Assessing the Economic Importance of *Dasineura oxycoccana* (Diptera: Cecidomyiidae) in Northern Highbush Blueberries

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ABSTRACT Infestation by blueberry gall midge, *Dasineura oxycoccana* Johnson, is common in northern highbush blueberries, but its effects on crop productivity are unknown. We examined whether infestation by blueberry gall midge reduces flower bud production when compared with uninfested shoots, and how infestation at different times affects the crop response. From the fall of 2009 to the spring of 2011, the number of flower buds on infested and uninfested shoots of blueberry bushes was counted and compared. Despite causing branching of vegetative growth, there was no significant effect of infestation on flower bud production. During the summer of 2010, damaged shoots were marked throughout the growing season in June, July, or August. The number of flower buds set per shoot declined with later infestation dates, and shoots damaged in August had significantly fewer buds than those damaged in June and July. We discuss the implications of these findings for management of blueberry gall midge in northern highbush blueberry.

KEY WORDS blueberry gall midge, flower bud, compensation, plant–insect interaction

Blueberries are an important specialty crop due to their nutritional value and high antioxidant content that supports mammalian health (Pedersen et al. 2000, Andres-Lacueva et al. 2005, Zafra-Stone et al. 2007). The United States is the leading cultivated blueberry producer in the world, with Michigan as a principal production and export state (Retamales and Hancock 2012). According to the USDA Census of Agriculture, in 2012 Michigan had 18,746 acres of harvested blueberries of the 81,953 acres in the United States (National Agricultural Statistics Service [NASS] 2014). Within this region, blueberry gall midge (*Dasineura oxycoccana* Johnson) is a potential pest of northern highbush blueberries because the larvae cause damage to tips of growing vegetative shoots. In contrast, in the southern states of Florida, Mississippi, and Georgia, this insect has been shown to damage both flower and vegetative buds of rabbiteye blueberries (Steck et al. 2000). Losses of up to 90% of flower buds in some southern US blueberry fields have been attributed to damage by blueberry gall midge (Lyrene and Payne 1992), and damage to the Florida blueberry industry by this insect has been estimated at US$20 million (Dernisky et al. 2005). In Massachusetts cranberries, this midge causes damage to the apical meristem of cranberry uprights, preventing them from producing flower buds until the next growing season (Tewari 2012). In Michigan, gall midge damage has not been observed in flower buds, but their eggs and larvae have been found inside young vegetative shoots. Damage to the apical meristem of vegetative shoots causes one or more lateral shoots to grow off the primary shoot due to loss of apical dominance. While infestation by this pest is common in some farms (Hahn and Isaacs 2012), the effect of this indirect damage on fruit set is unknown.

Blueberry bush development was reviewed by Eck (1988) and Gough (1994). During the growing season, blueberry shoot growth is variable, with cycles of slow and fast shoot elongation, depending on weather conditions. Shoot growth continues until the fall, when it stops as a result of changes in temperature and photoperiod. Some shoots will experience bud break and shoot growth in the fall, resulting in growth that cannot harden and survive the winter. These shoots are called proleptic shoots, and are known to have poor productivity (Gough 1994). Hardening of shoots begins when growth stops in the fall and continues during the first frost. Flower buds can be damaged by the formation of ice crystal within the bud as well as damage to the vascular tissue, which restricts nutrients, water, and hormones from the bud. The relative location of the flower bud on the stem influences its ability to survive through winter temperatures. Those at the tips of shoot are not able to harden as well as those lower on the branch, and are more likely to be killed during the winter (Iungerman and Pritts 2005).

When blueberry gall midge larvae damage the apical meristem of vegetative blueberry shoots, growth of additional lateral shoots is induced due to loss of apical dominance. High levels of infestation can result in an effect similar to witches' broom (Tanigoshi et al. 2010). Witches' broom is a deformity in woody plants typically caused by a pathogen that causes shoot clustering that

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form dense masses of twigs that looks like a broom (Phillips 2014). True witches' broom has not been observed in highbush blueberry bushes; however, up to three lateral branches have been observed growing from a single shoot infested by blueberry gall midge (Hahn and Isaacs 2012). This outgrowth of extra shoots has the potential to cause a decrease in net flower bud formation if the plant is investing resources in the additional lateral branching. Additionally, freezing temperatures may damage shoots and terminal flower buds if they form later in the season than undamaged shoots and do not have the time to become winter-hardy, potentially resulting in reductions in yield. Damaged shoots with more late-developing terminal buds may be more likely to sustain damage during Michigan's cold winter months, thereby affecting the next year's yield.

