Farm-level Losses and Grower Willingness to Try Management Strategies for Swede Midge in Vegetable Crops

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Keywords. Brassicaceae, Contarinia nasturtii, cruciferous vegetables, grower survey, integrated pest management, organic production

Abstract. Since its introduction to North America in the 1990s, the invasive swede midge (Contarinia nasturtii) has become an important pest of cruciferous (Brassicaceae) vegetables in the northeast and Great Lakes regions of the United States and the Canadian provinces of Québec and Ontario. Swede midge reduces yield in cruciferous vegetables through larval feeding that distorts growth. Overlapping generations, cryptic larval feeding, and lack of effective biopesticides pose challenges for managing swede midge effectively using current tools. In 2018, we distributed an online survey for commercial vegetable growers in the United States and Canada to measure farm-level economic impacts of swede midge and grower perspectives on new management strategies for this pest. Growers reported losing $3808 US ($4890 Canadian) on average per acre per year due to swede midge–related vegetable crop losses. Both organic and conventional growers expressed an interest in paying more for nonchemical swede midge management vs. insecticides and were interested in trying new management strategies, particularly biological control.

Swede midge (Contarinia nasturtii), a small (~1/16 inch) galling fly (Fig. 1), is a challenging invasive pest of cruciferous (Brassicaceae) vegetable crops in the northeastern United States and eastern Canada. This pest severely reduces marketable crop yield through specialized feeding behavior that results in deformities of marketable plant parts (Chen et al. 2011; Readshaw 1961). Organic growers in Vermont, New York, Québec, and Ontario have reported near complete losses, up to 85%, in broccoli (Brassica oleracea var. italica), kale (B. oleracea var. acephala and B. napus), and other cruciferous vegetables due to swede midge infestations (Chen et al. 2011; Hallett and Heal 2001). Climate-based models predict suitable habitat in many of the cruciferous vegetable producing areas of the United States and Canada, including southern Ontario, Québec, the Canadian Maritimes, and the eastern and central United States; the western Canadian Prairies and southwestern United States may not be suitable because of their dry climate (Mika et al. 2008; Offert et al. 2006). Swede midge populations have more recently been reported westward in Michigan (Phillips, 2015), Minnesota (Phillips et al. 2017), and Illinois (Estes 2018).

Broccoli and cauliflower (B. oleracea var. botrytis) are most susceptible to swede midge damage (Hallett 2007). Broccoli, cauliflower, and cabbage (B. oleracea var. capitata) alone accounted for more than 218,000 acres of 2019 cruciferous vegetable production in the United States [U.S. Department of Agriculture (USDA) 2020]. These three crops had a combined value of more than $1.85 billion US (USD) within the United States, with 95% to 99% of revenue from fresh market sales (USDA 2020). Very little to no cosmetic damage is acceptable in fresh market vegetables.

Unlike other foliar-feeding cruciferous vegetable pests, swede midge larvae have a unique ability to alter plant growth (Gagné 1989). Extraoral feeding in the meristem causes swollen petioles, crumpled leaves, scarring, uneven crown formation, and “blind” plants with no central head (Readshaw 1961; Fig. 2). In addition to reducing crop marketability, this feeding strategy provides swede midge larvae protection from contact with insecticides. Because larvae are hidden underneath the new leaves of the plant, insecticides that are not translocated systemically are largely ineffective for swede midge (Hallett et al. 2009; Wu et al. 2006). Compounding these challenges, damage thresholds are low for this pest; a single midge larva can render a cauliflower head unmarketable (Stratton et al. 2018).

Swede midge is particularly difficult to manage on small-scale organic operations. Small farms are unable to use spatial crop rotations to move away from infested fields. Furthermore, there are currently no Organic Materials Review Institute (Eugene, OR, USA)–listed or biological control options for swede midge (Abram et al. 2012; Corlay et al. 2007; Evans and Hallett 2016; Seaman et al. 2013). Although insect exclusion netting is effective for managing swede midge, it is costly and labor intensive to use (Hodgdon et al. 2017). On conventional farms, calendar sprays of neonicotinoid and other systemic insecticides are necessary to successfully manage this pest (Chen et al. 2011; Hallett et al. 2009).

