

Forecasting the emergence of the adult orange wheat blossom midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae) in Belgium



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ABSTRACT

Agronomists often underestimate the damage inflicted by the orange wheat blossom midge, *Sitodiplosis mosellana* (Géhin), a wheat (*Triticum aestivum* L.) pest. The main risk arises when the emergence of the adult midges coincides with wheat ear emergence. The emergence of adult midges was monitored in Belgium over four years and analysed against climate data, establishing the significance of specific rainfall events as triggers for the final phase of development prior to emergence. This discovery, combined with experience from previous models, was incorporated into a new forecasting model, described in this paper. The new model consists of three separate phases. The first phase comprised a temperature accumulation of 250 degree-days (DD) above 3 °C, starting from 1 January. Once this initial condition is satisfied, the second phase starts, and it lasts until the occurrence of a double signal consisting of a rise in the mean daily temperature up to 13 °C, followed by rainfall. This rainfall event triggers an accumulation phase of 160 DD above 7 °C. Once this last condition is met, the adults emerge.

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1. Introduction

The orange wheat blossom midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae), is a wheat (*Triticum aestivum* L.) pest found throughout the northern hemisphere. Recent outbreaks and associated damage have been observed in Europe, particularly in the United Kingdom (Bruce et al., 2007; Oakley, 1994), but also in Germany (Gaafar and Volkmar, 2010), France (Flodrops and Taupin, 2010) and Belgium (Jacquemin et al., 2008). Attacks by *S. mosellana* can result in significant reductions in grain yield and quality (Miller and Halton, 1960; Olfert et al., 1985). These midges also facilitate fungal infections (Mongrain et al., 2000; Oakley, 1994). In 2004, crop losses exceeded £60 million in the United Kingdom despite insecticide applications over 500,000 ha (Oakley et al., 2005). Although extensive research has been conducted in Europe (Affolter, 1990; Barnes, 1956; Basedow, 1977; Kurppa, 1989), North America (Harris et al., 2003; Lamb et al., 2002; Olfert et al., 1985) and Asia (Katayama et al., 1987; Wu et al., 2009), this insect remains difficult to control.

The main methods used to control *S. mosellana* are insecticide application (El-Wakeil et al., 2013) and the use of resistant wheat varieties (Ellis et al., 2009). Since these varieties are not fully

adapted to all the various cultural conditions, pesticide spraying is the approach most frequently used. In addition, the varietal resistance is based on a single gene, *Sm1*, which throws doubt on the durability of this resistance (Smith et al., 2007; Vera et al., 2013). In order to establish appropriate insecticide treatment, the risk of damage by *S. mosellana* needs to be assessed. Whatever the number of insects, this damage occurs only if the insect's emergence coincides with the susceptible growth stage of the host plant (Basedow and Gillich, 1982). For wheat, this stage begins at ear emergence and extends through to flowering (Barnes, 1956; Ding and Lamb, 1999). In addition, the sheltering habit of larvae means that a late insecticide treatment has little effect on the insects. Determining the emergence period is therefore a key element in the management of *S. mosellana* populations.

Although the range of factors triggering adult emergence remains unclear, some aspects of the biological life cycle of *S. mosellana* are well-known. This midge is a univoltine species. The larvae overwinter in the soil, inside a cocoon, where they may survive for several years (Barnes, 1956). Under favourable conditions, the larvae leave the cocoon and move towards the soil surface, where pupation takes place. The adults emerge during the spring and generally mate at the source site, and the females then fly away to find a host crop (Oakley et al., 1998). The eggs are laid on the spikes and hatch after 4–10 days (Basedow, 1977; Oakley, 1981). The midge larvae then feed for 3–4 weeks, damaging the young grains.

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The forecasting of adult *S. mosellana* emergence has been the subject of many studies over the decades, leading to several forecasting models based on the degree-day (DD) accumulations required for the insect to develop from the end of diapause through to adult emergence (Table 1) (Herms, 2004). These forecasting models had limited precision because the traps used to build them were not very efficient (Ellis et al., 2009) and the emergence traps used in some studies could modify the temperatures accumulated by the insects in the soil under the trap (Southwood and Siddorn, 1965). The identification of the sex pheromone of *S. mosellana* as (2S,7S)-nonadiyl dibutyrate (Gries et al., 2000) was a major milestone in the study of this pest. It led quickly to the manufacture of lures that, when placed in sticky traps, made it easier to detect this insect and monitor its flight patterns (Bruce et al., 2007). This new tool was leveraged in the study described here on monitoring *S. mosellana* emergence in Belgium over four consecutive years (2007–2010).

