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ORIGINAL PAPER

Non-native insects in agriculture: strategies to manage the economic and environmental impact of wheat midge, *Sitodiplosis mosellana*, in Saskatchewan

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Abstract Wheat midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae), was first detected as early as 1901 in western Canada. The first major outbreak in Saskatchewan was recorded in 1983. Today wheat midge infests much of the wheat-growing area of Manitoba, Saskatchewan and North Dakota (USA), and is beginning to invade Alberta and Montana (USA). In 1984, Saskatchewan wheat midge populations were found to be parasitized by the egg-larval parasitoid, *Macroglenes penetrans* (Kirby) (Hymenoptera). Through the successful implementation of conservation techniques, this parasitoid now controls an average of 31.5% of the wheat midge across Saskatchewan. Estimated value of the parasitoid, due to reduction in insecticide costs in Saskatchewan alone, was estimated to be in excess of $248.3 million in the 1990s. The environmental benefits of not having to apply this amount of chemical insecticide are a bonus. To minimize the economic and ecological impact of *S. mosellana* today, wheat producers in western Canada have access to one of the most comprehensive management programs of any insect pest of field crops. Forecasts and risk warnings, monitoring tools, cultural control, agronomic practices, chemical control, biological control and plant resistance are all available for producers to manage wheat midge.

Keywords Biological control · Conservation · Spatial analysis · Wheat midge

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Introduction

Wheat midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae), is Palearctic in origin and was accidentally introduced into North America in the 1800s (Felt 1912). It is now a chronic pest of wheat (*Triticum* spp.) in the northern Great Plains, including the Canadian prairies and is widely distributed in many parts of the world where wheat production occurs, especially between the 42nd and 62nd parallels (Affolter 1990). In western Canada, *S. mosellana* was first reported in Manitoba (Fletcher 1902) but was not considered to be a pest until the 1950s (Allen 1955). The first major outbreak of wheat midge in Saskatchewan was recorded in 1983 causing an estimated loss in yield of $30 million that year (Olfert et al. 1985).

The life cycle of *S. mosellana* has been reviewed by Barnes (1956) for the British Isles and Europe, by Reeher (1945) for British Columbia and Washington, and by Doane et al. (1987) and Mukerji et al. (1988)

for Saskatchewan. On the northern Great Plains, adults emerge over a six-week period beginning in late June or early July. The highest populations usually occur during the second or third week of July. Adults are relatively poor fliers and may be distributed over long distances by thermal updrafts and wind. They are difficult to detect during the day because they remain within the crop canopy close to ground level where it is more humid. Females become more active in the evening. Most egg-laying occurs at dusk when conditions are calm and temperatures are above 10–11°C (Pivnick and Labbé 1993). Females live 3–7 days and lay an average of 80 eggs underneath the glumes or on grooves on the floret surface. Eggs are laid singly or in clusters of up to four eggs on the florets of emerging wheat heads. Each larva crawls into a floret and feeds on the kernel surface for 2–3 weeks. Mature larvae remain within their cast skin in the wheat head when conditions are dry. Once moist conditions are detected, larvae drop to the ground, burrow into the soil, spin a larval cocoon and overwinter. The following spring, further larval development depends on temperature and soil moisture. If conditions are dry during May and June, larvae remain dormant until the following year; if moist, larvae leave their cocoons and move to the soil surface to pupate (Basedow and Schütte 1973; Doane et al. 1987; Elliott and Mann 1996).

Canadian varieties of hard red spring wheat, durum wheat and soft spring wheat differ in their susceptibility to damage (Elliott et al. 2000a, b). The extent of crop damage due to wheat midge depends on its population density, spatial distribution, and timing of oviposition relative to heading and anthesis (Wright and Doane 1987; Elliott and Mann 1996). In addition to causing yield loss, lesser damage to kernels also results in a lower grade for grain (Dexter et al. 1987; Elliott 1988; Lamb et al. 2000). Currently, *S. mosellana* infests much of the wheat-growing area of Manitoba, Saskatchewan, North Dakota and Idaho, and is beginning to invade Alberta and Montana (Lamb et al. 1999; Bechinski and Loftus 2000; Olfert et al. 2004; Shanower 2005). Wheat midge also occurs in wheat-growing areas of Nova Scotia, Ontario, Quebec, and British Columbia (Doane et al. 2002).