Alternative control measures are needed, particularly for organic growers lacking effective biopesticide options. Strategies currently under development, such as repellent essential oils and pheromone mating disruption, are appropriate for certified organic operations but can be costly, unavailable, and/or unreliable. A better understanding of the severity of swede midge losses, cruciferous vegetable pest management budgets on individual farms, and willingness to pay for new strategies can help shape future research and development programs. Alternative swede midge management tactics are needed to support the cruciferous vegetable industry.

Here, we report on the results of an online survey of commercial vegetable

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<tr>
<th>Units</th>
<th>To convert U.S. to SI, multiply by</th>
<th>U.S. unit</th>
<th>SI unit</th>
<th>To convert SI to U.S., multiply by</th>
</tr>
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<tbody>
<tr>
<td>0.4047</td>
<td>acre(s)</td>
<td>ha</td>
<td>2.4711</td>
<td></td>
</tr>
<tr>
<td>25.4</td>
<td>inch(es)</td>
<td>mm</td>
<td>0.0394</td>
<td></td>
</tr>
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</table>
Fig. 1. Adult female swede midge, ~1/16 inch (1.59 mm) in size. Image courtesy of Jorge Ruiz-Arrocho.

producers that was designed to improve our understanding of swede midge management challenges and grower interest in alternatives to insecticides for vegetable pest management. Our specific objectives included the following: 1) estimate yield losses of cruciferous vegetables due to swede midge on individual farms; 2) identify farm attributes associated with economic losses due to swede midge; 3) identify current management strategies and grower perceptions of efficacy; 4) estimate total grower budgets allocated to cruciferous vegetable pest and swede midge management and understand how pest management budgets differ by farm type; and 5) describe grower willingness to try new alternatives to insecticides for swede midge management. Using survey results from 112 vegetable producers in the United States and Canada, we captured estimates of cruciferous vegetable production on farms, swede midge losses, and budgets for pest management in cruciferous vegetable crops to inform future research and extension programs.

Methods

SURVEY DEVELOPMENT AND DISTRIBUTION. The survey consisted of 30 questions and was estimated to take 15 min to complete. The survey was divided into three sections to capture the following farm and respondent characteristics: Cruciferous vegetable production, cruciferous vegetable pest management, and demographics and farm information. Within the subset of questions associated with swede midge, growers were asked to quantify economic losses (dollars per unit area) to vegetable crops due to swede midge on their farms. Respondents were also asked to select from dollar value ranges how much they would be willing to spend on insecticidal and alternative management strategies for all cruciferous vegetable pests and swede midge specifically. Questions pertaining specifically to swede midge on the farm (losses, management practices currently used and their efficacy, etc.) were automatically omitted for respondents if they did not have experience with swede midge. When asked to rate efficacy of swede midge management strategies currently used, we used a Likert scale for responses, where 1 = very ineffective and 5 = very effective.

We created three versions of the survey: a version for growers in the United States in English and two versions for Canadian growers. The Canadian survey versions included metric units and Canadian dollar estimates, and was available for participants in French or English. Specifically, we sought grower respondents who currently grew cruciferous vegetable crops and had swede midge on their farms. The survey received an Institutional Review Board exemption (15–341) from the University of Vermont Committee on Human Research in the Behavioral and Social Sciences before distribution.

We used an online survey tool (LimeSurvey version 3.1.0; LimeSurvey GmbH, Hamburg, Germany) to distribute our survey to commercial vegetable growers in the northeastern and north-central United States and eastern Canada in regions where swede midge was known to be present: Michigan, Ohio, New Hampshire, New York, Ontario, Pennsylvania, Quebec, and Vermont. To increase survey distribution and improve response rates, we collaborated with extension agents, crop consultants, provincial ministries of agriculture, and vegetable grower organization representatives in each region who had existing relationships with local farmers experiencing swede midge damage. Collaborators advertised the survey using e-mail lists and posts on the social networking services Twitter (Twitter, Inc., San Francisco, CA, USA) and Facebook (Meta Platforms, Inc., Menlo Park, CA, USA). The survey was open to respondents beginning 9 Mar, and the survey was closed 1 Jun 2018.

STATISTICAL ANALYSIS. Our final data set consisted of complete surveys only. We used descriptive statistics to summarize survey responses and performed statistical analyses to answer specific research questions to address our survey objectives. Where analyses included comparisons of organic vs. conventional grower responses, we grouped together certified and noncertified...
practicing organic growers as “organic,” with all others as “conventional.” Means reported in the text are followed by ± standard error of the mean (SEM).

