Chapter 9
Implementation and Adoption of Integrated Pest Management in Canada: Insects

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Abstract Canada is one of the largest agricultural producers and exporters in the world, and agricultural production systems are as varied as might be expected in such a vast country with many different regions, soil types and climates. In this Chapter we present general background information on Canada and its agricultural insect pests followed by a discussion of pesticide use and the current situation regarding integrated pest management (IPM). Regulations, and roles and responsibilities of the various levels of government, universities, commodity organizations and private companies in research, development and extension, are discussed. Finally, four case studies are presented to illustrate the status of IPM for the cabbage maggot, *Delia radicum*, in vegetable brassicas, the wheat midge, *Sitodiplosis mosellana,* in wheat, and various insect pests in apples and grapes. These studies of IPM in very different production systems provide insight into the challenges of establishing robust integrated insect management approaches and the parameters required for successful IPM. The wheat midge IPM program for example, has been adopted widely, largely because the insect can be identified with confidence, and most key components for successful IPM are in place. These include cultural practices, an early-warning system, degree-day models and economic thresholds. In contrast, management of the cabbage maggot is challenging and IPM systems remain rudimentary. Despite a strong theoretical understanding of its ecology, species identification is difficult and unreliable, there are few economic thresholds and limited control options. In summary, it is clear that the development and extension of IPM programs for insect pests in agriculture is a priority in Canada.

Keywords Canada · Integrated pest management · Apple IPM · Wheat midge · *Sitodiplosis mosellana* · Cabbage maggot · *Delia radicum*

9.1 Introduction

Canada is a vast country (land: 9,984,670 km^2, water: 891,163 km^2), inhabited by 33 million people (Vincent 2011) and framed by the Atlantic, Pacific and Arctic Oceans (Fig. 9.1). Much of the Canadian landscape is forest, lakes, rivers and tundra, but there are areas in each province with suitable land and either a maritime or a rather temperate continental climate which allow agricultural production. Some areas located in southern Quebec, Ontario and British Columbia have relatively intense and diverse agricultural industries. Average winter and summer high and low temperatures, precipitation, number of frost-free days, soil types and other parameters relevant to agricultural production vary from region to region. Politically, Canada is divided into ten provinces and three territories with a central federal government headquartered in Ottawa, Ontario (Fig. 9.1).

Fig. 9.1 Map of Canada showing provinces and territories. (*N.B.* is New Brunswick, *P.E.I.* is Prince Edward Island and *Sask.* is Saskatchewan)

The origins of many of our insect pests are uncertain (Morris 1983) but a large proportion are invasive alien species introduced over the last 200 years in soil used as ship's ballast, in packing straw and on plants and animals (Lindroth 1957) and more recently through the global movement of humans and their goods. Several species invade periodically from more southerly sources. An example is the diamondback moth *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), which reaches outbreak levels in canola (*Brassica napus* L. and *B. rapaoleifera* (DeCandolle) Metzger), and vegetable brassicas in some years. Many native species reach pest status under favorable conditions including grasshoppers (*Melanoplus* spp. (Orthoptera: Acrididae)), the apple maggot (*Rhagoletis pomonella* (Walsh) (Diptera: Tephritidae)) and the Colorado potato beetle (*Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae)).

No comprehensive text exists on the history of integrated pest management (IPM) in Canada although Riegert (1980) discussed the development of economic entomology in the three Prairie Provinces and British Columbia. IPM in Canada followed a path similar to that of many other countries (see Kogan 1998; Walter 2003 and references therein, Brewer and Goodell 2012). Canadians have been at the forefront of the development of "integrated control" since the 1940s, with pioneering research in Nova Scotia by A.D. Pickett and associates from Agriculture and Agri-Food Canada (AAFC) (Figs. 9.2a and 9.2b). The insecticidal properties

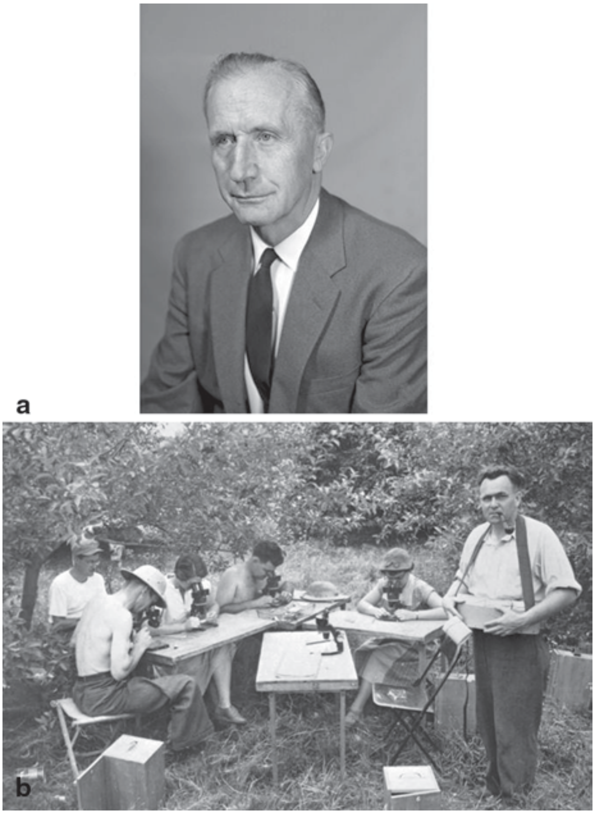

Fig. 9.2 **a)** A.D. Pickett, Entomologist, AAFC-Kentville, Nova Scotia, Canada. **b)** Staff from AAFC-Kentville, Nova Scotia, Canada identifying samples in the field (L to R – C. M. Phillips, Dr. A. W. MacPhee, H. J. Herbert, K. H. Sanford, E. J. Armstrong, and F. T. Lord, ca. 1950) (copyright ©1986. Catalogue number: A52-61/1986 E, AAFC. All rights reserved)

of DDT were recognized in 1939 and this insecticide dominated insect control in Canada and much of the world for the next 25 years. Spider mites became a problem in apple orchards in Nova Scotia only after DDT was used for spider mite control (McEwen and Stephenson 1979), and studies on the fauna of apple orchards in Nova Scotia were initiated in 1943 to determine the long term effect of the indiscriminate use of broad-spectrum spray chemicals on insects in the orchard environment (Pickett and Patterson 1953; MacLellan 1986). The development of IPM for agricultural insect control in Canada has continued to be a focus since that time.

