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# Mechanically-applied wax matrix (SPLAT-GBM) for mating disruption of grape berry moth (Lepidoptera: Tortricidae)

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An ATV-mounted mechanical applicator was designed to treat vineyards with SPLAT-GBM™ for mating disruption of grape berry moth, *Paralobesia viteana* (Lepidoptera: Tortricidae). SPLAT-GBM was applied to vineyards in 0.8 g drops at a density of 1544 or 3089 drops per hectare for a total of 1.3 or 2.5 kg per hectare. Trials were conducted in 2008 and 2009 in vineyards receiving grower-standard insecticide sprays for control of grape berry moth and other insect pests. In the first trial, SPLAT-GBM applied twice at 1.3 or 2.5 kg/ha caused a significant reduction in grape berry moth infestation at harvest on clusters at the border of the vineyards where infestation is highest, compared with the no-pheromone control, but three applications at 2.5 kg/ha did not result in lower infestation compared with both the control and other treatments. In the second trial, application of SPLAT-GBM 2.5 kg/ha in mid-June and late-July caused a significant reduction in grape berry moth infestation at harvest on clusters at the border of the vineyards. Application in early-May and late-June resulted in infestation that was similar to the other program, but not statistically different from the control. In both trials, there were no significant differences between any of the treatments of SPLAT-GBM and the control inside the vineyards where infestation is low. Among treatments of SPLAT-GBM, infestation was similar regardless of number, rate, or timing of the applications. This study shows that mechanical application of wax matrix drops to release pheromone is an effective method for control of grape berry moth using mating disruption.



## 1. Introduction

Grape berry moth, *Paralobesia viteana* (Clemens) (Lepidoptera: Tortricidae), is the primary insect pest of juice and wine grapes (*Vitis* spp.) grown in eastern North America (Jenkins and Isaacs, 2007a; Teixeira et al., 2009). Effective protection of fruit from larval infestation typically requires several applications of insecticides, primarily organophosphates, carbamates or pyrethroids, yet levels of control are often less than desired by growers. To diversify the tactics used to control this pest, and to reduce the environmental impact of grape production, there has been continued interest in protecting grapes from grape berry moth using environmentally-safe methods. Research on the use of sex pheromones for control of grape berry moth has been ongoing for several decades, starting in 1971 with the identification of (*Z*)-9 dodecenyl acetate as the major component of the pheromone blend (Roelofs et al., 1971). This led to Taschenberg et al. (1974) evaluating mass trapping and mating disruption for control, and their encouraging results with mating disruption were followed by other trials using different formulations of the pheromone for release in the vineyards, such as microcapsules and hollow fibers (Taschenberg and Roelofs, 1976, 1977). New trials were conducted after improvements in pheromone release technology with the introduction of polyethylene tube dispensers, showing economically-acceptable control of grape berry moth in New York and Ontario (Dennehy et al., 1990; Trimble et al., 1991; Trimble, 1993). However, more recent trials using a commercial product with similar polyethylene tube technology (Isomate GBM) showed insufficient control in vineyards located in Michigan, New York and Pennsylvania (R. Isaacs, unpublished). A new formulation of microencapsulated pheromone for mating disruption (3M Sprayable Pheromone) was also evaluated and found to provide acceptable control (Trimble et al., 2003; Trimble, 2007). A major advantage of this microcapsule formulation was that it could be applied using an airblast sprayer, but this product is no longer being manufactured. Another product for mating disruption that has recently been evaluated is SPLAT-GBM™ (ISCA Technologies, Riverside, CA), a proprietary wax matrix formulated with the sex pheromone of grape berry moth.

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When applied manually to vineyards, SPLAT-GBM caused a reduction in infestation at vineyard borders, where infestation levels are generally higher (Jenkins and Isaacs, 2008). Despite the promising results, adoption of mating disruption for grape berry moth has been limited, in part due to the labor and expense required for application of tube dispensers or wax dollops. Mechanical deployment of the wax matrix would reduce application costs, and may facilitate wider adoption of mating disruption for control of grape berry moth.