We conducted statistical analyses to address the following research questions within our survey objectives:

Which farm attributes influence economic loss associated with swede midge (Objective 2)?

We used a multivariate regression in statistical software [R ver. 3.6.1 (R Core Team 2021)] to identify whether the following farm attributes were correlated with reported economic losses due to swede midge: Farm size, total land use dedicated to cruciferous vegetable production, average number of cruciferous vegetable crops grown annually, number of months cruciferous vegetables are in production, use of cruciferous cover crops, organic or conventional farming practices, how many years swede midge has been present on the farm, and state or province. If respondents did not report losses due to swede midge in the specified format (dollars per acre or hectare), the values were omitted from the analysis. Here and throughout, confidence intervals of 95% were used for statistical analyses.

Do typical cruciferous vegetable pest management budgets differ between organic and conventional farms (Objective 4)?

When pooling economic data from participants from the United States and Canada, we used the exchange rate $1 USD = $1.28 Canadian dollars (CAD), the average rate during our survey distribution period, to convert reported losses between currencies. We used medians within farms representing organic, and an additional 23% used organic practices exclusively but were not certified. Notably, no grower respondents from Vermont identified their farms as conventional. The lack of conventional grower representation from Vermont and the respondent pool overall is likely due to our survey distribution efforts through organic grower listservs, and the large proportion of certified organic farms within the Vermont vegetable industry. Direct marketing was the most common way by which all grower respondents sold their crops, with 71% marketing directly to consumers. Fifty-five percent grew cruciferous vegetables for the wholesale market. Overall, our grower respondent profile reflected the average vegetable farm in the northeastern United States and eastern Canada that is most prone to severe economic losses due to swede midge: organic small-scale producers in cool northern climates that rely on cruciferous vegetables for retail sales. Although a larger-scale conventional cruciferous vegetable industry exists in this region (i.e., wholesale cabbage in western New York), fewer farms comprise this sector of the cruciferous vegetable industry by number.

Farms responding to the survey grew a variety of cruciferous vegetable crops. Most farms (53%) grew four or more cruciferous vegetables in succession each year. Cruciferous vegetables were growing for 4 to 6 months of the year on 45% of farms, and 7 to 9 months on 34% of farms. Farms grew more than nine types of cruciferous vegetables, with the most common crops being cabbage (80%), broccoli (78%), and kale (73%). Most farms (76%) did not use cruciferous cover crops.

Losses due to swede midge on farms (Objective 1). Growers reported that major losses are occurring on vegetable farms due to swede midge. On average, farms reported losing $3808 USD ($4890 CAD) per acre per year due to swede midge damage in cruciferous vegetable crops. These losses severely reduce the estimated gross profitability of cruciferous vegetable production, which ranges widely depending on market (wholesale or retail), organic certification, and other factors,

We tested if organic growers would be willing to spend more than conventional growers on cruciferous vegetable pest and swede midge management strategies with a Mann-Whitney U test using medians from response ranges. We used Wilcoxon rank-sum tests to examine whether organic and conventional farmers differed in their willingness to pay for insecticide vs. alternative strategies, and Kruskal-Wallis tests to determine whether willingness to pay differed by farm size.

Does grower willingness to try individual alternative strategies for swede midge management differ by farm type (Objective 5)?

We tested if organic vs. conventional growers differed in their willingness to try different pest management strategies by using Mann-Whitney U tests, and Kruskal-Wallis tests to examine whether willingness to pay differed according to farm size. We measured willingness to try based on a Likert scale of 1 to 5, where 1 = very unlikely and 5 = very likely. Where growers were surveyed on their use of or willingness to try “long” and “wide” crop rotation, we refer to temporal and spatial separation of cruciferous vegetable crops, respectively.

Results and discussion

Respondent characteristics.

Of the 112 people who responded to the survey, 93% represented commercial farms as owner/operators or employees. Respondents were predominantly women (64%), and most respondents were older than 50 years (63%). Growers from seven states or provinces filled out the survey; however, most of the respondents (87%) were from Québec, Vermont, or New York.