In terms of pesticide use in Canada, there is no coordinated national collection of data on the use of insecticides or any other pesticides. However, during the development of an agri-environmental indicator for risk of contamination of water by pesticides, data were collected for use between 1986 and 2006 (Cessna et al. 2010). The amount of pesticide applied to Canadian cropland during that period, remained relatively constant, ranging between 29.7 and 35.4 million kg annually. In 2006, approximately 84 % of pesticides was applied in the Prairie region of Canada, specifically the provinces of Saskatchewan, Alberta and Manitoba. Ninety-four percent of all pesticides applied in Canada in 2006 were herbicides (Cessna et al. 2010). Insecticides accounted for just 2 %, although the relative proportions of herbicides, fungicides and insecticides varied by province (Cessna et al. 2010). Pesticide use data and information about IPM approaches used for the production of three crops (apple, carrot, grape) were collected in a pilot survey commissioned by AAFC following the 2005 growing season. Although the survey provided excellent information for a snap shot of practices in the given crops, the pilot also demonstrated that the survey was not a feasible approach to track pesticide use and pest management practices for specific crops over time.

Some individual provinces collect data to assist in the development and tracking of policy objectives related to pesticide use and reduction. For example, "Food Systems 2002" (FS2002) was a program established in Ontario in 1987, with the explicit goal of reducing pesticides in food production by 50% by 2002. FS2002 consisted of various components, including research, education, field delivery and pesticide use surveys conducted every 5 years (Appleby and Murphy 2003). Between 1983 and 1998, FS2002 reported a reduction in pesticide use of 38.4%, primarily on large acreage field crops like corn and soybeans, and measured as tonnes of active ingredient. This reduction was attributed to the increased use of integrated pest management, as well as availability of new low volume products and formulations, improved spray technology, changes in cropping patterns, education and the use of genetically modified crops (Appleby and Murphy 2003). The province of Quebec initiated a similar program, Stratégie Phytosanitaire, several years ago (Stratégie Phytosanitaire 2012). This program has been renewed, with the goal of reducing pesticide use in the province by 25% between 2011–2021. According to the original Stratégie Phytosanitaire, from 1995 to 2002, average pesticide use in Quebec (on a per hectare basis) was reduced by 35.7%.

The approach we have taken in this Chapter is to first discuss the current situation regarding IPM in Canada in general, including regulations, and roles and responsibilities in research, development and extension. This is followed by four case studies of the status of IPM for Canadian agricultural insect pests in apples, grapes, vegetable brassicas and wheat. Apples were chosen partly because of their place in the history of integrated control, and because IPM in apples is more truly "integrated" with inclusion of several key insect pests as well as diseases. By contrast, the viticulture case study presents a very different situation, a reflection in part of the relative immaturity of the grape industry in Canada. The third example describes management of the wheat midge (*Sitodiplosis mosellana*, (Géhin) (Diptera: Cecidomyiidae)), where again a successful IPM program has been developed for this key insect pest in wheat. Finally, *Delia radicum* (L.) (Diptera: Anthomyiidae), the cabbage maggot, is discussed in relation to vegetable brassicas. The cabbage maggot illustrates a situation where there is a strong understanding of the pest biology and ecology, but its application in a practical IPM system remains elusive and current control methods largely preventative. We examine the details of each case in the context of implementation and the availability of key components of an IPM program, including knowledge of pest biology and ecology, monitoring tools, taxonomy, thresholds and control strategies. While this Chapter deals with insect pests, we recognize that IPM refers to all pests, including plant pathogens and weeds.

9.2 Current Situation

9.2.1 Roles and Responsibilities in IPM

Agriculture was established as a shared federal—provincial responsibility in Canada via Section VI: Distribution of Legislative Powers, of the Constitution Act of 1867. Over time, the provinces have had a predominant role in agricultural outreach and extension activities pertinent to regional and local conditions and needs, while the federal government has taken on leadership roles in research and development, international markets and trade, food safety and inspection, and business risk management for growers. The Pest Control Products Act (PCPA), which governs the import, registration for sale, and conditions for use of pesticides, is administered by the federal health department's Pest Management Regulatory Agency (PMRA) (Health Canada 2012a). The storage, transport, sale and use of pesticide products, including commercial applicator licencing, are governed via provincial legislation, allowing provinces to institute further restrictions on pesticide use within their borders, should they so choose. Education for safe use of pesticides is also a provincial responsibility.

Agriculture and Agri-Food Canada (AAFC), the federal agriculture department, delivers programming to enhance the sector's capacity for innovation and competitiveness in international markets, in an environmentally sustainable manner. Integrated pest management is a key to sustainable agriculture, and thus is represented across a range of programs delivered by AAFC or jointly with the Canadian provinces within the context of a comprehensive agricultural policy framework (Cass and Kora 2012). Federally supported IPM research takes place at twenty AAFC research centres located across Canada, with teams of researchers active in biological pest control, pest identification and biology, behavior, forecasting, cultural and mechanical pest and weed management methods, resistant variety development, discovery and development of biopesticides and semiochemicals, and integrated systems approaches to pest management to reduce reliance on chemical-based control (AAFC 2012). Some specific examples are provided in the case studies below.

In addition, AAFC has in place two federal technology transfer programs which specifically support integrated pest management implementation: the Minor Use Pesticides Program (MUPP) (MUPP 2011) and the Pesticide Risk Reduction Program (PRRP) (PRRP 2011). The MUPP, modeled on the successful USDA IR-4 Project (IR-4 2012), complements minor use work carried out at the provincial level. Within this program, regulatory data generation trials are conducted and submission packages are assembled and submitted to PMRA to make new pest management product uses available for Canadian growers of small acreage and specialty (i.e., "minor") crops, thereby expanding the options available to growers. The PRRP works with industry stakeholders and experts to develop and transfer integrated management strategies to address priority pest management issues, and supports IPM implementation projects which develop, validate and/or demonstrate and communicate new IPM tools and approaches. The PRRP also conducts data generation trials and provides regulatory support to facilitate the development and registration of biopesticides, important tools in the IPM tool-box.

Areas of joint federal—provincial activity include applied research, forecasting and monitoring, Environmental Farm Plans (EFPs) and Beneficial Management Practices (BMPs) adoption programs. Under the EFP and BMP programs, Canadian producers have accessed incentive payments for adoption of a number of BMPs pertinent to IPM including development of farm-scale IPM plans, use of biological control agents, and adoption of designated pest management approaches posing a lower risk to humans and environment.

Canadian provinces have assumed the lead in areas of applied research, grower education, awareness-raising regarding new approaches and best management practices, and certain IPM program elements such as pest monitoring and risk advisories, and pest management recommendations. Provinces provide extension services in different ways across the country; some but not all provinces have employees on staff to provide traditional in-field extension services. Most Canadian provinces have comprehensive resource websites where growers can access information relevant to pest management in their operations; many also offer telephone hotline services or pest advisories and alerts.

Experts at Canadian universities conduct research into aspects of IPM; some also provide grower training. Academics are included in advisory groups through which they provide policy advice to federal and provincial governments related to IPM planning and programming. Several Canadian academic institutions are particularly active in the area of agricultural IPM, such as the University of Guelph (Ontario), Dalhousie University (Nova Scotia), Macdonald Campus of McGill University (Quebec), the University of Saskatchewan (Saskatchewan), Simon Fraser University and Kwantlen College (British Columbia).