Starting in 1984, a research team began comprehensive biological, ecological and agronomic studies on this new invasive pest species. That year, *S. mosellana* populations in Saskatchewan were found to be parasitized by an egg-larval parasitoid, *Macroglenes penetrans* (Kirby) (Hymenoptera) (Doane et al. 1985, 1989). The female wasp is 1–2 mm long and lays an egg inside the egg of its host. Despite the presence of the parasitoid, the wheat midge larva completes its development and overwinters in the soil (Doane et al. 2002). The next spring, the parasitoid larva consumes its host, and emerges as an adult in July.

As with many non-native agricultural insect pests, the ecological impact of *S. mosellana* was more associated with efforts to control infestations using chemical insecticides than with impacts that this non-native insect pest had on native plant species (Wright and Doane 1987) and habitat (Floate et al. 1990). In the case of *S. mosellana*, insecticidal sprays were applied to 300,000–500,000 ha of wheat annually to minimize crop damage during a major outbreak in the 1990s (WCCP 1997).

This paper describes the increasing pest status of a non-native, agricultural insect pest (*S. mosellana*), and the positive influence that its natural enemy (*M. penetrans*) and management technologies have had on mitigating the potential economic and environmental impact of wheat midge.

Materials and methods

Surveys of *S. mosellana* and *M. penetrans* abundance and distribution were conducted annually in Saskatchewan in August 1991–2000. The overwintering larval cocoon is the best stage for comparing populations from one year to the next because it is sessile and is present throughout the autumn and early spring when sampling can be done to identify potentially damaging populations for the coming crop year. Four wheat fields per Rural Municipality were selected at random and sampled by taking 10 soil cores (15 cm deep, 5.06 cm^2 in area) in each field. The 10 cores per field were bulked to represent that field. Soil cores were processed by wet sieving as described by Doane et al. (1987). Wheat midge larvae were counted and then dissected to determine whether they were parasitized. Data from approximately 200–300 fields were compiled each year, and summarized to produce a forecast of the damage potential from *S. mosellana* for the subsequent growing season. The field locations (latitude and longitude) were entered into a database compatible for spatial analyses. *Sitodiplosis mosellana* and *M. penetrans* counts (larvae/m^2) were used to generate surface maps of abundance with the 'Potential Mapping' procedure in SPANS GIS® for OS/2—PCI Geomatics. This procedure calculates a weighted average of the point data based on the corresponding values of its 'nearest neighbors', selects the specified risk category and produces a contoured map with different colours representing five population level categories. The area (km^2) of each population level was calculated annually (Table 1).

To estimate wheat production within the areas infested with *S. mosellana*, as calculated by the SPANS GIS® software, we obtained estimates of: (i) the proportion of total land area that was in crop production in any given year; and (ii) the proportion of total crop production area that was in wheat production (Saskatchewan Agriculture and Food 2007a). Estimates of wheat production (% area) were then applied to calculate the impact of the parasitoid populations in reducing *S. mosellana* numbers below action threshold levels (Saskatchewan Agriculture and Food 2007b). Areas of reduced *S. mosellana* populations were then regarded as not requiring an application of insecticide for control of this invasive species.

The invasive potential of *S. mosellana* was estimated by calculating the dispersal of populations from northeast Saskatchewan (Melfort) from 1991 to 2000 in a southwest direction to the edge of new infestations, as depicted by the SPANS® GIS-produced distribution maps.

Results & discussion

Between 1991 and 2000, Saskatchewan experienced one major outbreak of *S. mosellana*, that lasted from 1994 to 1998 (Fig. 1). The outbreak resulted due to several consecutive years where weather conditions were highly suitable for oviposition during peak adult emergence. Wheat midge populations advanced approximately 360 km spreading from Melfort (52.50° N; 104.37° W) to Swift Current (50.28° N; 107.8° W). Populations advanced in south and westerly directions an average of 36 km/year; the greatest distance occurring in 1993 (90 km) and the least in 1997 (10 km) (Fig. 1). Populations of *M. penetrans* successfully followed the advance of *S. mosellana*, never lagging far behind (Fig. 2).