Farm characteristics. Although 44% of respondents represented farms smaller than 5 acres (2.0 ha), a range of farm sizes were represented, including 21% larger than 50 acres (20.2 ha). Similarly, many responding farms had a relatively small cruciferous vegetable acreage, with 29% of respondents growing less than 0.5 acre (0.2 ha), and 74% less than 5 acres. However, farms growing more than 20 acres (8.1 ha) of cruciferous vegetables were also represented (16% of respondents). On average, cruciferous vegetable acreage represented 29% of the total acreage in cultivation on farms, which is a larger proportion than many vegetable farms in the region (personal observation). Most responding farms used organic practices; 46% were certified organic, and an additional 23% used organic practices exclusively but were not certified. Notably, no grower respondents from Vermont identified their farms as conventional. The lack of conventional grower representation from Vermont and the respondent pool overall is likely due to our survey distribution efforts through organic grower listservs, and the large proportion of certified organic farms within the Vermont vegetable industry. Direct marketing was the most common way by which all grower respondents sold their crops, with 71% marketing directly to consumers. Fifty-five percent grew cruciferous vegetables for the wholesale market. Overall, our grower respondent profile reflected the average vegetable farm in the northeastern United States and eastern Canada that is most prone to severe economic losses due to swede midge: organic small-scale producers in cool northern climates that rely on cruciferous vegetables for retail sales. Although a larger-scale conventional cruciferous vegetable industry exists in this region (i.e., wholesale cabbage in western New York), fewer farms comprise this sector of the cruciferous vegetable industry by number.

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up to $37,000 USD per acre (Atallah and Gómez 2013). Growers in Vermont reported the highest losses, and Québec reported among the least (Fig. 3, Table 1). Major losses were clustered in north-central Vermont, the Montérégie region of Québec, and central New York (Fig. 3). Additional representation of Ontario respondents would have provided a more accurate estimate of losses in the province, the first documented site of swede midge infestation in North America (Hallett and Heal 2001).

**Farm attributes associated with economic loss due to swede midge (Objective 2).** Both organic and conventional farms reported large losses due to swede midge. No farm attributes (farm size, cruciferous vegetable production, organic certification, number of years with swede midge, or state/province) were significant predictors of economic losses due to swede midge ($P > 0.05$). Although we hypothesized that small-scale organic farms would suffer the highest losses from swede midge because of lack of land for rotation and effective biopesticides, these characteristics did not significantly influence loss in our statistical models. A field study conducted within the same timeframe as our survey in 2018–19 found slightly higher abundance of swede midge on organic farms vs. conventional farms in Michigan (Bloom et al. 2022). Surprisingly, only 36% and 41% of survey respondents with known swede midge infestations representing small (<50 acres) and large farms (>50 acres) indicated that this pest was one of their “most problematic pests,” respectively. Flea beetles (*Phyllotreta* sp.) were most frequently identified as being problematic by all growers, selected by 69% of participants, as this pest is also particularly challenging to manage.

Although conventional farms have access to insecticides that are largely effective against swede midge (systemic neonicotinoids, pyrethroids, and spiro-tetramat), insecticidal control can fail when swede midge populations are large (Hallett et al. 2009). Because swede midge is very small and damage can be difficult to diagnose, populations can go unnoticed on farms until losses are severe. The factors influencing swede midge population dynamics and migration are not yet fully understood. Further research to understand factors influencing losses, such as farm management practices and landscape factors, will be necessary to better predict losses from this pest.

**Swede midge management strategies currently used (Objective 3).** Growers responding to the online survey identified use of common swede midge management strategies (Table 2). We divided respondents by country for comparison among conventional and organic growers. Canadian growers, both conventional and organic, reported higher use of management strategies for swede midge when compared with their counterparts in the United States. The most common management strategies included long (temporal) and wide (geographically distant) crop rotation, the use of insect exclusion netting, insecticides, biological control measures, and planting fewer cruciferous vegetables. Notably, use of long crop rotation and netting was much higher among organic growers in Canada (94% and 76%) vs. organic growers in the United States (44% and 48%, respectively). Reported usage of kaolin clay sprays and repellent essential oils were the lowest (<14%) overall among growers in Canada and the United States.