In addition to governmental and academic IPM activities, many commodity organizations in Canada take a proactive approach to provide their members with support and guidance in implementing IPM systems in their agricultural operations. The Canadian Nursery and Landscape Association (C.N.L.A. 2012), the Canadian Horticulture Council (C.H.C. 2012), Saskatchewan Pulse Growers (S.P.G. 2012), the Canola Council of Canada (C.C.C. 2012), and Flowers Canada Growers (F.C.G. 2012) are examples of industry organizations which have put an emphasis on IPM and have made tools and information available to their member growers.

9.2.2 Methods in IPM Extension in Use in Canada

In general, the trend over the past several years has shifted toward mass communication of information via websites, e-mail and phone advisories, and recently, applications which can be accessed via smartphones. Most provinces use a combination of approaches to inform and educate growers about pest risks and advances in IPM.

Some examples of different approaches in use across the country include:

- extension services based upon on-line and winter-time training opportunities (workshops, conferences) complemented by in-season mass communications, and in-person advice delivered by crop/extension specialists at field days and grower meetings;
- information for growers provided mainly through mass communication approaches and grower hotlines/communication centers;
- delivery of extension services through a third party organization and consultants, (e.g., Perennia (2012) in Nova Scotia, Agri-Trend (2012) in the Prairie provinces, E.S. Cropconsult (2012) in British Columbia);
- delivery via grower agri-environmental advisory clubs (e.g., Quebec's "Clubs-conseils en agro-environnemental", groups of producers based in the various regions of the province which hire extension specialists with provincial funding).

Some services are provided free of charge by provincial governments (e.g., publications, pest information, and management recommendations) or by governmental and industry partnerships (e.g., on-line pest risk advisories and weather data), and some are available on a fee for service basis from various companies.

Specific farmer participatory training exercises are used in some provinces to accelerate the adoption of new IPM techniques and systems (e.g., Lygus plant bugs in strawberry, (AAFC PRR06-880 (2012)), grape IPM (AAFC PRR07-590 (2011b)), and demonstration of "Contans", a biofungicide containing *Coniothyrium minitans* (AAFC BP108-030 (2011a)), and on-line information modules (e.g., Ontario Crop IPM 2009)), webinars, crop pest diagnostic days (e.g., Manitoba (2012)), field tours, and other outreach events contribute to informing growers of new approaches in pest management.

9.2.3 Drivers for IPM Adoption in Canadian Agriculture

As in other OECD countries, a number of circumstances are combining to drive an increase in awareness and adoption of IPM in Canadian agriculture (OECD 2012). Markets are beginning to respond to consumer concerns over environmental sustainability in agricultural systems and chemical pesticides used in food production. Some specialized markets now require that growers comply with certain standards of production, which has given rise to a need for sophisticated record-keeping systems. Major buyers/processors can and do play an important role in driving the actual production practices of growers, including pest management practices. In Canada, this influence on growers' IPM practices is exemplified by the case of a potato IPM program (Potato IPM 2012) developed via a collaborative effort of the growers (as represented by the CHC potato council), a major potato buyer and processor (McCain's), and an end user (McDonald's). The voluntary program is centered on a survey of IPM practices which growers complete to assess their position on an IPM continuum.

The province of Quebec has renewed its "Stratégie Phytosanitaire" for the period 2011–2021. The stated goal of the strategy is to reduce risks to human health and to the environment associated with pesticide use in agriculture in the province by 25 % by 2021 in comparison with an average of pesticide use during the reference years 2006–2008 (Stratégie Phytosanitaire 2012). Farmers in the province will be provided training and better access to reduced risk pest management tools and decision support systems such as "SAgE pesticides" (SAgE Pesticides 2012), a system for selection of pesticides taking into account potential impact on health and environment. At the same time, growers will be provided with incentives to adopt IPM systems approaches. It can be anticipated that these measures will have a positive impact on adoption of IPM within Quebec.

In Canada, growers are interested in reducing their reliance on expensive chemical inputs to the extent possible, and in reducing exposure of workers on their farms to potentially harmful compounds. Certain older pesticides are being lost from the pest management tool-box as a result of regulatory re-evaluation, while the usefulness of some pesticides is being compromised due to a rise in pest population resistance to the active ingredients. Growers are forced to deal with new pest threats due to invasive alien species, e.g., *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae), and changes in pest biology or behavior as a result of climate change. These issues all demand long term, robust, systems-based and sustainable solutions.

At the same time that growers are being faced with these pressures, accessibility to IPM information via a number of channels has been greatly enhanced, as discussed above. Elements of IPM infrastructure such as reliable and timely weather data, degree-day forecasts, incorporation of specific geographic and soil information, and refined economic thresholds which take into account natural enemy numbers are becoming more readily available to growers through online and smart phone applications. The ease with which growers can customize IPM information to their own operations is a major factor in determining their success in adopting IPM practices. Together, these factors can be expected to combine to drive change along the IPM continuum toward the use of more integrated, systems based management approaches by Canadian growers.

9.3 Case Studies

9.3.1 IPM in Apple Orchards and Vineyards in Canada

9.3.1.1 Background and Context

It is useful to consider IPM in apple and grape production together given the issues which the two production systems have in common: in both cases fruit are produced by perennial plants planted in rows; production is relatively intensive in terms of plant density, labor and economic value per hectare; both apples and

Fig. 9.3 Apple orchard in bloom, Frelighsburg, Quebec, Canada (photo credit Charles Vincent)

grapes are grown for fresh and processed markets. As well, the rigor of Canadian winters is a major factor restricting the choice of cultivars, fungal diseases are major concerns and drivers of IPM programs, and the timing of IPM interventions can be guided by phenological crop stages.

By contrast, there are major differences between apple orchards (Fig. 9.3) and vineyards which have implications for IPM approaches. Apple trees over-bloom and, after fruit set, fruitlets fall to the ground in June, leaving just one or two fruits per cluster. On grape vines, the number of berries per cluster is frequently >60, with small berries appearing continually throughout the season, and with very few berries dropped to the ground prior to reaching maturity. Apple trees have definite growth whereas vines exhibit indefinite growth, offering a continuous supply of tender tissues to arthropod pests throughout the season. Most apples produced in Canada are aimed at the fresh market and, consequently, tolerance for cosmetic damage is very low. Most grapes grown in Canada are transformed into wine, and thus a certain amount of direct damage to grapes can be tolerated. Apple orchards and vineyards share very few pest species. Finally, from a research and knowledge perspective, a great deal more information has been published over the past decades concerning arthropods of apple orchards (several thousand), while ca. 1,000 articles have been published in viticultural entomology since 1972. As a consequence, radically different research and IPM programs have been developed to service the pomological and the viticultural industries.