In this paper, the use of earlier models of emergence is evaluated within the Belgian context by comparing the forecasts derived from these models with the observations made over the four years. The new model for forecasting emergence is then described. It is based mainly on the relationship observed between definite rainfall events and the emergence of the adults. A second study conducted under controlled conditions validated the hypothesis of water as a trigger factor of emergence. The paper also discusses the possibilities of extending this new model to other climatic contexts.

2. Materials and methods

2.1. Monitoring emergences in field

Observations were conducted around Gembloux, in Belgium, over four years (2007–2010). Pheromone traps were used each year to determine the emergence patterns of *S. mosellana*. These pheromone traps, as described by Bruce et al. (2007), consisted of delta traps fitted with a removable sticky insert and a rubber septum lure releasing the sex pheromone of *S. mosellana* females. The traps and lures were provided by Agrisense (Pontypridd, Mid Glamorgan, UK). The same rubber septum lure remained in place for the whole season. Each year, the traps were placed in two *S. mosellana*-infested fields in which wheat had been planted the previous year and cropped with sugar beet (*Beta vulgaris* L.) or maize (*Zea mays* L.) in the year of trapping. These crops were chosen because of their limited plant cover during the relevant period, making them unable to shelter emerged insects, which soon left these emergence sites (Ellis et al., 2009). The traps therefore caught only newly emerged

insects. Two traps were placed in each field, 50 m apart and at least 30 m into the crop. Observations were taken each morning; the sticky inserts were replaced and the insects captured were identified and counted using a stereomicroscope.

Meteorological data (air temperature and precipitation) were recorded at 10 min-intervals at the Royal Meteorological Institute's (IRM) weather station at Ernage, 6 km away from the experimental fields, to assess *S. mosellana* emergence.

2.2. Application of different models to assess *S. mosellana* emergence

Six emergence models developed to assess *S. mosellana* emergence were run using the meteorological data from the Ernage weather station from 2007 to 2010. These models are described in Table 1. Four of them consist of a simple accumulation of daily temperatures expressed in DD. The fifth one (a German model), however, distinguishes two discrete periods of temperature accumulation; the first period is similar to that of four models, but the second period starts from the first rainfall event after the end of the first period. The last model (a British one) uses days rather than DD as a unit of measure, and is based on temperature thresholds.

In order to test these six models, two dates on which 10% and 50% of all adults caught in the season were selected. For each year, the capture pattern was defined using four traps (two traps in each field). The daily data provided by the two traps in a field allowed the mean capture pattern for that field to be determined. The pattern for the year was the mean pattern of the two fields. In this computation, each field had the same significance. The models were tested using mean daily air temperatures.

2.3. Relationship between watering and emergence under controlled conditions

In 2012, an experiment under controlled conditions was run to test the hypothesis of a relationship between rain and emergence. In mid-March, the soil required for this experiment was sampled from the top 8 cm in two infested fields. These fields were 200 km apart and located in two distinct cereal-growing regions in Belgium. The first was at Juprelle (50°44'19"N, 5°33'20"E) in an area of loamy soil, and the second was at Veurne (51°4'15"N, 2°43'14"E) on a clay-rich soil of coastal polders. The levels of infestation were 1000 and 400 *S. mosellana* larvae per soil square metre at Juprelle and Veurne, respectively. The infested soil was collected at Juprelle on 13 March and at Veurne on 19 March. Soil samples were brought back to the laboratory on the same day and

Table 1
Existing models for forecasting the emergence of the orange wheat blossom midge, *Sitodiplosis mosellana*.

Source of the model	Event	Requirement (successive phases separated by //)	Reference
Finland	Adult emergence	1 January // 400 DD above 5 °C	(Husberg and Kurppa, 1988; Kurppa, 1989)
Saskatchewan (Canada)	10% adult emergence	1 March // 693 DD above 5 °C	(Elliott et al., 2009)
North Dakota (USA)	Emergence from the cocoon, migration towards the surface and start of pupation	1 March // 232 DD above 4.44 °C	(Knodel and Ganehiarachchi, 2008)
	10% female emergence	1 March // 704 DD above 4.44 °C	
Manitoba (Canada)	50% adult emergence in laboratory	1 March // 306 DD above 9 °C	(Wise and Lamb, 2004)
Germany	End of diapause	1 January // 220 DD above 3 °C // rainfall > 5 L/m ²	(Basedow and Gillich, 1982; Basedow, 1980, 1977)
	Pupation	within the following 5 weeks	
	Adult emergence	Surface layer wet of soil	
	End of diapause	End of diapause // 450 DD above 6 °C	
United Kingdom	Adult emergence	Soil temperature > 13 °C	(Oakley, 1994; Oakley et al., 1998)
	Pupation	Surface layer wet of soil	
	Adult emergence	End of diapause // 3 weeks // rainfall // soil temperature > 15 °C	

placed in 18 plastic pallet boxes (nine boxes for each field, each measuring 1110 × 710 × 425 mm). There was a basal 250 mm layer of damp sand in each container, covered with a geotextile cloth. A 120 mm layer (about 100 kg) of infested soil was placed on this cloth.

