	< 0.0001
Year x Trap type	20.74	1	< 0.0001	23.26	1	< 0.0001
Height x Sex x Year	2.74	2	0.2550	8.08	2	0.0176
Height x Sex x Trap type	25.88	2	< 0.0001	0.67	2	0.7160
Height x Year x Trap type	2.35	2	0.3090	25.18	2	< 0.0001
Sex x Year x Trap type	13.15	1	0.0003	10.03	1	0.0015
Height x Sex x Year x Trap type	0.63	2	0.7300	4.25	2	0.1200

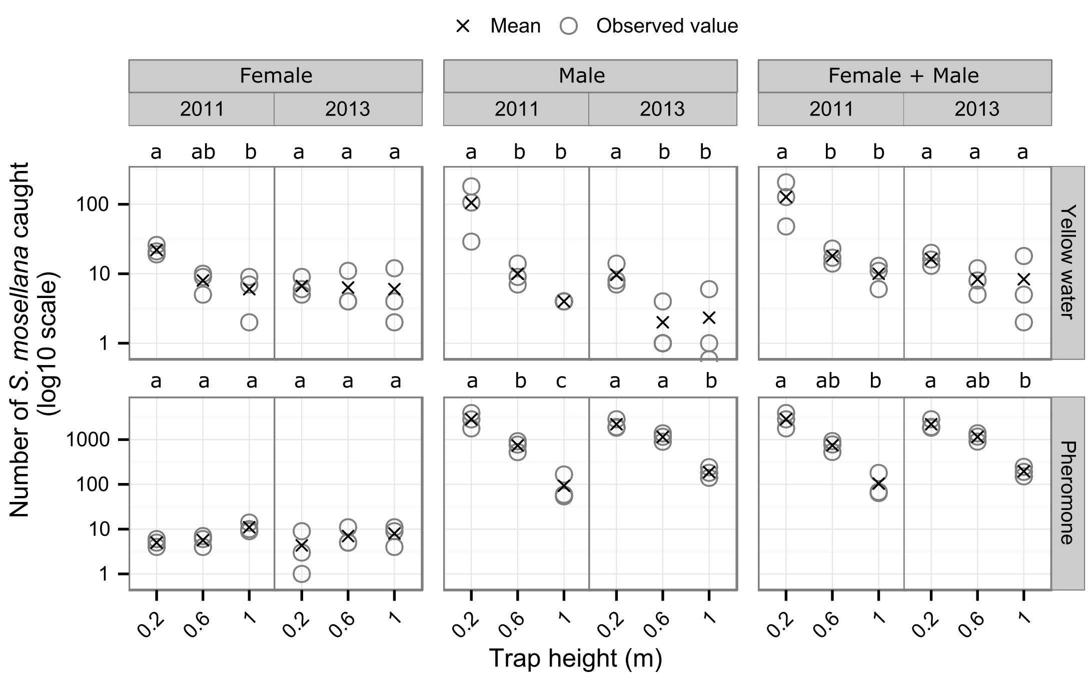

Fig. 3. Number of *Sitodiplosis mosellana* ($\log_{10}$ scale at Y-axis) caught with yellow water traps and pheromone-baited traps at 0.2, 0.6 and 1 m above ground level during the entire flight season, in 2011 and 2013. The data were analyzed separately for each species. Observed value is the total number of insects caught for each trap (3 repetitions/trap type). Means with at least one common letter (within a year, a sex combination and a trap type, i.e. in a subplot) are not significantly different based on the post-hoc tests (α = 0.05). See the figshare public repository for details about the post-hoc tests.