SPLAT formulations with physical–chemical properties similar to SPLAT-GBM have been successfully applied to apple orchards using a tractor-mounted mechanical applicator (Stelinski et al., 2006, 2007). This applicator was hydraulically-driven and dispensed SPLAT-OFM from a rotating distributor positioned above the tree canopy, for mating disruption of oriental fruit moth *Grapholita molesta*. For deployment of SPLAT-GBM in vineyards, we developed a mechanical applicator consisting of an air pressure-driven system that controls and delivers drops of wax matrix on the grape canopy (see details below). In an attempt to combine an efficacious product with a simple and inexpensive method of delivery, the present study describes research to evaluate whether mechanically-applied SPLAT-GBM provides control of grape berry moth. In addition, we compared SPLAT-GBM deployment rates and schedules for optimal mating disruption performance, with the goal of understanding how to deploy this new technology for greatest efficacy.

## 2. Materials and methods

### 2.1. Wax matrix

SPLAT-GBM (ISCA Technologies, Riverside, CA) is a registered formulation of wax matrix plus pheromone similar to those reported by Atterholt et al. (1998). SPLAT-GBM is viscous before application but hardens once applied to plant foliage and acts as a long-lasting dispenser of pheromone (Jenkins and Isaacs, 2008). SPLAT-GBM contains 3% (v/v) of grape berry moth pheromone blend consisting of a 9:1 mixture of (*Z*)-9 dodecenyl acetate and (*Z*)-11 tetradecenyl acetate.

### 2.2. Mechanical applicator

SPLAT-GBM was deployed using a mechanical applicator constructed by the Berry Crop Entomology Laboratory at Michigan State University. The applicator was designed to treat two grape rows at a time and was mounted in the bed of a two-wheel drive "Gator" ATV (John Deere, Moline, IL) (Fig. 1). Initially, the spray system included a 15.4 L cylinder of industrial grade nitrogen (Linde Gas, Murray Hill, NJ) fitted with a regulator to deliver pressurized gas to a 11.4 L (3 gal) tank holding SPLAT-GBM (R and D Products, Opelousas, LA). Later, the nitrogen propellant system was replaced with a 26.5 L (7 gal) air tank reservoir (R and D Products, Opelousas, AL) pressurized by a 12 V portable air compressor (Bon-aire Industries, Boise, ID), powered by the ATV's electrical battery. The air tank was custom-fitted with a regulator to control air pressure outflow. The SPLAT-GBM holding tank was connected through a PVC T-junction and two 1.9 cm ($^3/_4$ in) outside-diameter spray hoses (Goodyear, Akron, OH) to two Directovalve 144A-1 solenoid valves (Spraying Systems Inc, Wheaton, IL). The timing and duration of the opening of the solenoid valves was controlled by a LOGO! 12/24 RC programmable relay timer (Siemens, Chicago, IL). The solenoids and the timer were also powered by the ATV's battery. In 2008, each solenoid was fitted with a 1.9 cm threaded PVC plastic plug with a 0.32 cm (1/8 in) diameter hole drilled in the center to serve as a nozzle. In 2009, the PVC plug was replaced with a 1.9–0.64 cm outside-diameter (3/4–3/8 in) PVC hose barb connected to a 61 cm (24 in) length of 0.79 cm (5/16 in) outside-diameter copper tubing.

The solenoid valves were mounted on a metal frame that allows adjustment for trellis spacing and height, constructed from 1.8 m (6 ft) long, 2.5 × 2.5 cm (1 × 1 in) square steel hollow tube. These arms of the applicator were inserted in a 1.8 m (6 ft) high × 0.6 m (2 ft) width rectangular frame built from 3.8 × 3.8 cm (1.5 × 1.5 in) square steel hollow tube so the solenoids could be moved in or out by sliding the smaller tube through the frame. Both the horizontal portion of the top of the frame and the arms were drilled with 1.27 cm (1/2 in) holes every 15.2 cm (6 in) and the arms locked in place with 15.2 cm × 0.95 cm (6 in × 3/8 in) pins. SPLAT-GBM was applied in vineyards with different row spacings by holding the solenoids over the middle of the grape canopy, lining up a hole in the frame with another in the arm, and locking the arms in place with the pins.