The pallet boxes were stored outside, sheltered from wind and rain, until 26 March, when they were placed in a completely randomized design in an indoor area at 20 ± 2 °C. Air and soil temperatures were measured at a depth of 5 cm using ThermoPuce® (Waranet Solutions SAS, France). Each box was covered with a pyramid of black cloth, with a clear plastic trap on the top to collect the insects that emerged. The boxes were watered with the equivalent of 20 L/m² of rain. Six boxes (three on each site) were watered on day zero (D0, 28 March, treatment 1), six other boxes seven days later (D + 7, treatment 2) and six supplemental boxes were watered 14 days later (D + 14, treatment 3). In order to avoid damaging the surface structure of the soil, the water was not poured directly onto the soil, but onto a thick towelling fabric that had been stretched over the surface prior to watering and then removed once percolation was complete. All 18 pallet boxes were watered again six weeks after the first boxes had been watered on D0. *S. mosellana* emergence was recorded each day for 10 weeks, starting from D0, and within each box. Emerging individuals were identified, sexed and counted using a stereomicroscope.

3. Results

3.1. Monitoring emergence of *S. mosellana* in the field

The pheromone traps provided numerous and highly specific captures. The number of males caught per year and per trap ranged from 541 to 3878, with an average of 2377 over four years (Fig. 1). The numbers of catches in traps in the same field varied much less than in traps in different fields (Variance components (ANOVA): within field SD = 429.9, between field SD = 1060.1). This confirmed the influence of cropping history on population levels. In addition, the capture patterns in the same year were very similar in all the fields, suggesting that they were influenced by most of the prevailing factors, such as meteorological conditions. From year to year, the capture patterns of *S. mosellana* (Fig. 1) differed markedly. Depending on the year, the first emergences were recorded on dates up to 2–3 weeks apart: the period of 10% emergence, the one predominantly used by the forecasting models, occurred between 20 May and 5 June.

3.2. Application of forecasting models

None of the six tested models provided a reliable forecast across all four years (Table 2). The forecasts derived from these models were shown to be approximate and contradictory. The model in which forecasts were closest on average to observed *S. mosellana* emergence was the British model. The mean deviation, however, was in excess of 10 days, with a minimum of two days (2008) and a maximum of 23 (2007). This degree of imprecision makes it impossible to use these models for particular purposes such as putative treatments.

Observations over the four consecutive seasons showed that emergence is not simply a response to temperature accumulation. In 2007, the first emergence did not occur until 1 June, 19 and 14 days later than in 2008 and 2009, respectively, despite the warmer spring.

3.3. Triggers of emergence

The traps showed capture patterns with clearly discrete peaks that bore no relationship to the weather conditions on the day of

capture (Fig. 2). In addition, the traps could catch only newly emerged insects because they were located in sparsely covered fields. The capture peaks could therefore be considered to give a reliable picture of the waves of emergence.

The number of waves of emergence varied from one (2007) to seven (2010). Comparing the patterns of emergence with those of rainfall from mid-April to mid-May showed a strong convergence (Fig. 2). In 2007, the *S. mosellana* midges did not emerge until 1 June, despite favourable temperatures. That spring, no rain fell between 21 March and 7 May. A relevant conclusion was that this delay resulted from the lack of water. Rainfall during the evening of 7 May was followed by emergence on 1 June (i.e., 25 days, or 173 DD over 7 °C, later; Fig. 2). In 2008 and again in 2009, three periods of rainfall were followed by three waves of emergence. In 2010, seven waves of emergence were observed, each of which could have been triggered by an earlier period of rainfall.

The link between inductive rainfall and resulting wave of emergence was investigated for the four years of observations. Each wave of emergence was associated with the most likely inductive rainfall event, forming 14 inductive rainfall-waves of emergence pairs (Table 3). The moment of emergence was determined on the basis that at least 10% of the population of each peak had emerged, and that at least 5% had emerged in one day. The lengths of time between rains and associated emergences were not constant. Based on the notion that a DD constant was the likely link between cause and effect, base temperatures from 0 to 10 °C were tested. The base of 7 °C showed the best fit with the 14 inductive rainfall-waves of emergence pairs. The mean deviation between inductive rainfall event and emergence was 160 ± 8 DD over 7 °C, with extremes at 144 and 174 DD over 7 °C.