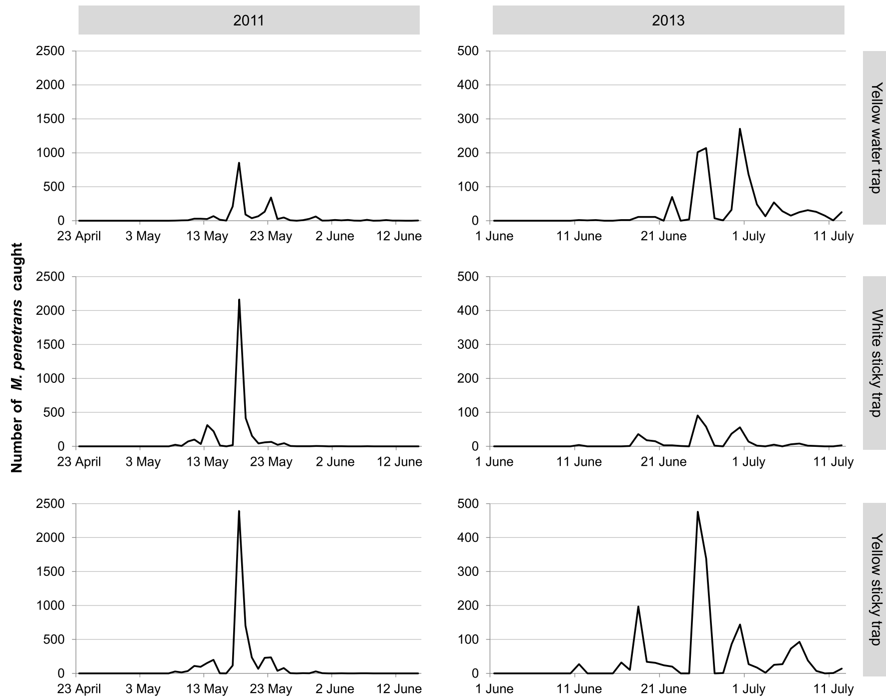

Fig. 4. *Macroglenes penetrans* flight patterns with yellow water traps, white and yellow sticky traps at 0.6 m above ground level during the entire flight season in 2011 and 2013. Total number of *M. penetrans* caught for each trap (3 repetitions/trap type).

males fly in swarms around some females, especially during sunny afternoons. Unlike *S. mosellana*, *M. penetrans* adults tend thus to move around and not to remain hidden in the crop canopy.

Complete information about *S. mosellana* and *M. penetrans* can be obtained by coupling two trapping systems together: (i) pheromone-baited traps installed in identified source fields to monitor midge emergence with high sensitivity, and (ii) yellow water traps installed in non-source wheat fields to quantify the populations of midges and their parasitoids. Monitoring the flight of *S. mosellana* with these reliable traps can help in assessing the risk for the wheat crop and in determining the timing of insecticide treatments. The decision making for an insecticide treatment can be completed by a visual assessment of active females on wheat ears in the evening (Ellis et al., 2009). When an insecticide treatment is necessary, it should be applied in the evening at

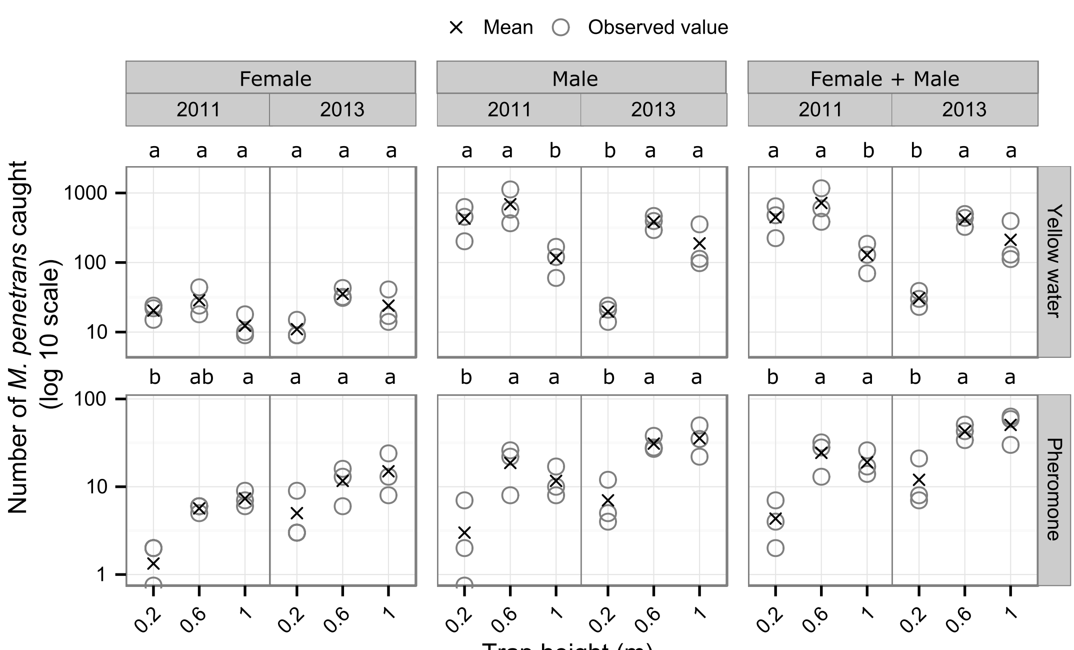

Fig. 5. Number of *Macroglenes penetrans* ($\log_{10}$ scale at Y-axis) caught with the yellow water traps and pheromone-baited traps at 0.2, 0.6 and 1 m above ground level during the entire flight season, in 2011 and 2013. The data were analyzed separately for each species. Observed value is the total number of insects caught for each trap (3 repetitions/trap type). Means with at least one common letter (within a year, a sex combination and a trap type, i.e. in a subplot) are not significantly different based on the post-hoc tests (α = 0.05). See the figshare public repository for details about the post-hoc tests.

the time when female midges are most active in order to avoid its parasitoids and to achieve greater efficiency in the chemical control of *S. mosellana*. The conservation of parasitoid populations could reduce dependence on chemical control and improve the integrated management of *S. mosellana*.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cropro.2018.10.010 and in a public repository at https://doi.org/10.6084/m9.figshare.5702764.

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