For experiments in 2008, the mechanical applicator was pressurized to 20 psi and calibrated to deliver 0.8 g drops of SPLAT-GBM at a rate of 1544 or 3089 point sources of pheromone per hectare (625 or 1250 drops per acre) for a total amount of 1.3 or 2.5 kg of wax matrix per hectare (0.5 or 1 kg per acre). SPLAT-GBM contains 3% of pheromone blend (v/v), so 37 or 74 g of grape berry moth pheromone (A.I.) was applied per hectare in the low and high rate, respectively. To achieve the 1.3 or 2.5 kg/ha application rates, the applicator was driven at 16.1 km/h (10 mph) and the solenoid controller was set to open the valves for 0.03 s every 0.54 or 0.27 s, respectively, such that one or two drops were deployed per vine. When the applicator was driven through the vineyard, ground speed was monitored using an Etrex GPS unit (Garmin, Boulder, CO) mounted on the dashboard of the vehicle. In 2009 the applicator with modified nozzles was recalibrated and pressurized to 40 psi and the solenoid controller was set to open the valves for 0.12 s every 0.54 s which resulted in 0.8 g droplets delivered at a rate of 3089 droplets and 2.5 kg of SPLAT-GBM per hectare.

### 2.3. Study sites

This study was conducted in commercial grape farms in Van Buren and Berrien Counties, southwest Michigan. In 2008, four farms were used, while in 2009 the experiments were conducted in five farms. At each farm, 0.5–2.1 ha (1.1–5.1 ac) juice grape vineyard plots with a history of grape berry moth infestation were chosen. All plots were planted with *Vitis labrusca* L. cv. Concord or Niagara. Plots were either contiguous or separated by less than 100 m. Control plots were chosen so that they would be located upwind from treated plots, according to the predominant wind direction in southwest Michigan in summer. Of the four farms used in 2008, three were used again in 2009. When the same farm was used, plots were reassigned to different treatments and new plots were used for the control. All vineyards received the grower's standard insecticide and fungicide management program (Wise et al., 2008). This program usually includes 1–3 sprays of organophosphate, carbamate or pyrethroid insecticides for grape berry moth and other vineyard pests, such as flea beetle, rose chafer, Japanese beetle and leafhopper. All farms received a 10-day post-bloom insecticide spray against grape berry moth. Subsequent treatment varied by farm, but each plot in the same farm received the same insecticide and fungicide treatments.

### 2.4. SPLAT-GBM application rate comparison

In 2008, vineyard plots in each farm received one of the following four treatments: (1) Control (standard insecticide sprays, no-pheromone); (2) Low rate applied two times consisting of 1.3 kg/ha SPLAT-GBM applied on 6–12 June and 16–24 July; (3) High rate applied two times consisting of 2.5 kg/ha SPLAT-GBM


**Fig. 1.** ATV-mounted mechanical applicator for deploying drops of SPLAT-GBM in vineyards. A: steel frame, solenoids and nozzles; B: programmable timer; C: dashboard switches; D: SPLAT-GBM holding tank; E: pressurized air tank; F: electric air pump.

applied the same dates as the previous treatment; or (4) High rate applied three times consisting of 2.5 kg/ha SPLAT-GBM applied the same dates as the previous treatments and on 12–14 August.