9.3.1.2 IPM in Apple Orchards

The principles on which IPM programs for tree fruits rely have been reviewed in Aluja et al. (2009). In Canada, at least 30 arthropod species attack apple orchards (Vincent and Rancourt 1992; Chouinard et al. 2000). As these species can vary in absolute and relative numbers across Canada, optimal IPM programs are tailored to meet specific regional needs. For instance, the plum curculio (*Conotrachelus nenuphar* Herbst (Coleoptera: Curculionidae)) is present in Nova Scotia, Quebec and Ontario, but absent in British Columbia (Vincent et al. 1999; Leskey et al. 2009). In Quebec and Ontario, it is a major pest that requires insecticidal treatments. Similarly, due to wet climate, the pressure exerted by apple scab (*Venturia inaequalis* (Cke) Wint.) in eastern Canada is much greater than in British Columbia, where apple production regions, particularly in the Okanagan Valley, enjoy a drier climate. Conversely, the codling moth (*Cydia pomonella* L. (Lepidoptera: Tortricidae)) is an example of a pest which has been handled differently in different regions of Canada (it is a key pest in the Okanagan Valley but seldom a problem in eastern Canada). The climate and other factors in the Okanagan apple production region have allowed the successful application of an area-wide approach to codling moth management involving sterile insect release. On the other hand, Ontario, Quebec and Nova Scotia reported that this pest continued to have widespread, yearly occurrence with high pest pressure (AAFC 2009b), and resistance to insecticides has been reported in some pest populations.

Alternatives to Insecticides Throughout the years, numerous research projects yielded information frequently formatted as research articles or technical bulletins. This information has been blended into optimal apple IPM programs which have, for the past decades, been based upon chemical pesticides. However, the need for alternatives to the use of insecticides for many of the reasons identified earlier in this chapter including consumer awareness of environmental issues and legal restrictions on the use of some insecticides is clear. In particular, the regulatory phase out of azinphos-methyl (a broad spectrum insecticide widely used in apple IPM programs) in 2010 presented challenges for apple producers. In preparation for this, the Pest Management Regulatory Agency (PMRA) and AAFC's Pest Management Centre implemented strategies to ensure adequate reduced risk alternative products were brought forward for Canadian registration, and that IPM approaches and alternative tools be added to the tool-box where possible. As a result of these efforts, 24 new minor use submissions of alternative products were made, novel pest monitoring tools were developed and projects demonstrating the use of all of these IPM tools were supported (Sethi 2011).

Numerous soft alternatives have been investigated or developed in Canada. For example, AAFC's Pest Risk Reduction Program funded a research project to support the use of *Lathrolestes ensator* Brauns (Hymenoptera: Ichneumonidae), a larval parasitoid of the European apple sawfly (*Hoplocampa testudinea* Klug (Hymenoptera: Tenthredinidae)) (Fig. 9.4) (Vincent et al. 2001, 2013). Virosoft CP4, a baculovirus-based biopesticide (Lacey et al., 2008), has been developed through a partnership between Biotepp Inc. (Mont-St-Hilaire, Quebec) and AAFC (Vincent et al. 2007). Mating disruption techniques (i.e., saturation of the atmosphere by sex pheromones) are commercially available. Persistence of insecticidal activity of novel encapsulated formulations of *Bacillus thuringiensis* var. *kurstaki* has been determined in field trials against the oblique banded leafroller (*Choristoneura rosaceana* Harris (Lepidoptera: Tortricidae)) (Côté et al. 2001). The Okanagan-Kootenay

Fig. 9.4 **a)** Adult European apple sawfly, *Hoplocampa testudinea*, on apple flower (photo credit Leo-Guy Simard), **b)** European apple sawfly, *Hoplocampa testudinea,* damage on apples (photo credit Julien Saguez)

Sterile Insect Release (OKSIR) program has successfully kept codling moth below problematic levels for a number of years through an integrated approach consisting of: mandatory area-wide control application of sterile insects or mating disruption; surveillance via pheromone traps and visual inspections; enforcement, and; grower education. Between 1991 and 2008, the amount of organophosphate insecticide used per hectare was reduced by 93 % (OKSIR 2012).

Few alternative methods have the potential to impact several organisms belonging to different classes (Vincent et al. 2003). Noteworthy exceptions are apple leaf shredding, which can impact both apple scab and the spotted tentiform leafminer, (*Phyllonorycter blancardella* (Fabr.) (Lepidoptera: Gracillariidae)) (Vincent et al. 2004), and cellulose sheeting, which can impact weeds, the European apple sawfly and the plum curculio (Benoit et al. 2006). Other physical methods such as perimeter trapping of apple maggot adults have been researched with some success (Bostanian et al. 1999).

While the use of insecticides remains the only feasible approach in some cases, the use of a border spray strategy may dramatically reduce the quantities of insecticides recommended compared to full orchard treatment. An example is the plum curculio, where a border row strategy using products targeting the adults can reduce insecticide use by up to 60 % (Vincent et al. 1997, 1999). Such savings are achieved at the cost of increased labor, i.e., frequent monitoring of fresh oviposition scars. Likewise, border row strategies have been developed in Ontario for the codling moth and the apple maggot (Trimble and Solymar 1997). However these strategies need further verification when applied to the use of newer, reduced-risk products (AAFC PRR09-020 2011c). Although some insecticides have been used each year for ca. 50 years, little resistance has been documented so far in Canadian orchards, with the exception of the spotted tentiform leafminer in Ontario (Pree et al. 1986), and the oblique banded leafroller in Quebec (Smirle et al. 1998). Strategies to maximize populations of natural enemies are being investigated including approaches to attract beneficial arthropods. To that effect, Bostanian et al. (2004) planted flowering plants in orchards to attract beneficial arthropods. Selection of the least disruptive chemical is another strategy to conserve natural enemies, for example Lefebvre et al. (2011) assayed six "reduced risk insecticides"on *Galendromus occidentalis* (Nesbitt) (Phytoseiidae), a major predator in the Okanagan Valley of British Columbia. Information collected in a voluntary survey of pest management practices in apple production during 2005 indicated that of the 528 tonnes of insecticide active ingredient applied, 88 % (465 tonnes) was mineral oil, a reduced risk product used to prevent pest population buildup (AAFC 2008).

IPM Delivery Programs in Apple As mentioned above, in Canada, provinces are responsible for extension services, and the modalities of program delivery vary from one province to another. The Quebec Apple network is an organization that coordinates information across all stakeholders in that province (Chouinard et al. 2006). Information is gathered mostly by agro-environmental clubs (i.e., nonprofit organizations) that are co-financed by apple growers and the Quebec Ministry of Agriculture. This ensures real-time access to information by the participants. Traditionally, the results of research programs have been made available through a number of technical bulletins (e.g., Vincent and Rancourt 1992; Chouinard et al. 2000). As in other provinces, information flow has been streamlined due to the availability of web-based documents in recent years. An unusual example of IPM delivery is the model used by British Columbia's OKSIR (OKSIR 2012), which is delivered by an organization funded through municipal taxes, the only example of its kind in Canada.