For the agricultural areas of the province that were surveyed annually for wheat midge, the estimated area under crop production was 51% of the total land base (Saskatchewan Agriculture and Food 2007a). Non-crop production areas included summer fallow, improved pasture, unimproved pasture and wooded

Table 1 Area (km^2) of wheat midge, *Sitodiplosis mosellana* (Géhin), infestation in Saskatchewan, 1991–2000

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total midge larvae (m ^{2})										
None	287	2376	22495	22439	25613	20981	17739	5058	11423	7496
<600	67667	107544	89419	81585	138821	143843	86289	103223	143324	202616
600 ≤ 1200	18699	12703	29352	46438	44615	38222	54993	52868	70891	48073
1200 ≤ 1800	1226	5300	5865	18024	10218	10663	26621	37529	21272	7467
>1800	540	3131	9271	19135	7135	8456	45011	37828	12494	6966
Viable midge larvae (m^2)										
None	287	4776	22682	22687	28305	21569	18681	5086	11576	11855
<600	81168	115631	113934	125836	162047	164892	117778	133841	198494	243398
600 ≤ 1200	6771	7086	14508	23891	26647	25145	49787	58735	39925	12764
1200 ≤ 1800	125	1429	1977	8558	4395	5944	19623	19528	6408	3866
>1800	68	2132	3302	6648	5008	4616	24785	19316	3001	740
≥600 midge larvae (m^2)										
Total midge	20465	21134	44488	83597	61968	57341	126625	128225	104657	62506
Viable midge	6964	10647	19787	39097	36050	35705	94195	97579	49334	17370
Difference (area)	13501	10487	24701	44500	25918	21636	32430	30646	55323	45136

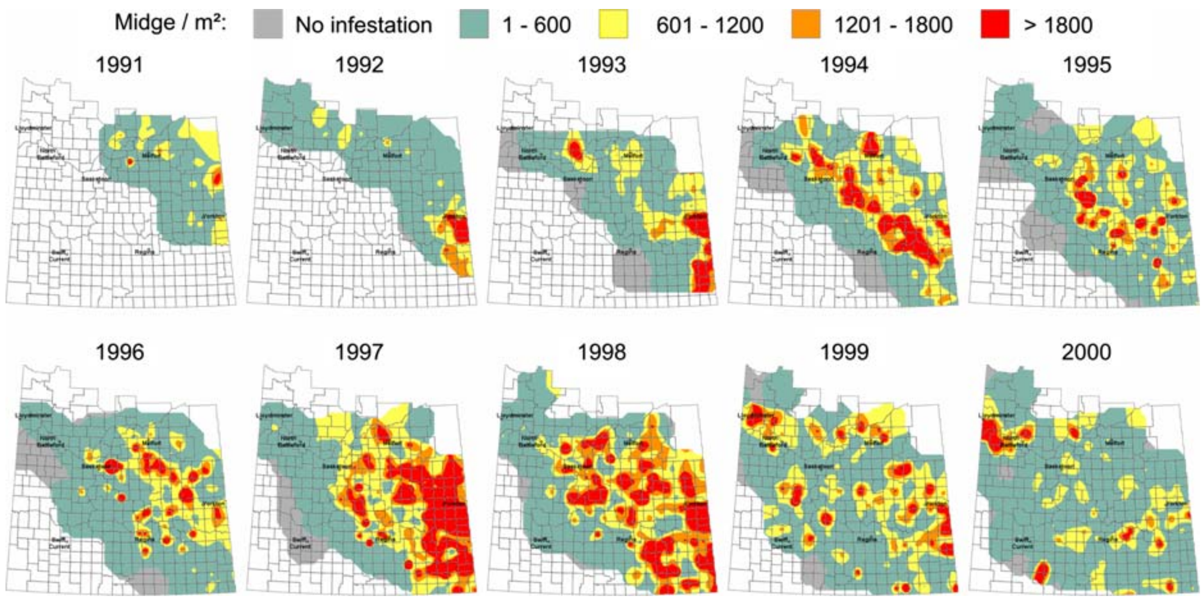

Fig. 1 Larval populations of wheat midge, *Sitodiplosis mosellana* (Géhin), estimated from soil core samples in Saskatchewan from 1991 to 2001