Despite the potential for reduced yield, growers show little concern for blueberry gall midge and some have even suggested that blueberry gall midge is beneficial because of the promotion of extra lateral growth and flower buds. However, infestation may also reduce flower bud formation and fruit set, and increase the risk of freeze damage to buds. This has not been investigated in highbush blueberries, and it would be important to determine whether damage to vegetative shoots causes a reduction in flower bud or flower counts. This study examined the effect of blueberry gall midge damage on flower bud yield by comparing bud formation and survival on uninfested and infested shoots through two fall-to-spring seasons at blueberry farms. The timing of infestation was also examined to determine whether later-formed buds were less likely to be productive in the next spring.

Materials and Methods

Effect of Blueberry Gall Midge Damage on Highbush Blueberry. In October 2009, 30 shoots showing branching symptoms of blueberry gall midge damage and 30 uninfested shoots were selected for assessment in each of four "Bluecrop" variety highbush blueberry fields. The infested shoots selected were those exhibiting signs of leaf curling and blackened shoot tips. They were confirmed to be infested by blueberry gall midge larvae through inspection of the damaged shoot tips. Specimens were collected and later confirmed to be in the genus *Dasineura* using the Cecidomyiidae key by Gagné (1981), and this was confirmed by Dr. Blair Sampson (USDA-ARS). Voucher specimens were submitted to the Michigan State University insect collection. Due to the short generation time of the midge, damage was assumed to have occurred previously when the larvae were present in the shoot tips. Whenever possible, the uninfested shoots were selected from the same bush on which the infested shoot was selected. The fields were located at four different farms in Berrien County (1), Van Buren County (2), and in Grand Traverse County (1), MI. The number of flower buds was counted on each of the infested shoots including their lateral branches. On the uninfested shoots, the number of flower buds was counted along the whole length of the shoot (Fig. 1). After counting, each shoot was flagged and the number of buds was recounted in the spring of 2010 to determine bud survival.

Effects of Timing of Blueberry Gall Midge Damage. In the summer of 2010, three blueberry (cv. Bluecrop) fields at three different farms in Van Buren County, MI, were assessed to determine the effect of the timing of blueberry gall midge damage on flower bud production. At each site, 20 gall midge-infested shoots were flagged in each of the months of June, July, and August. At two sites, only 10 infested shoots were found during the August timing when infestation by gall midge was lower. Depending on the local infestation levels, bushes had between zero and multiple infested shoots. Uninfested shoots with no sign of lateral branching or prior damage by blueberry gall midge were also selected during the bud count in November.

In November of 2010, at each field, the number of flower buds present along the complete shoot of each selected infested and uninfested shoot was counted. On infested shoots, the number of lateral branches and the number of flower buds on each of those branches were counted. In March 2011, the number of flower buds on the infested and uninfested shoots was recounted, and the number of flowers per bud was also counted.

Statistical Analysis. The total and average numbers of buds per shoot found in 2010 and in 2011 were compared between infested and uninfested shoots, using analysis of variance followed by means separation with Tukey's HSD test (JMP 10.0.0, SAS, Cary, NC). Due to the variability among farms in the background level of infestation by blueberry gall midge, each farm was analyzed separately, to determine how infestation status and timing affected bud abundance. Prior to analysis, all data were transformed using a square root transformation to address homoscedasticity in the data. Levene's test was used to test for equality of variances and the residuals were plotted to check for normality using a Q-Q plot. To determine the effect of blueberry gall midge infestation on bud survival from fall 2009 to spring 2010, for each shoot the number of buds in the fall was subtracted from the number of buds in the spring to calculate the number of buds lost during

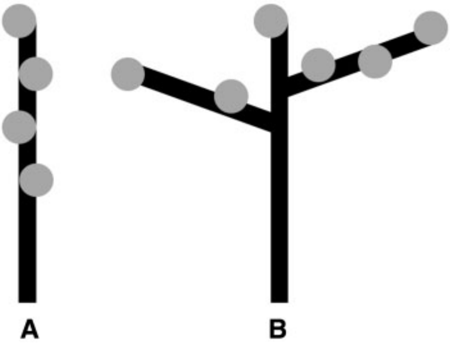

Fig. 1. Buds on a highbush blueberry shoot that is uninfested (A) and a branched shoot (B) infested by blueberry gall midge.

the winter. Farm was included as a random model effect and infestation status (uninfested or infested) was included as fixed model effect. Data on the number of flower buds on uninfested shoots and those shoots infested either in June, July, or August of 2010 were compared with month of infestation and infestation status tested as model effects.