### 2.5. SPLAT-GBM application timing comparison

In 2009, vineyard plots in each farm received one of the following three treatments: (1) Control (standard insecticide sprays, no-pheromone); (2) Early program consisting of 2.5 kg/ha SPLAT-GBM applied on 6–8 May and 26 June; or (3) Late program consisting of 2.5 kg/ha SPLAT-GBM applied on 12 June and 30 July. The SPLAT-GBM application in early-May was conducted before grape leaves had fully expanded. Standard mechanical application would have resulted in excessive loss of SPLAT from droplets falling to the ground. To ensure that the drops fell on the canes and new shoots present this early in the season, we employed a semi-mechanical method consisting of using a hand-held pole to direct a plastic hose connected to the nozzle towards the grape vines. The same amount of SPLAT-GBM was applied per hectare as in the other deployments, but the ATV was driven at 5 km/h and SPLAT was applied to alternate rows in dollops that were ~4 times larger than standard drops.

### 2.6. Trap inhibition

In each plot, large plastic delta traps (Trece Inc., Adair, OK) were used to monitor male grape berry moth. Traps were deployed in each vineyard in two transects that were spaced at least 30 m apart. Each of these transects had a trap on the border and a trap 60 m in the interior of the vineyard. Traps were baited with red rubber septa lures containing grape berry moth pheromone (Trece Inc., Adair, OK). Traps were checked weekly throughout the season from May to September 2008. Grape berry moth males were counted and removed, and the sticky insert was replaced when needed. Lures were replaced every four weeks. Separate averages per plot were calculated from the number of moths captured in the two interior traps and the two border traps. The percentage of trap inhibition for each treatment, which measures the decrease in male moth catch in traps deployed in treated plots versus the control plots, was calculated separately for interior and border positions as (1 − average moth catch in the treated plots/moth catch in the control plots) × 100. In 2008, we calculated trap inhibition before and after the first application of SPLAT-GBM. In 2009, because we were evaluating the effect of distinct application timing, we calculated the percentage of trap inhibition in both the early and late programs based on moth capture throughout the season.

### 2.7. Cluster infestation

Cluster infestation by grape berry moth was assessed three times during both seasons, in late-June or early-July, mid-August, and late-September. At the vineyard border, the number of damaged clusters and the total number of damaged berries was examined on 5 randomly-selected clusters on 5 vines evenly distributed along the border, for a total of 50 clusters. In the interior of the vineyard, in 2008, we examined 5 randomly-selected clusters on 5 vines evenly spaced in each of two transects across the vineyard, for a total of 50 clusters. In 2009, we increased the sampling effort in the interior of the vineyard because cluster infestation was lower inside than at the border. We examined 5 randomly-selected clusters on 5 vines randomly chosen in each of four transects, for a total of 100 clusters. By increasing the sample size inside the vineyard, we sought to decrease the variance among plots caused by the low cluster infestation.

### 2.8. Statistical analysis

Moth catch and cluster infestation data were analyzed by ANOVA in a randomized complete block design, using PROC MIXED (SAS Institute, 2001), with blocks (farms) as random effects and treatments as fixed effects. Treatment means separation was conducted using the Tukey test. Before analysis, data on percentage of infested clusters were arcsine-transformed for uniformity of variance and normality.

## 3. Results

### 3.1. SPLAT-GBM application rate comparison

Application of SPLAT-GBM caused a reduction in the number of male moths caught on traps (Fig. 2). In the period prior to the first application of SPLAT-GBM, from 27 May to 9 June 2008, there were no significant differences in moth capture in the interior or border of plots assigned to different treatments ($F = 1.30$; d.f. = 3,9; $P = 0.30$, and $F = 1.66$; d.f. = 3,9; $P = 0.25$, respectively). After the first application of SPLAT-GBM, from 16 June to 22 September, moth catch was significantly lower in the interior of plots treated with SPLAT-GBM than the control, but not significantly different at the border ($F = 5.38$; d.f. = 3,9; $P = 0.02$, and $F = 2.11$; d.f. = 3,9; $P = 0.17$, respectively). Trap inhibition following treatments of SPLAT-GBM low rate applied two times, high rate applied two times, and high rate applied three times was 21.9, 56.2 and 91.8% in the interior of the vineyard, respectively, and 86.0, 81.6, and 89.0% at the border.