3.4. Relationship between watering and emergence under controlled conditions

The experiment conducted under controlled conditions confirmed the role of rainfall as a trigger for the emergence of *S. mosellana*. The emergence in each pallet box occurred in the same order in which the boxes had been watered. There was little difference in the mean lag between inductive rainfall event and emergence of the *S. mosellana* populations at Juprelle and Veurne (Fig. 3). The mean number of DD (above 7 °C) required for emergence in the boxes at Juprelle was 216 ± 0 , 181 ± 14 and 173 ± 7 DD for treatments 1, 2 and 3, respectively. For the boxes at Veurne, the mean number of DD (above 7 °C) required was 208 ± 7 , 185 ± 7 and 164 ± 7 DD, respectively.

In all the pallet boxes, regardless of date of watering, little emergence was observed before the true peaks (Fig. 3). These early emergences need to be considered as an artefact resulting from a few individuals (7% of the total number of males) coming into contact with the damp geotextile cloth along the edges of the boxes. These emergences were therefore not taken into account in the calculation of 10% emergence.

Despite continuing the experiment for 10 weeks, no further emergence was observed after the peaks cited above. This could indicate that the last round of watering in the experiment, applied six weeks after D0 (i.e., 547 DD above 7 °C), had no effect on the remaining cocoons. Soil analysis estimated their numbers at between 15 and 300 midge larvae/m², depending on the pallet box.

4. Discussion

Among the existing models of emergence, none was able to provide a reliable forecast. The reasons for the inaccuracies varied, depending on the model. In common with all single temperature accumulation models, the Finnish model does not take into