Apple orchards are mature systems in terms of research and markets. Overall, owing to the activities described above, pesticide usage in apple orchards has remained relatively stable and the expected gain in further reducing pesticide input is likely to be small.

9.3.1.3 IPM in Vineyards

Among horticultural crops in Canada, vineyards have experienced great economic growth in the past 40 years; this trend appears to be steady in the foreseeable future.

As mentioned previously, the scientific literature pertaining to Canadian vineyards is limited and the need for information urgent.

The principles on which IPM programs for vineyards rely have been discussed in Vincent et al. (2012). Grape diseases are major problems (Carisse et al. 2009) driving IPM programs, and in Canada, research efforts differ across provinces. The most serious insect pest management problems differ from one province to the next, and research activities in the producing regions also reflect this reality (AAFC 2009a). In Quebec for instance, the strategy has been to first systematically document the biodiversity of arthropods in unmanaged or lightly managed vineyards (summarized in Vincent et al. 2009). Thus, Bostanian et al. (2003) reported on the main arthropod pests, Goulet et al. (2004) found 124 carabid species, while Bolduc et al. (2005) found 97 spider species, Bouchard et al. (2005) reported 73 species of curculionids, Lucas et al. (2007a) reported 20 species of coccinellids, and Lesage et al. (2008) reported 59 species of chrysomelids. Such information should prove to be useful for the development of strategies to manage vineyards with relatively little use of broad-spectrum insecticides. The status of some important horticultural insect pests remains unclear. In laboratory experiments Fleury et al. (2006) found that adults and nymphs of the tarnished plant bug (*Lygus lineolaris* P. de B. (Hemiptera: Miridae)) may feed on vines early in the season and have a minimal impact at that time of year. In Ontario, the multicolored asian ladybeetle (*Harmonia axyridis* Pallas (Coleoptera: Coccinellidae)), originally imported as a biocontrol agent (Lucas et al. 2007b), became a problem in some years; when abundant and crushed with the grapes at harvest, it releases alkyl-methoxypyrazines that, in small concentrations, taint the wine (Vincent and Pickering 2013).

Alternatives to Insecticides In Ontario Trimble (2007) worked on the development and implementation of pheromone dispensing technologies to manage the grape berry moth (*Paralobesia viteana* (Clemens) (Lepidoptera: Tortricidae). Because of the sustained demand for planting new vineyards, Canada had to import vines from other countries, notably from Europe. However, to prevent the importation of phytoplasma diseases (vectored by cicadellids—see Olivier et al. 2012), the Canadian Food and Inspection Agency (CFIA) is enforcing strict regulations. Thus, thermal treatment of imported vines is required to prevent phytoplasma dissemination.

IPM Delivery Programs in Vineyards In Canada, IPM programs in viticulture do not benefit from the wealth of information and tradition enjoyed by their colleagues working in pomiculture. Owing to the paucity of local research information, a peek at the web sites of neighboring states in the USA is common. As described for apple orchards, viticultural information is available through provincial web sites. However the sustained growth of the viticultural industry and the advent of invasive arthropod species will exert pressure to increase resources devoted to research and extension.

Fig. 9.5 Adult wheat midge, *Sitodiplosis mosellana,* on wheat head; insert shows *Macroglenes penetrans*, a parasitoid of the wheat midge (photo credits AAFC- Saskatoon)

9.3.2 Management of the Wheat Midge, Sitodiplosis mosellana (Géhin)

9.3.2.1 Background and Context

Wheat is Canada's largest crop both in relation to area seeded (~14 million ha) and production (~30 million tonnes). Canada's annual wheat export revenues are approximately CDN$ 5.5 billion, making wheat the highest earner of all exported agricultural products. The major provincial producers are Saskatchewan (46 %), Alberta (30 %), Manitoba (14 %) as well as Ontario and Quebec (10 %). Wheat midge, *Sitodiplosis mosellana* (Géhin) (Diptera: Cecidomyiidae) (Fig. 9.5), is an invasive alien species accidentally introduced into North America in the early 1800s (Felt 1912). First reported in western Canada in 1902 (Fletcher 1902), *S. mosellana* did not emerge as a major pest until wheat growers in northeast Saskatchewan experienced losses in excess of CDN$ 30 million in 1983 (Olfert et al. 1985). Today, while the wheat midge is still a major pest of spring wheat, *Triticum aestivum* L., durum wheat (*Triticum durum* Desf.), and triticale (*X-Triticosecale*) in most wheat-growing areas of Canada and several neighboring U.S.A. states (Olfert et al. 2009), growers have access to a comprehensive integrated pest management program developed over the past 15–20 years.

9.3.2.2 Development of a Successful Integrated Management Program

As with all new pest problems, the development of an effective IPM program begins with knowledge of the biology of the pest and the nature of the pest/host crop interaction. The life cycle of *S. mosellana* was reviewed by Mukerji et al. (1988) for Canada. Adults emerge over a six-week period beginning in late June or early July. Populations tend to peak during the second or third week of July in western Canada. Females are most active in the evening, with egg-laying occurring primarily at dusk when conditions are calm and temperatures are above 10–11 °C. Eggs are laid singly or in clusters of up to four eggs on the florets of emerging wheat heads. Larvae crawl into the floret and feed 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 occur, larvae drop to the ground, burrow into the soil, spin a 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; however, if moist, larvae leave their cocoons and move to the soil surface to pupate.

Although traditional Canadian wheat varieties differ in their susceptibility to damage, the severity of damage is largely dependent on the synchrony between egg-laying and heading. Wheat heads are most susceptible to damage when egg-laying occurs during heading (Zadoks growth stages 51–59; Elliott and Mann 1996). Damage declines dramatically when egg-laying occurs after the anthers are visible. Moist conditions in May and June favor larval development. Injury is caused by larvae feeding on the surface of developing kernels. A single larva developing on a kernel will result in scarring; however, three or more larvae within a floret will result in kernel abortions or not filling properly. Mature kernels from infested florets are cracked, shriveled or deformed. Damaged kernels that are harvested will lower grain quality (i.e., milling and baking properties).