In all infestation assessments (Fig. 3), cluster infestation was much higher at the border than at the interior of the vineyards in early-July, mid-August, and late-September ($F = 7.26$; d.f. = 1,24; $P = 0.01$, $F = 13.0$; d.f. = 1,24; $P = 0.001$, and $F = 24.4$; d.f. = 1,24; $P < 0.001$, respectively). Inside the vineyards (Fig. 3), there were no significant differences in cluster infestation among treatments in early-July, mid-August or late-September ($F = 0.98$; d.f. = 3,9; $P = 0.45$, $F = 0.90$; d.f. = 3,9; $P = 0.48$, and $F = 0.43$; d.f. = 3,9; $P = 0.74$, respectively). At the border of the vineyards, there were no significant differences in infestation in the first two assessment dates in early-July and mid-August ($F = 0.93$; d.f. = 3,9; $P = 0.47$ and $F = 1.82$; d.f. = 3,9; $P = 0.21$, respectively). At the third assessment date, in late-September prior to harvest, there were significant differences in infestation between treatments ($F = 5.43$; d.f. = 3,9; $P = 0.02$). Plots treated with SPLAT-GBM low rate applied two times and high rate applied two times had significantly less infestation than the control, whereas infestation in plots treated with SPLAT-GBM high rate applied three times was 43% lower than the control but not significantly different from the control or the other treatments of SPLAT-GBM (Fig. 3).

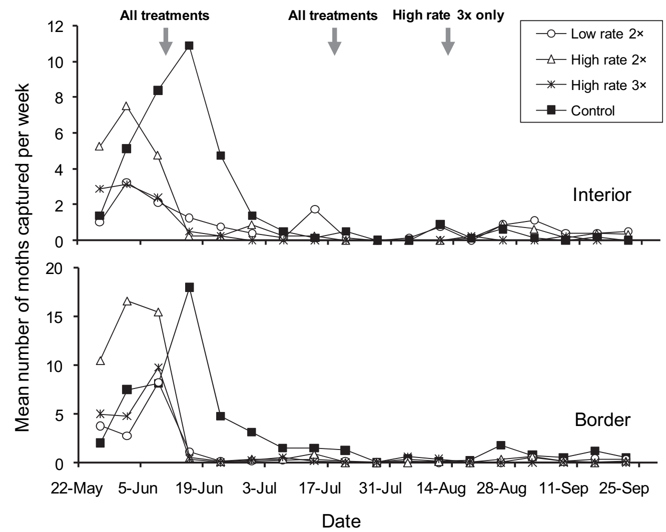


**Fig. 2.** Grape berry moth capture at the interior and border of vineyards following application of SPLAT-GBM at 1.3 kg/ha on 6–12 June and 16–24 July 2008 (Low rate 2×), application at 2.5 kg/ha on 6–12 June and 16–24 July (High rate 2×), or application at 2.5 kg/ha on 6–12 June, 16–24 July, and 12–14 August (High rate 3×).

### 3.2. SPLAT-GBM application timing

Significantly fewer moths were captured throughout the season in the interior and border of plots treated with the SPLAT-GBM early