It is possible that growers who experience low levels of swede midge damage may not implement strategies specifically to target swede midge. For example, many of the conventional insecticides that are effective on swede midge are also effective against *P. brassicae*; however, even if this pest is a minor problem on farms in the United States, spraying for *P. brassicae* may provide additional control of swede midge. However, it is readily apparent from growers’ comments that the primary pest they are using insecticides for is *P. brassicae*. For some growers, the use of insecticides is based more on the presence of *P. brassicae* than on swede midge infestations, and vice versa. Some growers also noted that management of swede midge is easier when other pests are controlled.

### Table 1. Mean economic cruciferous vegetable crop losses in US dollars (USD) or Canadian dollars (CAD) per acre or hectare per year due to swede midge reported by respondents in each region participating in a 2018 online survey of vegetable growers (N = 56).

<table>
<thead>
<tr>
<th>State/Province</th>
<th>USD/acre per yr&lt;sup&gt;1&lt;/sup&gt;</th>
<th>SCAD/acre per yr&lt;sup&gt;1&lt;/sup&gt;</th>
<th>SCAD/hectare per yr&lt;sup&gt;1&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>Massachusetts</td>
<td>5,000</td>
<td>6420</td>
<td>15,865</td>
</tr>
<tr>
<td>(n = 1)</td>
<td></td>
<td></td>
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<tr>
<td>Michigan</td>
<td>2,000 ± 577</td>
<td>2,568 ± 741</td>
<td>6,346 ± 1,832</td>
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<tr>
<td>(n = 3)</td>
<td></td>
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</tr>
<tr>
<td>New York</td>
<td>3,706 ± 1,394</td>
<td>4,759 ± 1,790</td>
<td>11,760 ± 4,423</td>
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<tr>
<td>(n = 8)</td>
<td></td>
<td></td>
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<tr>
<td>Ontario</td>
<td>156</td>
<td>200</td>
<td>494</td>
</tr>
<tr>
<td>(n = 1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Québec</td>
<td>1,450 ± 457</td>
<td>1,863 ± 587</td>
<td>4,600 ± 1,450</td>
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<tr>
<td>(n = 25)</td>
<td></td>
<td></td>
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<tr>
<td>Vermont</td>
<td>7,565 ± 3,124</td>
<td>9,714 ± 4,011</td>
<td>24,003 ± 9,912</td>
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<tr>
<td>(n = 18)</td>
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<sup>1</sup> $1/acre = $2.4711/ha, $1/ha = $0.4047/acre.
Conventional Organic United States (n = 30)
Conventional Organic Canada (n = 31)

et al. 2013), it is not surprising that ro-
2012; Evans and Hallett 2016; Seaman
against swede midge (Abram et al.
cides or biological controls are effective
poral rotation of crucifers away from in-
uninfested ground, as well as spatiotem-
fi
Research in New York has shown that
mifen mesh insect exclusion netting over
crop rotation refers to temporal crop rotation, where two cruciferous crops are separated by time in a production area, whereas “wide” crop rotation refers to the separation of cruciferous crops by geographic distance within a farm landscape.

Table 2. Swede midge management strategies currently used by vegetable growers in northeastern and north-central United States and Ontario and Québec, Canada, reported in a 2018 online survey (N = 61).

<table>
<thead>
<tr>
<th>Region and farm type</th>
<th>Long crop rotation</th>
<th>Wide crop rotation</th>
<th>Insect exclusion netting</th>
<th>Insecticides</th>
<th>Biological control</th>
<th>Kaolin clay spray</th>
<th>Repellent essential oil</th>
<th>Planting fewer crucifers</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States (n = 30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic (n = 29)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Conventional (n = 1)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>0</td>
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</table>

midge are commonly used in cruciferous vegetable production for control of imported cabbage worm (Pieris rapae), diamondback moth (Plutella xylostella), crucifer flea beetles, and other insect pests; some growers may not need to apply additional swede midge-specific control measures. Of most significance is the number of farms that have had to reduce their cruciferous vegetable acreage to manage swede midge: 43% of organic farms and 33% of conventional farms responding now grow fewer swede midge crop hosts.

Both conventional and organic growers most frequently used crop rotation (long and wide) and insect exclusion netting to manage swede midge, and netting received the highest efficacy score among all respondents [mean 3.8 ± 0.22 (Fig. 4)]. Research in New York has shown that fine mesh insect exclusion netting over uninfested ground, as well as spatiotemporal rotation of crucifers away from infested ground, can successfully reduce swede midge pressure (Hodgdon et al. 2017; Hoepning and Vande Brake 2020). Because no effective biopesticides or biological controls are effective against swede midge (Abram et al. 2012; Evans and Hallett 2016; Seaman et al. 2013), it is not surprising that rotation and netting were identified as the most effective, followed by reducing cruciferous vegetable production.