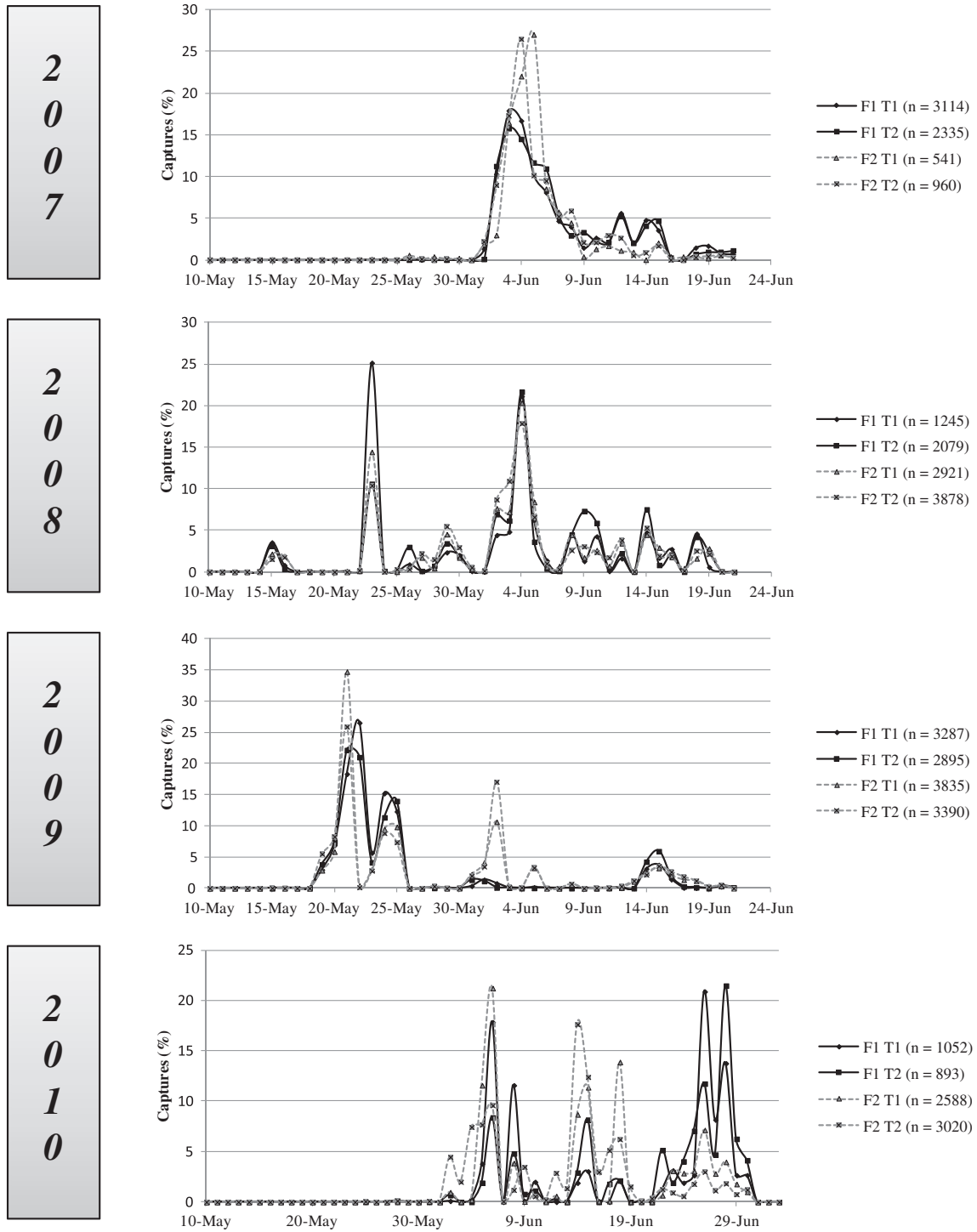


Fig. 1. Capture patterns of *S. mosellana* males in the fields (F1 or F2) with pheromone traps (T1 or T2) over four years.

account the insect's water needs. In 2007, emergence occurred late (1 June) because of the dry spring. This was also the case in 2010, when drought conditions prevailed from 8 April to 3 May. Forecasts from this type of model are therefore unreliable in dry years. The German model also remains invalidated. It was shown to be particularly ineffective in 2009 and 2010, which were distinguished from the previous two years by longer, colder winters. The 220 DD above 3 °C were therefore accumulated late in the season and, under such conditions, the 450 DD above 6 °C resulted in an

emergence forecast that was much too late. The length of this second phase is clearly not relevant for our region. The main merit of the German model is that it distinguishes two periods of temperature accumulation. Basedow (1977) also highlighted the key role of soil water in enabling larvae to leave their cocoon. This assertion has been confirmed in our laboratory (data not shown). This hatching of the larvae from the cocoon constitutes an important step in the development of *S. mosellana*, but it generally happens too early in the season to determine the time of adult

Table 2
Observed date of emergence and deviation (number of days) from the forecasts produced by different models.

Emergence observed in Gembloux	2007	2008	2009	2010	
10% emergence	1 June	22 May	20 May	5 June	
50% emergence	4 June	3 June	23 May	16 June	
Source of the model	Difference (days) between forecast and observed emergence				Mean deviation (days)
	2007	2008	2009	2010	
Finland ^a	-33	-7	+2	-5	11.8
Saskatchewan (Canada) ^a	+10	+32	+34	+24	25.0
North Dakota (USA) ^a	+7	+28	+29	+21	21.3
Manitoba (Canada) ^b	+3	+8	+27	+11	12.3
Germany ^a	-5	+16	+31	+26	19.5
United Kingdom ^a	-23	+2	-6	-10	10.3

^a Forecasted date for reaching emergence of 10% of the population.

^b Forecasted date for reaching emergence of 50% of the population.

emergence. When hatching occurs, the cocoons are scattered at different depths in the soil and the larvae need different lengths of time to reach the surface. The British model is based on temperature thresholds. The replacement of Basedow's 220 DD above 3 °C with a mean daily temperature threshold of 13 °C could call the validity of this model into question (Oakley et al., 1998). In most cases, this has no impact, but in a very early spring, such as that in 2010 when mean daily temperatures exceeded 13 °C from 20 to 29 March, the model ceases to be reliable. Oakley et al. (1998) suggested rain was needed to trigger the immediate emergence of the adults. The observations made in the current study ruled this out, along with the condition that the temperature should exceed 15 °C for emergence to occur.

The notion of 'waves of emergence' is an original contribution of this study. These waves have hitherto remained unnoticed because three conditions are needed to ascertain them: high numbers of capture, day-to-day survey of traps, and erasing captures of adults staying at the emergence site for more than one day. These conditions were met in the current study thanks to the pheromone traps and their location in very sparsely covered fields, with insufficient shelter for the midges. The number of waves appeared to vary from year to year. In 2007, a unique rainfall-emergence relationship was observed, suggesting that, with enough water, all the emergence requirements of the adults could be met simultaneously. The year 2009 showed a relationship between quantity of water and proportion of emerged insects, suggesting that, if there is not enough water to drench the soil deeply, only those insects that have been soaked will be activated. The existence of successive waves of emergence increases the probability of coincidence with the susceptible stage of the cereal. The relationship between rainfall events and waves of emergence, previously observed in the field, was confirmed under control conditions, with each watering leading to a wave of emergence. The lag between these two events corresponded with a constant accumulation of temperature of 160 DD above 7 °C. The bases used in earlier models were generally below 7 °C. This difference could be explained from a phenological perspective. The relevant period could correspond to pupation, which earlier models have never considered separately. The temperature requirements of the phases of development prior to pupation (i.e., emergence from diapause, emergence from the cocoon and the migration of the midge larvae towards the soil surface) are less stringent.