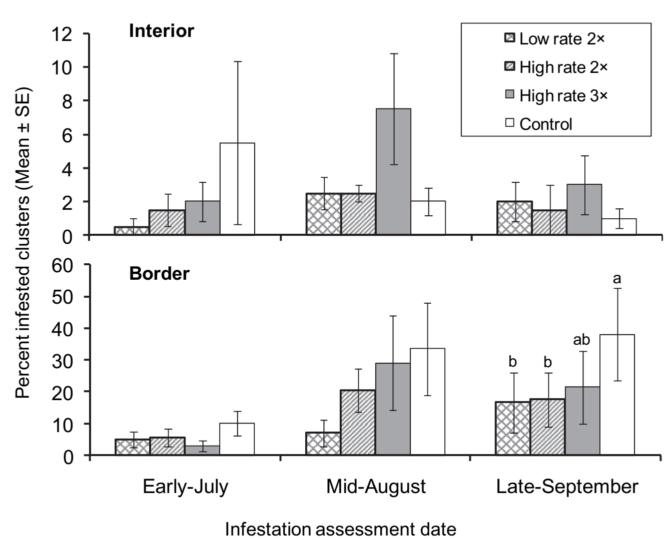


**Fig. 3.** Cluster infestation by grape berry moth at the interior and border of vineyards not treated with pheromone (Control), and following application of SPLAT-GBM at 1.3 kg/ha on 6–12 June and 16–24 July 2008 (Low rate 2×), application at 2.5 kg/ha on 6–12 June and 16–24 July (High rate 2×), or application at 2.5 kg/ha on 6–12 June, 16–24 July, and 12–14 August (High rate 3×). Columns with the same letter are not significantly different (Tukey test, $P > 0.05$).

program than the control (Fig. 4), but differences in moth captures between the SPLAT-GBM late program and the control were not statistically significant ($F = 7.19$; d.f. = 2,8; $P = 0.02$ and $F = 4.49$; d.f. = 2,8; $P = 0.05$ in the interior and border, respectively). Trap inhibition by SPLAT-GBM at the interior of the vineyard was 98.7 and 61.7% with the early and the late programs, respectively, and at the border was 86.7 and 46.8%, with the early and the late programs, respectively.

Cluster infestation was not statistically different between the border and interior of the vineyards (Fig. 5) in mid-June ($F = 3.25$; d.f. = 1,22; $P = 0.09$), but cluster infestation was much higher at the border than at the interior of the vineyards in mid-August, and late-September ($F = 28.3$; d.f. = 1,22; $P < 0.001$ and $F = 28.8$; d.f. = 1,22; $P < 0.001$, respectively). Inside the vineyards (Fig. 5), there were no significant differences in cluster infestation among treatments in late-June, mid-August or late-September ($F = 0.44$; d.f. = 2,8; $P = 0.66$, $F = 2.35$; d.f. = 2,8; $P = 0.16$, and $F = 2.04$; d.f. = 2,8; $P = 0.19$, respectively). At the border of the vineyards, there were no significant differences in infestation in the first two assessment dates in late-June and mid-August ($F = 3.84$; d.f. = 2,8; $P = 0.07$, and $F = 1.40$; d.f. = 2,8; $P = 0.30$, respectively). Immediately before harvest in late-September, there were significant differences in cluster infestation between treatments ($F = 5.31$; d.f. = 2,8; $P = 0.03$). Plots treated with the late program had significantly lower infestation than the control, whereas infestation in plots treated with the early program was 48% lower than the control but not statistically different from the late program or the control (Fig. 5).

## 4. Discussion

Previous research has shown that mating disruption using tube dispensers, microcapsules and manually-applied SPLAT-GBM can reduce infestation by grape berry moth (Dennehy et al., 1990; Trimble et al., 1991; Trimble, 1993; Jenkins and Isaacs, 2008). This study showed that mechanically-applied SPLAT-GBM can also reduce grape infestation by this pest. In 2008, two application of SPLAT-GBM at the rate of 1.3 or 2.5 kg/ha resulted in significantly lower cluster infestation than the control in the border area, although application at 2.5 kg/ha three times in the season resulted in cluster infestation in late-September that was 43% less but not statistically different from the control. This treatment may not have caused lower cluster infestation that treatments consisting of two applications because the third application, on 12–14 August, was too late in the season to affect mating. In 2009, there were significant differences in cluster infestation at the border between the late program of SPLAT-GBM consisting of applications in mid-June and late-July and the control. Cluster infestation with the early program consisting of applications in early-May and late-June was 48% less but not statistically different from the control. Overall, our results indicate that the timing of SPLAT-GBM application is flexible when treatments are applied before the late season peak in oviposition (Teixeira et al., 2009). The use of a degree-day driven phenological model currently being validated will help growers correctly time applications.