Although there are no commercially available biological control agents specifically targeted toward swede midge, a small number of growers (n = 8) reported using biological control with a mean efficacy of 3.0 ± 0.33 (moderately effective). They did not specify which biological control agents were used specifically for swede midge. Few respondents indicated that they use kaolin clay and repellent essential oils, which received the lowest mean ratings. Had we surveyed more conventional vegetable growers, it is likely that insecticides would have been more frequently used among respondents, particularly those in the United States.

GROWER WILLINGNESS TO PAY FOR INSECTICIDE VERSUS ALTERNATIVE MANAGEMENT OPTIONS FOR PESTS OF CRUCIFEROUS VEGETABLES (OBJECTIVE 4). Overall, organic growers indicated that they typically spend significantly more (an additional $211 USD per acre on average) for overall cruciferous vegetable pest management than conventional growers [U = 961.5, P = 0.020 (Table 3)]. Similarly, organic growers would be willing to spend 2.1 times more (maximum) on total cruciferous vegetable pest management than conventional growers (U = 970, P = 0.024). We hypothesized that organic growers would be willing to spend more on pest management, specifically alternatives to insecticides, because organic produce is often sold for higher prices. In addition, organic agriculture principles favor an integrated pest management approach, including cultural, biological, and physical controls in addition to insecticides. Many growers expressed that they do not like to spray, and would be willing to pay for alternatives to insect exclusion netting. As a result, organic growers reported a significantly higher willingness to pay than conventional growers for alternatives to insecticides for cruciferous vegetables (U = 1005, P = 0.041).

For swede midge management specifically, organic growers were willing to spend significantly more ($38 USD more per acre; Z = −2.335, P = 0.020) on alternatives to insecticides vs. insecticides for swede midge management. Although not statistically significant, conventional growers indicated that they would be willing to spend an average of $95 USD more per acre on alternatives to insecticides for swede midge management. It is important to note that the higher amount that conventional growers were willing to spend on alternatives for swede midge management may be skewed by the smaller sample size (n = 15) and the large variation between responses.

More than half (56%) of all respondents indicated that they would be willing to pay more for swede midge management strategies in the future if their losses increased. Forty-one percent of respondents would rather grow fewer cruciferous vegetables, and 12% would stop growing cruciferous vegetables altogether. These results suggest that grower budgets for swede midge management could increase in the future if swede midge populations increase.

WILLINGNESS TO TRY NEW ALTERNATIVES TO INSECTICIDES (OBJECTIVE 5). Survey participants expressed a strong interest in using biological control for swede midge management (Fig. 5).
Biocontrol received a mean rating of 4.3 (likely to try). Several write-in responses expressed the desire to avoid spraying in favor of supporting natural enemies and using alternative tactics overall (15 comments), and for swede midge specifically (six comments). Unfortunately, there have been no effective biological control strategies developed to date.

Attempts to identify a natural enemy of swede midge in Europe for release in North America were unsuccessful (Abram et al. 2012). Although researchers have found a parasitoid wasp, Synopes myles, that attacks swede midge in Canada and Europe, the wasp is not host-specific to swede midge and does not achieve high enough parasitism rates to be considered a promising candidate for classical biocontrol releases (Abram et al. 2012; Ferland 2020). In addition, Ferland (2020) hesitates to recommend classical and conservation biological control in promoting S. myles populations until more is known about its host range and impacts on native insect hosts. Application of entomopathogenic nematodes (Heterorhabditis bacteriophora, Steinernema carpocapsae, and Steinernema feltiae) and fungi (Meta
drhizium brunneum) to soil infested with swede midge pupae have resulted in mixed success, suppressing midge emergence in laboratory trials and in some field sites, but not on a commercial farm (Evans et al. 2015). Crop growers are increasingly interested in “native persistent” nematode strains originally isolated from New York soils; these strains are considered to be adapted to regional conditions and better suited to the Northeast, resulting in management success for other pest species with soilborne life stages (Shields 2015). A minimum of two to three seasons is required for native nematode strains to become established, and to date no long-term studies have examined the effects of the New York nematode strains for swede midge management. These avenues warrant further research, given the interest documented among our survey respondents.