The observations taken in the field indicate values close to 160 DD above 7 °C between rainfall events and the resulting waves of emergence. The deviation between these values and those

observed under controlled conditions probably resulted from the difference between air temperatures and the temperatures experienced by the insects just beneath the soil surface. Under controlled conditions, the constant ambient temperature of the indoor area (20 ± 2 °C) meant that air temperatures were representative of the temperatures experienced by the insects underground: there was a close correlation between the two measures, which were recorded throughout the experiment ($r = 0.99$). This was not the case in the field, however where the values of DD accumulation calculated on the basis of air temperatures underestimated those calculated based on soil temperatures (McMaster and Wilhelm, 1998). In addition, the time lag between watering and emergence decreased gradually from the first watering (D0) to the third one (D + 14). This lag, getting shorter and shorter, was observed for the soil from Veurne as well as Juprelle. This could indicate that the preconditions for inductive rainfall to be effective might not have been met fully at the time that watering first occurred. These preconditions could relate, for example, to the precise placement of larvae just below the soil surface.

In order to develop a new forecasting model, it is important to define the features of the inductive rainfall. In the instances observed, these rainfall events were all preceded by a period during which temperatures had reached at least 13 °C. This was also the temperature threshold fixed by Oakley et al. (1998) at which the first pupae could be observed in the soil. The rainfall event does not have to occur simultaneously with the 13 °C threshold being exceeded (note how the positions of R₂-E₂ and R₃-E₃ are related in 2010, for example). These two required conditions alone are not sufficient. In fact, in 2009 and 2010 several rainfall events took place after the 13 °C threshold had been exceeded, with no resulting emergence, suggesting that the insects had not yet acquired sufficient physiological maturity to respond to these stimuli. Basedow (1977) made similar observations about the yellow wheat blossom midge, *Contarinia tritici* (Kirby), a closely related species. This author demonstrated that the *C. tritici* larvae did not leave their cocoons before 220 DD above 3 °C had been accumulated after the cold period. Applied to the *S. mosellana* midge, this theory might explain why the first rainfall events in 2009 and 2010 that proved to be inductive were on 17 April in 2009 (281 DD above 3 °C) and 25 April in 2010 (301 DD above 3 °C), not on the earlier dates of 11 April 2009 (224 DD above 3 °C) and 8 April 2010 (212 DD above 3 °C), although these latter dates satisfied the first two conditions described above. Taking account of the observations recorded in the field and under controlled conditions, as well as the work by Basedow (1977) on the conditions of development of *C. tritici*, a new model for forecasting the emergence of *S. mosellana* was developed.

In northern Europe, the requirements in terms of cold weather conditions are always met (Oakley et al., 1998). They were therefore disregarded in constructing the model. The starting point of the model is set at 1 January. This date does not reflect any biological circumstance, other than falling in the middle of the winter. From this date onwards, an accumulation of 250 DD (average of 224–281) above 3 °C is required for the midge larvae to emerge from their cocoons. Emergence remains possible for four to six weeks, provided that there is enough soil moisture. As in the model developed by Basedow (1977), emergence seems to be time-constrained, with a ceiling time limit enabling larvae that have not yet emerged from their cocoon to remain in the soil until at least the following year. Through this mechanism, the species maintains a stock of larvae for several years, able to compensate for a failure of coincidence. The phase during which the midge larvae move towards the soil surface and wait for the inductive rainfall can vary in duration. At the end of this phase, the soil