9.3.2.3 Successful Management Tools

Biological Control

In 1984, *S. mosellana* populations in Saskatchewan were found to be parasitized by a native egg-larval parasitoid, *Macroglenes penetrans* (Kirby) (Hymenoptera: Pteromalidae) (Fig. 9.5) (Doane et al. 1989). Despite the presence of the parasitoid within the egg, the wheat midge larva completes its development and overwinters in the soil (Doane et al. 2013). The next spring, the parasitoid larva consumes its host, and emerges as an adult in July. In 1985, a study was initiated to evaluate parasitoids that could be introduced to augment the biological control provided by *M. penetrans*. From European studies (Affolter 1990), it was determined that *Platygaster tuberosula* Kieffer (Hymenoptera: Platygasteridae) was a good candidate for introduction into North America. Females of *P. tuberosula* lay their eggs in *S. mosellana* eggs or early-instar nymphs, and the parasitoid adults emerge from the host pre-pupae or pupae. Major releases of *P. tuberosula* were carried out in the mid-1980s. Although its overall impact on *S. mosellana* populations still needs to be quantified, the introduction of *P. tuberosula* to Saskatchewan was successful. Meanwhile, evidence shows that *M. penetrans* continues to play a lead role in regulating *S. mosellana* infestations in western Canada. In 2011, soil core samples from the major release site revealed that 33 % were found to be parasitized with *M. penetrans* and 22 % with *P. tuberosula*. The findings suggest that the two species are co-existing to enhance the control of *S. mosellana.*

Resistant Wheat Varieties

Wheat midge-tolerant wheat varieties were developed to mitigate the lower yields and market grades caused by wheat midge and to offer producers more flexibility in crop rotations (Barker and MacKenzie 1996). Expression of the *Sm1* gene activates a natural response within seeds that prevent larvae from establishing by releasing ferulic and p-coumaric acids (Ding et al. 2000). To conserve the effectiveness of the *Sm1* gene, new tolerant cultivars have been released as a blend, containing a ratio of 90 % resistant seed and 10 % seed of a registered susceptible cultivar. The blend helps to prevent the development of resistant mutations in midge populations by allowing sufficient numbers of susceptible midge to survive and mate with midge that become resistant to the *Sm1* gene. The susceptible cultivar also serves as a refuge and helps to conserve the parasitic wasp, *M. penetrans.*

Cultural Practices

Cultural practices were also found to be an important management strategy (Elliott and Mann 1996). Continuous wheat cropping can result in a buildup of *S. mosellana* populations. In areas where populations exceed 1200 larvae m^{-2}, growers are encouraged to plant resistant crops such as canola (Fig. 9.6), flax, *Linum usitatissimum* L., and legumes instead of wheat. In addition, other cereal crops such as barley, *Hordeum vulgare* L., oats, *Avena sativa* L., and annual canary grass, *Phalaris canariensis* L., can be grown with little or no risk of wheat midge damage. For low to moderate infestations, damage can be reduced by selecting less susceptible varieties of spring wheat, planting early, and at higher seeding rates. These practices promote uniform, advanced heading to avoid high adult *S. mosellana* populations.

Fig. 9.6 AAFC field staff collecting wheat midge and parasitoids in wheat (*Triticum aestivum*) adjoined by canola (*Brassica napus*) in Saskatchewan, Canada (photo credit AAFC-Saskatoon)

Decision Support Tools

At the same time as these management tools were being developed, economic thresholds for insecticide applications were determined and widely adopted by growers. The recommendation was that insecticides should be used only when there was at least one adult midge for every four to five wheat heads at several locations in the field (Elliott 1988a, b), and that applications should be made at dusk. More recently, an early-warning system of crop risk associated with wheat midge populations has been established as a successful decision support tool. Surveys of the abundance and distribution of overwintering larval cocoons of both the pest (*S. mosellana*) and the native parasitoid, *M. penetrans*, are conducted annually in the fall (Olfert et al. 2011). The results identify potentially damaging populations for the following crop year (Fig. 9.7). In addition, accumulated degree-day models accurately predict the emergence of adult *S. mosellana* (Elliott et al. 2009) and the parasitoid, *M. penetrans* (Elliott et al. 2011) throughout the infested areas, and assist producers in scheduling the scouting of their fields for the presence of the pest and its natural enemy. Producers are encouraged to adjust the timing, rate and placement of sprays for control of wheat midge to protect and conserve natural enemies. The mean rates of parasitism in Saskatchewan ranged from 25 to 46 % and from 12 to 38 % in Alberta for the years 2001–2010 and resulted in an estimated saving of $248.3 million in pesticide costs alone. The environmental benefits of not having to apply this amount of chemical insecticide are additional (Olfert et al. 2009).

9.3.2.4 Summary

In conclusion, wheat producers in Canada have access to a comprehensive management program to minimize the economic and ecological impact of *S. mosellana*. This IPM tool kit was developed over a span of 15–20 years, and has been success-

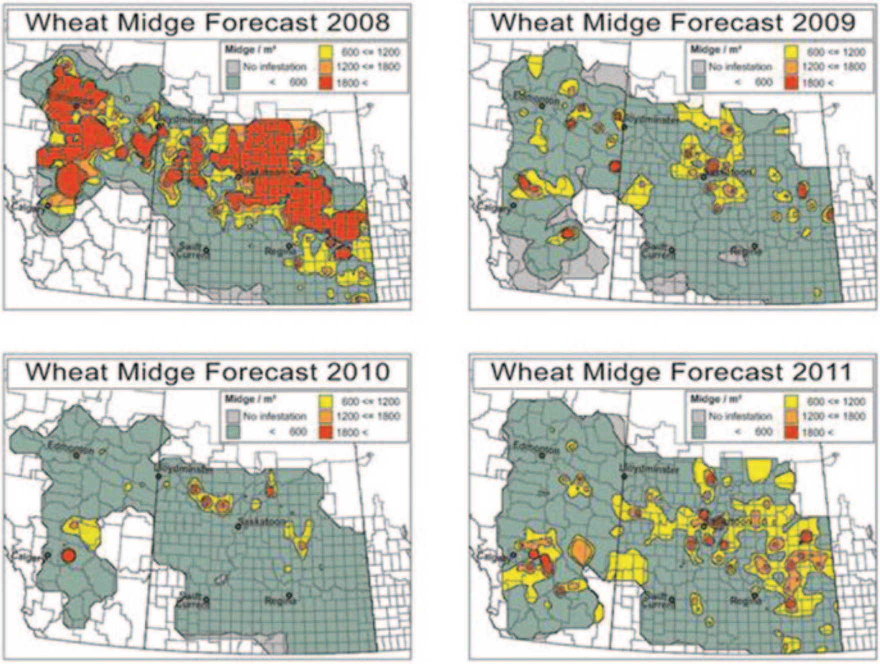

Fig. 9.7 Population distribution and density of wheat midge, *Sitodiplosis mosellana,* in western Canada (2008–2011) (photo credit AAFC-Saskatoon)

fully adopted by producers, in large part due to the technology transfer efforts of researchers and provincial entomologists. Forecasts and risk warnings, monitoring tools, cultural control, agronomic practices, chemical control, biological control and host plant resistance are all available for the industry to manage *S. mosellana*. Prior to the growing season, forecast maps predict high risk areas. If the rotation allows, the producer may choose not to grow wheat, grow a resistant variety of wheat, 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. Producers are encouraged 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, sticky cards, and pheromone traps 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. Late insecticide applications should be avoided as they are not cost effective and may adversely affect biological control agents.