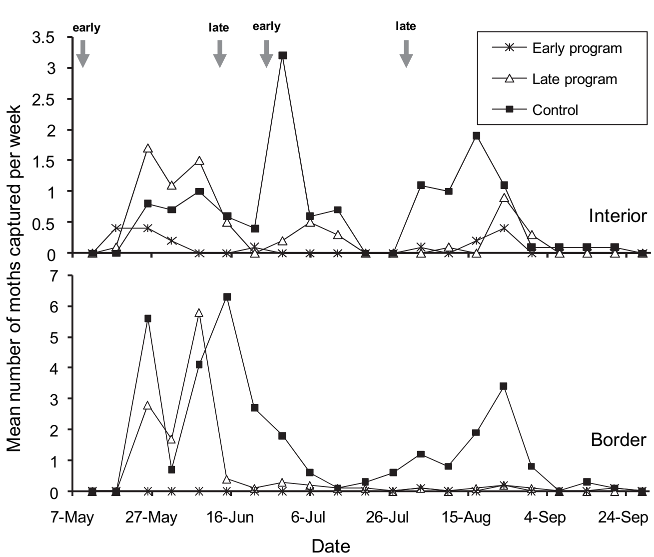


**Fig. 4.** Grape berry moth capture at the interior and border of vineyards following application of 2.5 kg/ha SPLAT-GBM on 6–8 May and 26 June 2009 (Early program), or on 12 June and 30 July (Late program).

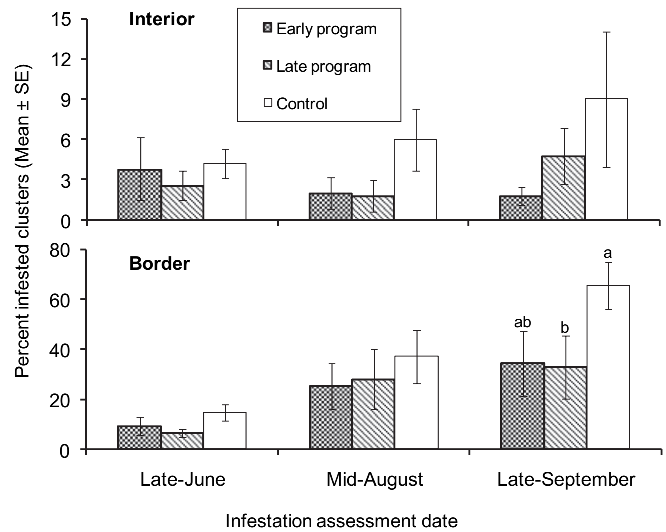


**Fig. 5.** Cluster infestation by grape berry moth at the interior and border of vineyards not treated with pheromone (Control), and following application of 2.5 kg/ha SPLAT-GBM on 6–8 May and 26 June 2009 (Early program), or on 12 June and 30 July (Late program). Columns with the same letter are not significantly different (Tukey test, $P > 0.05$).

Similar to results obtained previously when SPLAT-GBM was applied manually (Jenkins and Isaacs, 2008), with mechanically-applied SPLAT-GBM there were significant differences in infestation at the border of the vineyard but not at the interior. In Michigan, the border areas of vineyards often face wooded areas containing wild *Vitis* plants, and usually show much more grape berry moth infestation than areas in the interior of the vineyard (Botero-Garcés and Isaacs, 2003, 2004; Jenkins and Isaacs, 2007b). It is remarkable that application of SPLAT-GBM decreased infestation at the border of the vineyard where infestation is high, because mating disruption is expected to perform better at low moth population density (Cardé and Minks, 1995; Gut et al., 2004). However, prior work showing very low moth catch in traps baited with 0.2–1 ml drops of SPLAT-GBM (Jenkins and Isaacs, 2008) suggests that the behavioral mechanism responsible for disruption of grape berry moth is not competitive-attraction but instead a non-competitive mechanism such as camouflage or sensory imbalance (Miller et al., 2006). In this case, disruption is expected to depend on the area covered by the plume emanating from the dispensers and not on moth population density, which could explain SPLAT-GBM efficacy in border areas of the vineyard.