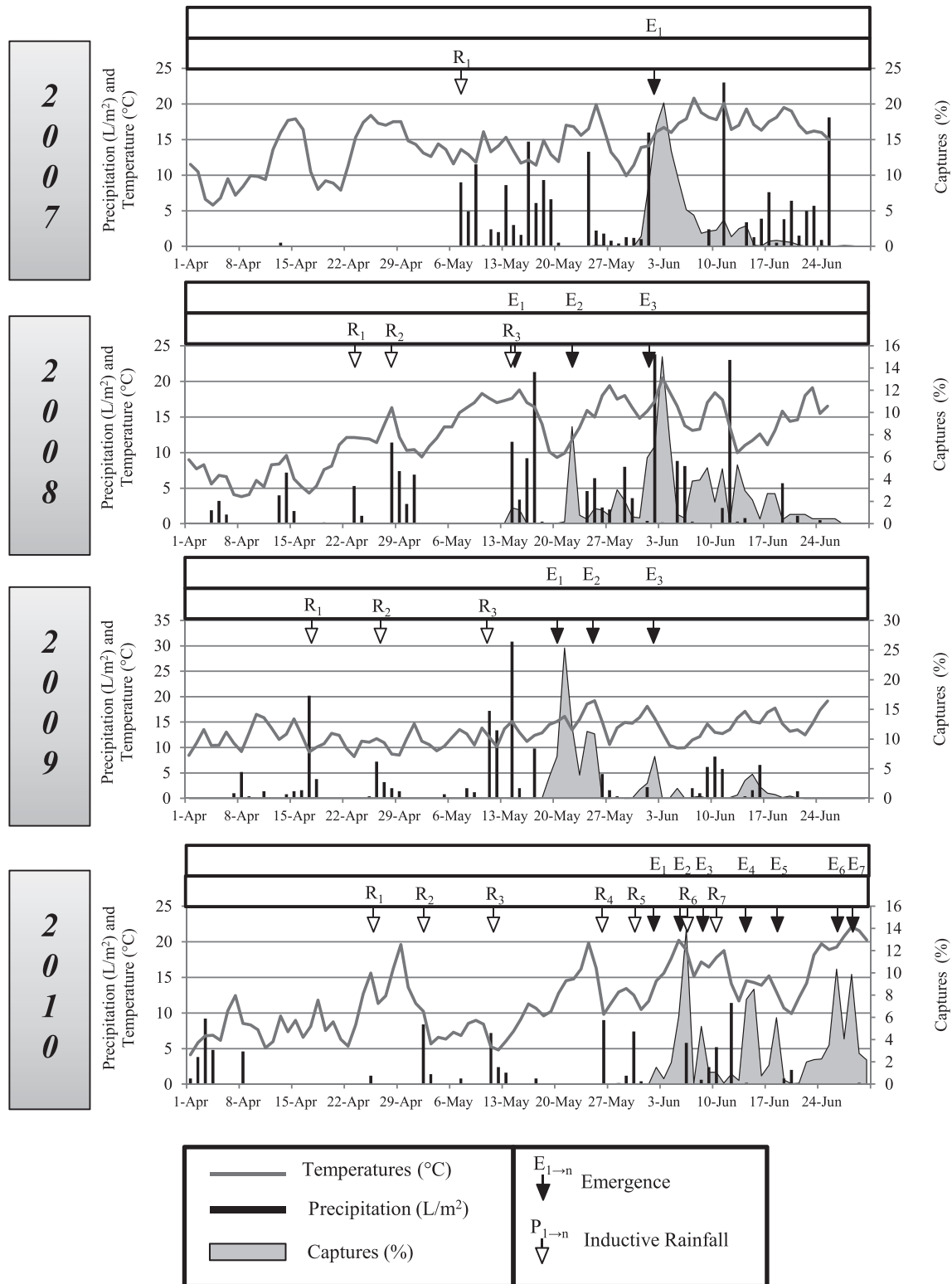


Fig. 2. Flight patterns of *S. mosellana* males in relation to climatic conditions (precipitation and temperature) over the four years. The arrows labelled 'R₁...n' correspond to the rainfall events thought to have triggered corresponding waves of emergences, indicated by the arrows labelled 'E₁...n'.

reaches 13 °C and the next rainfall event triggers the second temperature-dependent phase, which brings the insects to maturity in 160 DD above 7 °C.

Applying this model to the meteorological conditions recorded from 2007 to 2010 in Gembloux showed that forecasting was

accurate to within one to two days (Table 4). The precision of the developed model allows it to be applied in integrated pest management. In Europe, numerous insecticide treatments are currently applied systematically without paying attention to the presence of this pest. The use of the forecast model by the early warning

Table 3
Time lags and temperature accumulations between inductive rainfall events and waves of emergence.

Year	Inductive rainfall event			Wave of emergence		Time lag between inductive rainfall event and wave of emergence	
	No.	Date	(Time) L/m ²	No.	Date	Days	Degree-days above 7 °C
2007	R ₁	7 May	(>18.00)	9.0	E ₁ 1 June	25	173.6
2008	R ₁	23 April	(>18.00)	5.3	E ₁ 14 May	21	154.4
	R ₂	29 April	(<06.00)	18.8	E ₂ 22 May	23	169.7
2009	R ₃	15 May	(06.00–12.00)	14.9	E ₃ 1 June	17	143.9
	R ₁	17 April	(<06.00)	21.8	E ₁ 20 May	33	157.9
	R ₂	26 April	(<06.00)	7.6	E ₂ 24 May	28	161.2
2010	R ₃	11 May	(<06.00)	17.4	E ₃ 1 June	21	162.4
	R ₁	25 April	(<06.00)	1.2	E ₁ 2 June	38	161.5
	R ₂	2 May	(06.00–12.00)	18.8	E ₂ 5 June	34	151.6
	R ₃	11 May	(>18.00)	10.0	E ₃ 8 June	28	171.3
	R ₄	26 May	(06.00–12.00)	22.2	E ₄ 14 June	19	156.2
	R ₅	30 May	(<06.00)	10.0	E ₅ 17 June	18	154.9
	R ₆	6 June	(12.00–18.00)	7.1	E ₆ 25 June	19	163.6
	R ₇	10 June	(<06.00)	5.8	E ₇ 28 June	18	162.2
Mean						24.4	160.3
Standard deviation						6.8	8.0
Coefficient of variation (%)						27.8	5.0

Note: The inductive rainfall events R_{1–n} and resulting emergences E_{1–n} are also shown in Fig. 2.

services could reduce the number of treatments, especially in the year with no coincidence.