9.3.3 Management of the Cabbage Maggot, Delia radicum (L.)

9.3.3.1 Background and Context

Vegetable brassicas are well suited to the climates of many regions across Canada and many are important as fresh and processing vegetables in British Columbia, Ontario, Quebec and the Atlantic Provinces in particular (AAFC 2005, 2010; Munro and Small 1997). *Delia radicum* (L.) (Diptera: Anthomyiidae), the cabbage maggot, is widespread through temperate regions of the Holarctic (35–60 N) and is one of the most chronic and challenging agricultural insect pests in Canada. It was accidentally introduced from Europe, probably during the nineteenth century (Griffiths 1991; Biron et al. 2000) and now occurs in every Canadian province. *Delia radicum* has undergone frequent name changes since first described (Finch 1989; Griffiths 1991). In Europe it is known as the cabbage root fly (Holliday et al. 2013), and the French Canadian common name is "mouche du chou". *Delia planipalpis* (Stein) and *Delia floralis* (Fallén) are sibling species of *D. radicum* and also crucifer pests, although they are thought to be native and their geographic distributions are more limited. Infestation of brassica roots by larvae of *Delia platura* Meigen and *Delia florilega* (Zetterstedt), is generally secondary (Griffiths 1991), but their presence further complicates an already taxonomically difficult situation. Brooks (1951) attempted to provide a key to the common species of root maggots infesting cruciferous crops in Canada. Correct identification is of course the basis of any IPM program but in the case of *Delia* spp, it is challenging because small and sometimes variable characters must be used to separate species (Brooks 1951; Griffiths 1991). The identification keys found in Brooks (1951) have been the standard reference in Canada for many years but according to Griffiths (1991), not all of Brooks' descriptions are now valid and should be used with caution and in conjunction with other literature.

Delia radicum larvae feed on the roots of many Brassicaceae, such as rutabaga (*Brassica napus napobrassica* (L.)) (Fig. 9.8a), turnip (*Brassica rapa rapa* L.), cole crops including broccoli, cabbage, cauliflower, (varieties of *Brassica oleracea* L.), and canola (Soroka et al. 2002). Canola is a genetic variation of rapeseed developed by Canadian plant breeders specifically for its low level of erucic acid in the oil and low glucosinolates in the meal. Although this section is focused on vegetable brassicas, the large acreage under canola production on the Canadian prairies is relevant as it acts as a huge reservoir for *Delia* pest species.

The insect overwinters as pupae in the soil and spring emergence of flies varies with temperature, soil type, moisture and whether the individual expresses the early- or late-emergence biotype (Finch and Collier 1983; Turnock and Boivin 1997; Andreassen et al. 2010). Eggs are deposited on or near the base of the host plant, usually just below the soil surface (Dixon et al. 2002). One to four generations occur annually in Canada, and they often overlap, in part due to different emergence biotypes (Andreassen et al. 2010; Dixon and Collier 2001). Further details of damage, host finding and life history can be found in Ritchot et al. (1994) and Parsons

Fig. 9.8 **a)** *Delia radicum* larvae on rutabaga (*Brassica napus napobrassica*) (photo credit Carolyn Parsons), **b)** Polyethylene insect netting demonstration on a field of rutabaga (*Brassica napus napobrassica*), St. John's, Newfoundland and Labrador, Canada (photo credit Anna DeMello)

et al. (2007). Natural enemies affect all stages of this insect. A summary of the biology of each species and past deliberate releases in Canada are given in Soroka et al. (2002) and Holliday et al. (2013). Several of the primary parasitoid species that attack *D. radicum* in Europe are present in Canada, presumably introduced along with their hosts. These include *Aleochara bilineata* Gyllenhall (Coleoptera: Staphylinidae) and *Trybliographa rapae* (Westwood) (Hymenoptera: Figitidae). Parasitism of *D. radicum* in Europe by *Aleochara bipustulata* (L.) can exceed 40 % (Brunel and Fournet 1996). *A. bipustulata* does not occur in Canada but its potential as a classical biological control agent has been investigated since 2004 (Andreassen et al. 2009), in part due to its synchronization with *D. radicum* in the spring.

In the past a number of insecticides were available for use against the cabbage maggot, but currently the organophosphate insecticide chlorpyrifos is the only one registered in Canada for management of this insect in vegetable brassicas (Malchev et al. 2010; Health Canada 2012b). With only one insecticide, it is perhaps not surprising that resistance to chlorpyrifos has been reported; in fact this led to an emergency registration of cypermethrin in 2011 in British Columbia (British Columbia 2011).

9.3.3.2 Current Management Practices

A summary of current methods used in cabbage maggot management in vegetable brassicas was obtained through interviews with extension personnel and crop scouts in each province, as well as IPM extension documents.

Cultural Control

Crop rotation is practiced by most growers, primarily to reduce the incidence of soil-borne diseases or other insects such as the swede midge, (*Contarinia nasturtii* (Keiffer) (Diptera: Cecidomyiidae)), but cabbage maggot infestations may be reduced if fields can be separated by a sufficient distance. Adult *D. radicum* are able to fly long distances (Finch 1989) and a limited land base on many farms limits the effectiveness of this practice. There is some indication that fall tillage is beneficial, with up to 75 % of *D. radicum* pupae killed when fields are tilled in the fall, compared with 40 % in the spring (Finch and Skinner 1980). The benefits of fall tillage for reducing *D. radicum* populations would have to be balanced against potential negative impacts like erosion. Many IPM guides recommend controlling weeds like shepherd's purse (*Capsella bursa-pastoris*). This is beneficial for disease management but it is less clear whether cruciferous weeds act as significant reservoirs for the cabbage maggot (Finch 1989).

Resistant Varieties

There are no resistant varieties available.

Insect Identification

The basis of an IPM program is accurate identification of the insect but as described, this is a major challenge with *Delia* spp. Eggs are rarely identified to species in the field. It is possible to separate eggs of some species, but not others, by examination of the pattern of grooves on the chorion (i.e., *D. radicum* and *D. platura* but not *D. radicum* and *D. floralis* (Brooks 1951; Biron et al. 2000)). This however requires the use of a microscope or hand lens. Identification of flies from traps is difficult, time-consuming and requires a microscope and specialized training. The traps available for this are non-selective, and there is a high likelihood that other species will be present. Flies often are not identified but are assumed to be either *D. radicum* or a related species requiring control. The level of precision required will vary with the region and the specific circumstances, for example, in an area where both *D. radicum* and *D. floralis* are present consistently and each pose a threat, does it really matter which species laid the eggs? To further complicate matters, there often is little correlation between egg counts or trap catches of adults, with damage or infestation levels, partly because weather and predation can affect the survival of immature stages. In situations where the majority of trapped flies are determined to be either *D. radicum* males, or *D. platura*, as sometimes happens, the implications for crop damage are not clear.