Results

The effect of infestation of vegetative buds by blueberry gall midge on the total number of flower buds per shoot was variable among farms. In the fall of 2009, the total number of buds on infested shoots was significantly higher than the total number of buds on uninfested shoots at two of the four farms monitored (Table 1). However, when the average numbers of buds per shoot was analyzed, the number of flower buds was significantly lower on infested than uninfested shoots at three of the four farms monitored (Table 1). Between the fall of 2009 and spring of 2010, there was no significant loss of flower buds on uninfested shoots or shoots infested by blueberry gall midge in any of the surveyed fields (Table 1). In the fall of 2009 and spring of 2010, there was a significant interaction effect between farm and infestation (2009: $F = 4.12$; df = 3; $P = 0.007$; 2010: $F = 6.32$; df = 3; $P = 0.0004$), so infestation at each farm for all analyses was conducted separately.

We found significant effects of farm, month of infestation, and the interaction effect of the two factors when examining how infestation timing affects the total number of buds present on blueberry shoots (Farm: $F = 30.52$; df = 2; $P < 0.001$; Month of infestation: $F = 10.63$; df = 3; $P < 0.001$; Farm × Month of infestation: $F = 5.81$; df = 6; $P < 0.001$). A similar pattern was found when examining the average number of flower buds (Farm: $F = 36.75$; df = 2; $P < 0.001$; Month of infestation: $F = 38.47$; df = 3; $P < 0.001$; Farm × Month of infestation: $F = 6.64$; df = 6; $P < 0.001$). However, there was no significant effect of any of the factors on the number of flower buds lost between fall 2009 and spring 2010 (Farm: $F = 0.28$; df = 2; $P = 0.75$; Month of infestation: $F = 0.53$; df = 3; $P = 0.66$; Farm × Month of infestation: $F = 1.16$; df = 6; $P = 0.33$). These analyses show that the month of infestation has varying effects on the number of flower buds per shoot, and that this effect varies among farms.

When uninfested and infested shoots damaged during June, July, or August were compared, the total number of flower buds was not significantly different among timings at Farm 1. However, on Farm 2 and Farm 3 we observed a decline in the total number of buds and the average number of buds on infested shoots as the summer progressed. These declines were most apparent at Farm 3 (Fig. 2). The data also indicated no significant loss of flower buds between 2010 and 2011 on uninfested or infested shoots (Table 2), and there were no patterns in the number of buds killed through the winter based on the timing of infestation.

When flowers per shoot were examined in spring 2011, we found lower numbers of buds, but these were not significantly different for shoots damaged in any of the three months in Farms 1 and 2. However, we observed a dramatic reduction (from 29.8 to 3.0 flowers per shoot) at Farm 3 (Table 2). The effect of infestation by gall midge on the average number of flower buds per shoot varied between farms, with Farm 1 exhibiting a reduction in the number of flowers per bud, Farm 2 continuing to exhibit no significant difference, and Farm 3 showing a reduction in flowers per bud (Table 2).

Table 1. The total and average number of flower buds (±SE) on highbush blueberry shoots infested or uninfested by blueberry gall midge in fall 2009 and the number of flower buds (±SE) lost on infested or uninfested shoots between fall 2009 and spring 2010

Farm	*F*(df)	*P*	Number of flower buds	
			Infested	Uninfested
Total flower buds per shoot				
Farm 1	$F(1,58) = 0.47$	0.50	4.57 ± 0.99	4.23 ± 0.44
Farm 2	$F(1,58) = 0.61$	0.44	4.93 ± 0.56	5.23 ± 0.41
Farm 3	$F(1,58) = 4.12$	<0.05	9.20 ± 0.89	6.93 ± 0.61
Farm 4	$F(1,58) = 15.16$	<0.001	7.33 ± 0.59	4.50 ± 0.51
Average flower buds per shoot				
Farm 1	$F(1,58) = 18.41$	<0.001	1.95 ± 0.38	4.23 ± 0.44
Farm 2	$F(1,58) = 41.11$	<0.001	2.17 ± 0.23	5.23 ± 0.41
Farm 3	$F(1,58) = 17.59$	<0.001	3.49 ± 0.25	6.93 ± 0.61
Farm 4	$F(1,58) = 3.07$	0.085	3.17 ± 0.19	4.50 ± 0.51
Number of flower buds lost				
Farm 1	$F(1,58) = 0.34$	0.56	0.93 ± 0.29	0.67 ± 0.19
Farm 2	$F(1,58) = 0.05$	0.82	0.50 ± 0.14	0.67 ± 0.25
Farm 3	$F(1,58) = 2.85$	0.09	0.63 ± 0.27	0.17 ± 0.11
Farm 4	$F(1,58) = 0.21$	0.65	0.23 ± 0.09	0.20 ± 0.12