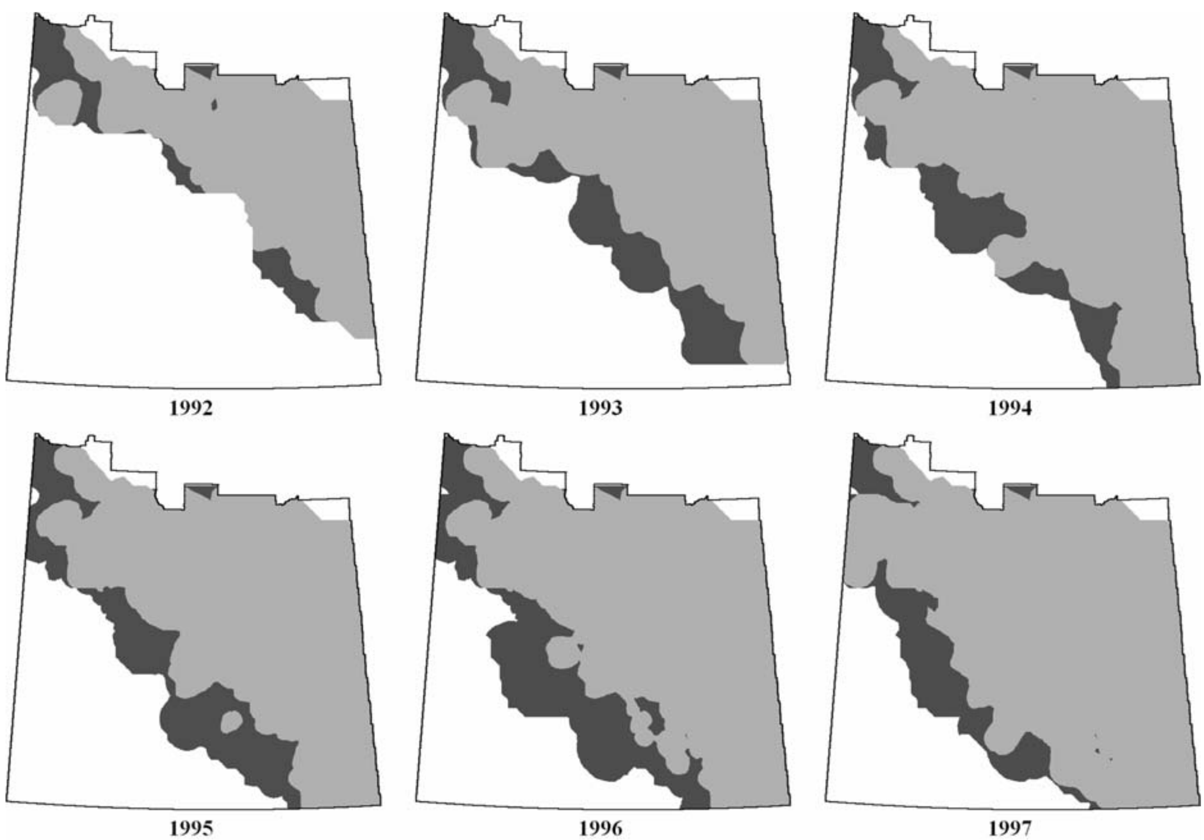

Fig. 2 Area infested with wheat midge, *Sitodiplosis mosellana* (Géhin) (total shaded regions) and area where wheat midge larvae were parasitized with *Macroglenes penetrans* Kirby (light shaded region) in Saskatchewan from 1992 to 1997

areas. The total area that was seeded to wheat in any given year ranged from a high of 8.5 million ha (68.6% of total production) in 1991 to a low of 5.9 million ha (43.9% of total) in 1999 (Saskatchewan Agriculture and Food 2007a). The extent of wheat midge infestations and parasitoid populations in wheat in Saskatchewan is detailed in Table 1. In any given year, >95% of the area infested with wheat midge also had some level of parasitism. Of this total wheat production during the 1990s, there were approximately 15.5 million hectares of wheat in Saskatchewan that did not require a pesticide application because parasitism reduced the density of viable wheat midge larvae to less than 600/m^2 (Saskatchewan Agriculture and Food 2007b). At a cost of $16.00/ha (Saskatchewan Agriculture and Food 2007c), the total saving in pesticide costs alone were $248.3 million. The environmental benefits of not having to apply this amount of chemical insecticide are additional.