Grape berry moth catch in pheromone baited traps is a poor indicator of disruption activity because moth catch is much higher early in the season, even though most infestation occurs late in the season (Teixeira et al., 2009). In 2008, low moth catch in the period following application of SPLAT-GBM is likely the reason why there was not a consistent difference in moth capture and trap inhibition among treatments of SPLAT and the control. In 2009, the first application of the early program was conducted before the beginning of the flight, and a significant decrease in moth catch caused by the early program in relation to the control was still measured. The effect of the late program in relation to the control was not clear because moth catch was low following the first application in mid-June. Low moth catch late in the season may also be the reason why there was a poor association between trap inhibition and cluster infestation in 2009, as trap inhibition was much higher with the early program, but it was the late program that resulted in significantly lower cluster infestation with respect to the control. It is also possible that because of protandry (Tobin et al., 2002) male moths emerged and were captured much earlier than when mating began, making the early deployment of SPLAT-GBM a less effective strategy.

The cost of synthetic pheromone remains a significant hurdle to widespread adoption of mating disruption for insect control. In addition, labor and fuel costs associated with deploying tube dispensers or microcapsules add to the expense and may deter growers from using mating disruption. The mechanical applicator that we developed and used for this research overcomes the labor and fuel cost limitations, as one person can quickly treat a large area of vineyard, and the fuel consumption of the ATV is negligible compared to a tractor. The applicator enabled application of SPLAT-GBM to vineyards at a rate of 4 ha per hour, much faster than manual application (approximately 10-fold faster) or application using a tractor-mounted sprayer (approximately 3 times faster). In 2009, we found that the pressure generated by filling the air tank to ~70 psi using the 12 V pump powered by the ATV's battery was sufficient to deploy SPLAT-GBM in all plots at each treatment date, for a total area of ~6 ha application, although the air tank can be refilled at any time using the electric pump during operation. Once grape leaves expand, very little SPLAT-GBM drops to the ground during application, but drop integrity remains a challenge for this technology because of the potential for shearing of droplets on impact on the canopy. The material costs for building an applicator are relatively low, estimated at ~600 USD using easily-available materials, and many growers already own an ATV. To avoid each grower needing to build such a machine, applicators could be built and stationed at grower cooperatives for use in treating the members' vineyards.

The release rate of pheromone from a wax matrix increases with the surface area to volume ratio (Atterholt, 1996). Although the applicator always dispenses drops of the same weight, shearing from hitting the plant canopy and different impact velocities from hitting the canopy from different distances create a wide variety of deposit volumes and shapes. These heterogeneous deposits likely contribute to decreased residual activity of SPLAT-GBM compared with optimal drops like those deposited manually, such as tested by Jenkins and Isaacs (2008). For this reason, SPLAT-GBM will likely have to be applied mechanically more than once to cover the entire active grape berry moth season in Michigan. Approaches to expand the effective period of SPLAT-GBM include increasing the concentration of pheromone, changing the formulation to slow the release of pheromone, and changing application procedures. Changes to the nozzles from 2008 to 2009 helped decrease drop spreading by shortening the distance the drops fall before hitting the canopy, but visual observation of SPLAT-GBM deposits after mechanical application indicates that some spreading and shearing still occurs. Although improvements can still be made to parts of the system, this study showed that the current design of the applicator and formulation of SPLAT-GBM can be used to effect mating disruption of grape berry moth and reduce cluster infestation by this pest.

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