Data were square root transformed to meet normality assumptions.

Discussion

Blueberry gall midge does not infest flower buds in highbush blueberries in Michigan, but it has been found to damage vegetative shoot tips. Because damage to the apical meristem of a shoot can induce lateral branching (Cline 1991), infestation could indirectly cause a reduction in flower bud set and yield in the year following damage. While this study demonstrates that blueberry gall midge has the potential to impact yield of highbush blueberries by affecting the number of flower buds that develop after infestation, the effect is variable among farms and across the season. There was no strong evidence of increased loss of flower buds due to death from winter freezes on infested shoots in comparison to losses on uninfested shoots, so the effect on yield seems to be primarily caused by reduction of bud formation during the season.

The data presented here indicate that there can be significant differences between the resulting number of flower buds on uninfested shoots and infested shoots. We detected a farm × month of infestation interaction, suggesting that there is variability between farms in how blueberry bushes are affected by blueberry gall midge damage. At two of the farms monitored, the total number of buds on infested shoots was significantly greater than the number on uninfested buds (Table 1), supporting some of the anecdotal observations of

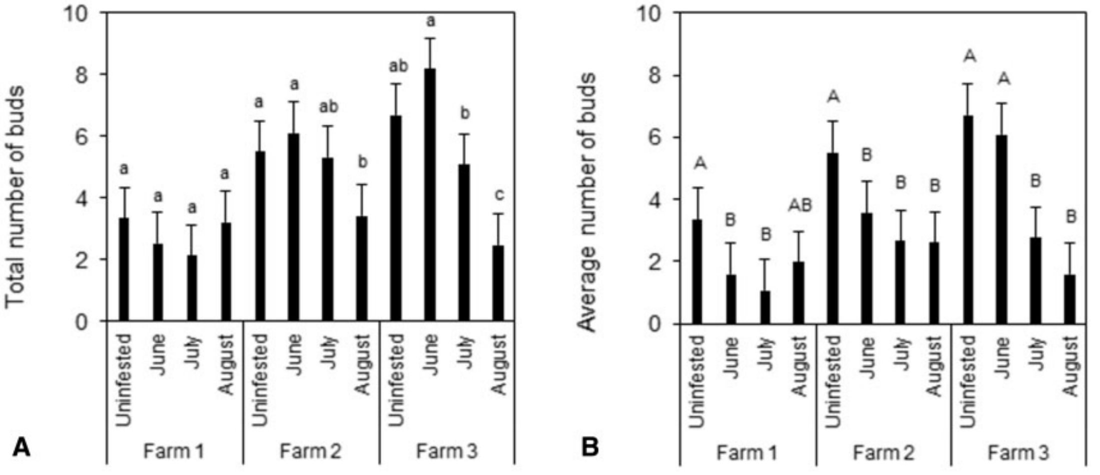

Fig. 2. The total (A) and average (B) number of flower buds (±SE) in fall 2010 on uninfested shoots and shoots infested by blueberry gall midge during different months of the summer. Means with the same letters are not significantly different ($P < 0.05$).