Crop Scouting

Monitoring of eggs or flies primarily is conducted to help improve timing of application of chlorpyrifos (see chemical control section), so that it coincides with pest activity. The proportion of brassica vegetable acreage scouted varies among provinces. In some, scouting consists of a small number of growers who search for eggs on their own farms, whereas in others, crop scouting is done more widely via grower associations, private companies and consultants who look for eggs, and occasionally, flies. Monitoring eggs in crops which are vulnerable until harvest, like rutabaga, continues through the season in areas where monitoring is carried out at all. Felt egg traps developed in Europe (Freuler and Fischer 1982) have been tested in Canada but did not adequately detect the start of cabbage maggot oviposition in the critical early season (Dixon et al. 2002). Crops are scouted for *D. radicum* eggs much more frequently than for adults, but flies can be monitored using yellow sticky traps, or sometimes, yellow pan traps containing water. Several provincial IPM guides recommend using traps for adults, but provide little guidance for correct identification. Occasionally, growers look for flies on leaves of the host plant during the day.

Prediction of Spring Emergence and Oviposition

The timing of emergence of flies from overwintering sites, and the start of oviposition, can be estimated indirectly using indicator plants or degree day accumulations. This sometimes is used to indicate when to start crop scouting. A proportion of growers and crop scouts use indicator plants; the blooming of yellow rocket (*Barbarea vulgaris*, Brassicaceae), pin cherry (*Prunus pensylvanica,* Rosaceae) and various species of *Amelanchier* (Rosaceae) (e.g., Saskatoon berry, service berry, wild pear, chuckley pear) is considered to coincide with *D. radicum* spring activity and oviposition. Using plant phenology lacks precision, but it is probably sufficient to indicate when monitoring should start. Degree day requirements and base thresholds for development for *D. radicum* have been assessed in some provinces, including Manitoba (Bracken 1988), Newfoundland and Labrador (Coady and Dixon 1997) and Ontario (Ontario Crop IPM 2009). However, accurate prediction of *D. radicum* emergence is complicated by the presence of emergence biotypes and overlapping generations as well as a complex of species, as discussed previously. The proportion of “early” and “late” biotypes in a population of *D. radicum*, varies by region and within a region, and over time (Turnock and Boivin 1997; Dixon and Collier 2001; Andreassen et al. 2010). With a large proportion of late emergers, and more than 1 generation, potentially flies could be present throughout the season, making forecasting difficult. However, forecasting may be useful as a simple indicator of timing to initiate crop scouting for eggs or flies, much like plant phenology.

Economic Thresholds

There are no published economic thresholds in use currently. The assumption usually is made that if eggs are present, regardless of species or quantity, action is required. This is not really an economic threshold, but simply an indication of presence/absence to improve timing of a control strategy like an insecticide drench. The presence of flies on traps can be used as an aid to optimize timing of a drench, or to indicate when to start looking for eggs. Difficulties with fly identification make this approach somewhat questionable.

Chemical Control

There are growers who do not use insecticides and rely on cultural control and physical exclusion methods like insect netting (Fig. 9.8b), but chlorpyrifos is used widely. Generally speaking, most growers apply liquid chlorpyrifos one or more times as a soil “drench”. A granular formulation sometimes is used at planting, particularly in rutabaga, and this is often followed by one or more drenches. Many growers apply drenches prophylactically according to a schedule recommended on the product label, especially in regions with extensive canola production where growers assume that they will have cabbage maggot problems.

9.3.3.3 Summary

There is a strong theoretical understanding of the biology and ecology of *D. radicum*, yet it remains a serious chronic pest. In terms of the key components of an IPM program, tools are available for monitoring flies and eggs but accurate identifications are difficult and time-consuming, there are no resistant varieties, few economic thresholds and limited control options. Most growers use preventative/prophylactic management strategies like insect netting or an insecticide drench, because the risks of crop loss are high if action isn’t taken. Recent Canadian research has focused on various aspects of integrated pest management for *D. radicum*, including physical exclusion by fences (Vernon and Mackenzie 1998) and insect netting (Dixon et al. 2011) (Fig. 9.8b), undersowing (Dixon et al. 2004) and relay cropping (Parsons et al. 2007), varietal resistance (Malchev et al. 2010) and biological control (Holliday et al. 2013; Andreassen et al. 2010). Meanwhile, to address the important issue of species identification, attempts to develop methods for rapid, accurate identification of flies, eggs and larvae are underway. Continuing and future work could be directed to improving trap technology, developing new reduced risk control products including biopesticides, assessing the potential of the sterile male technique, and revisiting the precision of indicator plants, the impact of *D. platura* and *D. florilega*, fall tillage, and brassicaceous weeds as a reservoir for *D. radicum*.

In 2009 the Pest Management Centre of AAFC established a working group consisting of stakeholders including growers, private IPM companies, provincial extension personnel and both University and government scientists. This group has focused on the prioritization of solutions and research needs for the cabbage maggot in Canada, and projects on exclusion fencing, physical barriers applied to the soil, development of resistant cultivars (rutabaga) and on-farm testing of insect netting from Europe, have been conducted. Some of these projects continue previous research with the hope that they will bring IPM approaches to the practical level for implementation by growers.

Vegetable brassicas are affected by many other insect pests and a number of serious diseases (Ritchot et al. 1994), some of which have more advanced IPM programs with accurate identification and economic thresholds. Root feeding maggots remain a problem apart, and are not yet able to be incorporated within a truly integrated program for multiple insect pests, diseases and weeds.

9.4 Conclusions

Agricultural production systems are complex and variable, as are IPM programs, and each requires an understanding at many levels, not only the ecology of the individual species but also their interactions and the ecology of the ecosystem. Unless IPM practices are easy, fast, and cost effective or there is a crisis such as insect resistance or loss of materials, their adoption by growers can be expected to be slow. The case studies presented illustrate examples of successful and not-so-successful IPM programs for agricultural insect pests in Canada. IPM in apple orchards is more developed than that in viticulture for a number of reasons, the most important being the increased research effort and consequent knowledge of the ecosystem in apples compared with grapes. The wheat midge is univoltine on the prairies, it can be identified with confidence, and most key components for successful IPM are in place: cultural practices, an early-warning system incorporating fall surveys, degree-day models, parasitism and economic thresholds. The development and wide adoption of the wheat midge IPM system has resulted in a decrease in the amount of insecticide used for its control. *Delia radicum* is a different story. Although its biology and ecology are well known, IPM programs for *D. radicum* in vegetable brassicas in Canada are rudimentary. Extension information and recommendations are available in most provinces, but implementation and uptake has been patchy. The main reason for this seems to be not a lack of interest on the part of growers, but that several key components needed for an IPM program to be successful, are underdeveloped or missing. Difficulties with accurate identification, few economic thresholds and limited control options coupled with a high risk of crop loss, mean that most growers use preventative management for this insect.

In comparison to many other regions of the world, agriculture in Canada is a relatively new activity. However, over the span of about 200 years, Canada has become one of the largest agricultural producers and exporters in the world. Also during that time, agricultural science has met the challenge to make significant gains in the integrated management of pest species.

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Saskatchewan. http://www.agriculture.gov.sk.ca/.
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