The application of this model to other climatic contexts may be possible. Given the number of situations observed in the field and induced under controlled conditions, this study underlines the

Table 4
Application of the proposed model.

Year	1 January + 252 ^a DD above 3 °C	13 °C	Inductive rainfall event	160 DD above 7 °C (calculated emergence)	Observed emergence	Deviation between forecast and observed emergence (in days)
2007	7 March	12 April	7 May	30 May	1 June	2
2008	29 March	26 April	23 April	15 May	14 May	1
	29 March	26 April	29 April	21 May	22 May	1
	29 March	26 April	15 May	3 June	1 June	2
2009	14 April	15 April	17 April	21 May	20 May	1
	14 April	15 April	26 April	24 May	24 May	0
	14 April	15 April	11 May	1 June	1 June	0
2010	17 April	25 April	25 April	2 June	2 June	0
	17 April	25 April	2 May	6 June	5 June	1
	17 April	25 April	11 May	7 June	8 June	1
	17 April	25 April	26 May	15 June	14 June	1
	17 April	25 April	30 May	18 June	17 June	1
	17 April	25 April	6 June	25 June	25 June	0
	17 April	25 April	10 June	28 June	28 June	0
Mean (days)						0.8

^a Mean between 220 and 281 DD above 3 °C.

relationship between inductive rainfall and emergence for *S. mosellana*. The required temperature accumulation and, to a lesser extent, the relevant base (of temperature), however, would need to be adapted to the different climatic contexts. In conclusion, numerous Cecidomyiidae are listed as major pests around the world. The rainfall-emergence relationship and the notion of

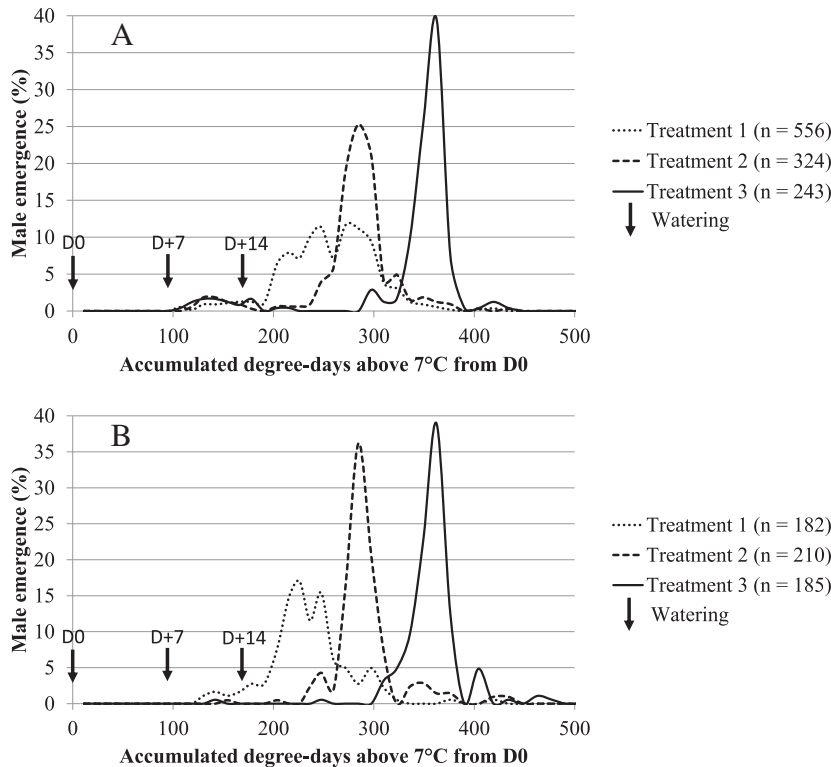


Fig. 3. Emergence under controlled conditions of male *S. mosellana* midges in relation to accumulated degree-days above 7 °C, starting from the watering of the first pallet boxes (D0) at Juprelle (A) and Veurne (B). The pallet boxes in treatment 1 were watered on D0, 7 days later on (D + 7) for treatment 2, and 14 days later on (D + 14) for treatment 3.

'waves of emergence' are worth testing elsewhere and might also be extendable to other pest species.

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