Table 2. Comparison of uninfested shoots and shoots infested by blueberry gall midge in June, July, or August

Farm	*F*(df)	*P*	Uninfested	June	July	Aug.
Flower buds lost						
Farm 1	*F*(3,73) = 0.27	0.85	0.55 ± 0.19	0.68 ± 0.20	0.85 ± 0.27	0.67 ± 0.30
Farm 2	*F*(3,72) = 1.11	0.35	0.70 ± 0.31	0.32 ± 0.22	1.06 ± 0.49	0.67 ± 0.33
Farm 3	*F*(3,61) = 1.25	0.30	0.85 ± 0.34	0.82 ± 0.53	0.36 ± 0.2	1.41 ± 0.4
Flowers per bud						
Total flowers per shoot						
Farm 1	*F*(3,44) = 1.98	0.13	20.6 ± 3.12	12.62 ± 4.21	10.64 ± 3.05	15.00 ± 3.04
Farm 2	*F*(3,41) = 0.58	0.63	34.86 ± 6.21	37.00 ± 12.02	33.85 ± 6.11	26.71 ± 4.15
Farm 3	*F*(3,50) = 27.96	<0.001	30.23 ± 3.58A	29.80 ± 3.87A	11.00 ± 3.08B	3.00 ± 1.04C
Flowers per shoot						
Farm 1	*F*(3,73) = 3.93	0.01	8.14 ± 0.77A	4.51 ± 1.06AB	3.46 ± 0.94B	4.54 ± 0.70AB
Farm 2	*F*(3,72) = 0.83	0.48	9.40 ± 0.74	6.86 ± 0.47	8.34 ± 0.94	7.34 ± 0.85
Farm 3	*F*(3,61) = 14.22	<0.001	5.01 ± 0.45A	4.87 ± 0.48AB	3.30 ± 0.60B	1.56 ± 0.58C

Data are presented for the number of flower buds (±SE) lost between fall 2010 and spring 2011, the number of flowers (± SE) in spring 2011, and the number of flowers per shoot. Values in a row followed by the same letter are not significantly different.

Data were square root transformed to meet normality assumptions.

higher potential yield provided by farmers. It has been suggested that plant–herbivore mutualisms exist due to overcompensation of growth in plants, creating additional habitat or feeding sites for herbivores (Agrawal 2000), and blueberry gall midge infestation may serve to increase habitat for subsequent generations. However, during this study, the number of buds per individual branch of infested shoots was significantly lower than that on uninfested shoots. This growth of multiple short lateral branches may increase the risk of winter damage because the terminal buds are the most susceptible to frost damage (Gough 1994). However, our data indicate no significant loss of flower buds during winter, suggesting that blueberry gall midge injury to highbush blueberry in temperate climates poses a minimal threat to blueberry production. Blueberry bushes in regions with shorter growing seasons and harsher winters may experience increased death and dieback of developing shoots. Although this may be a concern in northern latitudes, highbush blueberry was found to be less sensitive to mild freezes than rabbiteye blueberry, which has a large reduction in fertilization and fruit set in these conditions (Patten et al. 1991, NeSmith et al. 1999). The data are encouraging, as there was no evidence found for reduced overwintering flower bud set or greater flower bud death in infested shoots.

When comparing the effect of the timing of blueberry gall midge infestation, the number of flower buds and flowers on shoots that were damaged in June, July, and August varied among farms. One farm exhibited no significant difference in the number of flower buds and flowers on uninfested and infested shoots while another had significant differences in flower buds and flower counts between all three months. We also observed a slight increase in the number of flowers per shoot when shoots were damaged in June. These varied data are not due to cultivar, as all farms sampled in this study were “Bluecrop.” These results may be a result of within-farm variation in fertility or topography. Future studies with more control over bush health and with manipulations of key factors that can affect bud hardiness could be developed to tease apart these effects.

Although shoots damaged in August tended to have fewer flower buds, low populations of blueberry gall midge occur at this time of year. Additionally, the largest numbers of vulnerable green shoots appear in the beginning of May, over two months before peak blueberry gall midge infestations in July and August, when there are very few vulnerable shoots suitable for infestation (Hahn 2012). Declining bud numbers over time may also reflect a change in the inherent bud initiation phenology of blueberry bushes. Although late-ripening cultivars such as "Elliott" may have more vulnerable shoots later in the season than earlier varieties such as "Bluecrop," the number of vulnerable shoots may still be comparatively low compared with the number available in spring. If blueberry gall midge were to have a large increase in population early in the growing season due to a mild winter or warm spring, it could pose a risk to early-season blueberry plants that have flushes of vegetative growth in the early summer.

Due to its quick generation time and continuous emergence throughout the summer, blueberry gall midge is a challenging insect to control (Roubos 2013). However, this study indicates that it does not directly damage flower buds of blueberries in Michigan and its vegetative shoot damage does not have a significant effect on flower bud yield. We therefore conclude that the need for control of this insect is minimal in mature highbush blueberry fields in the Great Lakes region.

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