Resistant plant varieties and pheromone mating disruption also received high mean “willingness to try” ratings from survey participants, 4.3 and 4.2, respectively. There are currently no swede midge–resistant crop varieties, although variation in swede midge crop preference has been observed on farms (Hoepting and Vande Brake 2020). Growers expressed an interest in mating disruption, a strategy currently in the research and development phase that may become commercially viable in the future (Hodgdon 2019). Growers ranked intercropping, trap cropping, and ground barriers the lowest. These strategies often require taking land out of production to grow a noneconomic crop (e.g., a trap or intercrop), or leaving land fallow for a portion of the year if using tarps, landscape fabric, or other ground barriers to reduce swede midge emergence. If not managed correctly, a trap crop could create even higher swede midge pressure.

Although rated highly effective by growers, insect exclusion netting received the second lowest rating (3.2). Many respondents (23 write-in comments) mentioned high cost, labor, and logistical difficulties related to using netting. Netting is costly to purchase (~$400 USD per 100 ft row or $512 CAD per 30.5 m row), and requires labor to install and remove during activities such as weed control, pesticide application, and harvest. The desire for alternatives to netting have been voiced by growers in other surveys, specifically for flea beetle in cruciferous leafy greens, another cruciferous vegetable pest with limited organic management options (Bull CT, unpublished data).

Conclusions

Although swede midge is known to cause serious crop losses, no grower surveys have previously quantified farm-level economic losses due to this pest. Although there was variation among states and provinces surveyed, losses from swede midge averaged $3808 USD per acre. All farms, regardless of management (organic vs. conventional), size, and history of swede midge infestation, were susceptible to large losses. Strong dissatisfaction toward currently available swede midge control measures paired with extensive losses point toward a need for future research and development efforts to manage this pest to protect the cruciferous vegetable industry in the United States and Canada.

On average, growers were willing to spend $245 USD per acre per year for insecticides and $312 USD for alternatives to insecticides per acre for swede midge management, a small amount considering the respondents’

Fig. 4. Strategies used for swede midge management on farms in the northeastern and north-central United States and Ontario and Québec, Canada. Perceived efficacy ratings for crop protection were reported by respondents in the 2018 online survey using a Likert scale, where 1 = very ineffective and 5 = very effective (N = 61). “Long” and “wide” crop rotation refer to temporal and geographically distanced separation of cruciferous vegetable crops, respectively.
estimates of economic losses. Many growers expressed their support for preventive practices to reduce swede midge populations in the long term. More than half of respondents indicated that they would prefer to pay more for swede midge management strategies if their losses increased, rather than grow fewer crucifers or stop growing them altogether. Estimates of grower willingness to pay for new strategies (insecticides and alternatives) should provide guidance when considering a target price point for those in applied research and development testing novel swede midge and other vegetable pest management tools.

Overall, our survey demonstrated a dire need for the development of additional swede midge management options, and highlighted flea beetle as a problematic pest on farms. Although our survey included mostly organic growers, it presents a snapshot of an important issue threatening the cruciferous vegetable industry. In future survey efforts, more conventional growers, particularly those in Ontario and Vermont, should be surveyed to obtain more robust estimates of losses for producers relying on insecticidal control. Grower meetings at which conventional farms are represented...
may be one method of recruiting more farmers in this category. In addition, using paper surveys to include Plain/Anabaptist population (Amish and Old Order Mennonite) vegetable growers who do not use technology will better characterize the cruciferous vegetable industry where they play an important role in the agricultural community. Eighty-four percent of all respondents were moderately or highly concerned about swede midge losses in the future. Investment in research to better understand the cruciferous vegetable industry and swede midge management are needed to support growers in afflicted regions.

Specifically, vegetable growers desire effective biological control strategies to limit the need for exclusion netting and insecticide applications. Although existing efforts to locate specialist natural enemies have fallen short, further research understanding the role of S. mylæ in North American ecosystems and examining the roles of generalist enemies, such as native strains of entomopathogenic nematodes and fungi, are promising future research avenues given respondent interest and past study results. We hope that our survey results may serve as a call to action and justification for future grant proposals, research initiatives, and extension programs.

References