Annually, *M. penetrans* controlled an average of 20–45% of the wheat midge population in Saskatchewan (Fig. 3). In some individual fields, the rate of parasitism was as high as 80%. In 2000, the average rate of parasitism across Saskatchewan was 45%, which is still below parasitism levels (64%) commonly recorded in Europe for *S. mosellana* (Carl and Raps 1992). Researchers at Saskatoon Research Centre, collaborating with scientists in Europe, successfully introduced a second parasitoid, *Platygaster tuberosula* Kieffer (Hymenoptera), to further improve biological control of wheat midge (Olfert et al. 2003).

To protect this valuable resource, new pest management tools must continue to preserve parasitoid populations into the future. For example, the recent development of wheat cultivars that are resistant to wheat midge feeding (Lamb et al. 2002a) will negatively impact localized populations of the parasitoid in situations where the host is decimated. Smith et al. (2004) designed an agronomic practice of providing a refuge for virulent *S. mosellana* which allows producers to grow resistant wheats while at the same time protecting the resistance gene from being overcome by *S. mosellana*, and providing a host population for preserving parasitoid populations. In relation to chemical control options, Elliott et al. (1991) and Elliott and Mann (1997) developed reduced-risk strategies for insecticides to control *S. mosellana* while minimizing the impact of insecticides on parasitoid populations.

In conclusion, to minimize the economic and ecological impact of *S. mosellana*, wheat producers in western Canada have access to a comprehensive management program (Elliott et al. 2007). Forecasts and risk warnings, monitoring tools, cultural control, agronomic practices, chemical control, biological control and plant resistance are all available for the industry to manage *S. mosellana*. Prior to the growing season, forecast maps predict high risk areas (Olfert et al. 2004). If the rotation allows, the producer may choose not to grow wheat, grow a resistant variety of wheat (Lamb et al. 2002a), or grow an alternate resistant crop instead. If a lower degree of infestation is predicted, producers may stick to their plans to grow wheat, but may choose a less susceptible wheat cultivar and plant early to avoid high midge populations during heading (Elliott et al. 2000a). Producers are urged to monitor crops closely in all areas where *S. mosellana* is present during the susceptible period (emergence of the wheat head from the boot until anthesis begins). Field scouting tools, including visual counts (Elliott and Mann 1996), sticky cards (Lamb et al. 2002b), and pheromone traps (Gries et al. 2000) are readily available for producers to utilize. An insecticide application is recommended when the crop is heading but not yet flowering and wheat midge density is one adult per 4–5 wheat heads. To maintain optimum grade, insecticide should be used when the pest population reaches one adult per 8–10 heads (Elliott et al. 2000b). Late insecticide applications should be avoided as it is not cost effective and may adversely affect biological control agents (Elliott and Mann 1996).

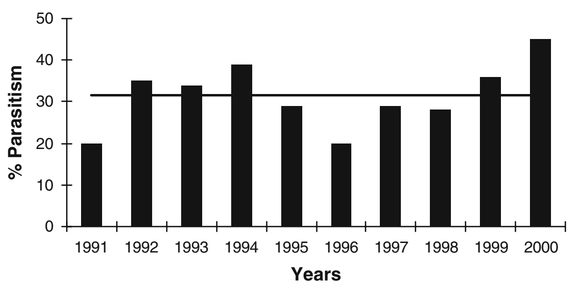

Fig. 3 Annual provincial average rates of parasitism of wheat midge, *Sitodiplosis mosellana* (Géhin), in Saskatchewan in 1991–2000. *Solid line* indicates overall mean rate of parasitism

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