TWO SCREENING TRIALS ON EXPERIMENTAL INSECTICIDES IN THE ONGOING SEARCH FOR SUGARBEET ROOT MAGGOT CONTROL ALTERNATIVES

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Introduction:

The sugarbeet root maggot (SBRM), *Tetanops myopaeformis* (Röder) is an annual economic threat to sugarbeet production on up to 85,000 acres of the Red River Valley (RRV) growing area. Unfortunately, only a limited number of insecticide products are currently registered by the U.S. Environmental Protection Agency (EPA) for insect management in sugarbeet. As a result, RRV sugarbeet producers have had to rely heavily on the same insecticide mode of action (i.e., acetylcholinesterase [ACHE] inhibition) to manage this pest for over four decades.

The frequently severe root maggot infestations that occur in the central and northern RRV often necessitate two to three applications of these materials each growing season to protect the crop from substantial economic loss. This long-term use of multiple applications of ACHE-inhibiting insecticides has exerted intense selection pressure for the development of insecticide resistance in root maggot populations in the RRV. Therefore, research is critically needed to develop alternative materials and strategies for root maggot management to ensure the long-term sustainability and profitability of sugarbeet production for growers affected by this pest. This research involved two experiments that were carried out to achieve the following objectives: 1) test several natural and/or botanical insecticides for efficacy at managing the sugarbeet root maggot; and 2) evaluate commercially available, EPA-registered conventional chemical insecticides that are currently not registered for use in sugarbeet to determine if their performance would warrant future pursuit of labeling for sugarbeet root maggot control.

Materials and Methods:

This research involved two experiments (Study I and Study II) that were carried out on a commercial sugarbeet field site near St. Thomas (Pembina County), ND. Both experiments were planted on 14 May, 2018 with Betaseed 89RR52 glyphosate-resistant seed by using a 6-row Monosem NG Plus 4 7x7 planter set to plant at a depth of 1¼ inch and a rate of one seed every 4½ inches of row length. Plots were six rows (22-inch spacing) wide with the four centermost rows treated. Insecticide was excluded from the outer "guard" rows (i.e., rows one and six) on each side of each plot, and those rows served as untreated buffers. Individual treatment plots were 35 feet long, and 35-foot-wide alleys between replicates were maintained weed-free via cultivation throughout the growing season. Both studies were arranged in a randomized complete block design with four replications of the treatments. Counter 20G (granular) insecticide was used for comparative purposes as a planting-time SBRM management standard in both experiments. The Counter 20G was applied by using band (B) placement (Boetel et al. 2006), which consisted of 5-inch swaths of granules delivered through Gandy™ row banders. Granular application rates were regulated by using a planter-mounted SmartBox™ computer-controlled insecticide delivery system calibrated on the planter immediately before all applications. Study-specific materials and methods for the two respective experiments are described below, and they are followed by descriptions of materials and methods used for root injury assessments, plot harvest, and data analyses that were common to both studies:

<u>Study I</u>: Planting-time liquid insecticides in Study I included the following: 1) Aza-Direct (active ingredient: azadirachtin, a neem tree-derived insect antifeedant and growth disruptor); 2) Knack 0.86EC (an insect growth regulator insecticide); Endigo (a combination insecticide containing lambda-cyhalothrin [a pyrethroid insecticide] and thiamethoxam [a neonicotinoid] as active ingredients), and Larva Biocontrol (a liquid solution containing insect-pathogenic nematodes [*Steinernema carpocapsae*]). Planting-time liquid products in Study I were delivered in 3-inch T-bands over the open seed furrow by using a planter-mounted, CO_2-propelled spray system calibrated to deliver a finished spray volume output of 5 GPA through TeeJet™ 400067E nozzles. Water used for all planting-time liquid insecticide applications in Study I was adjusted to pH 6.0 about one week before planting.

Postemergence insecticide treatments in Study I included the following sprayable liquids: Captiva (an insect repellent comprised of capsicum [pepper] extract, garlic oil, and soybean oil]), Dibrom Emulsive (active ingredient: naled, a conventional organophosphate insecticide), Ecozin Plus 1.2%ME (azadirachtin), Evergreen Crop Protection 60-6EC (pyrethrum + a synergist), Spidermite Control (active ingredient: containing geraniol, a monoterpenoid and an alcohol, as its active ingredient), Spore Control (active ingredient: Thymol, a phenolic antimicrobial compound), Veratran D (a botanical material containing insecticidal alkaloids from the Sabadilla plant), Vydate C-LV (active ingredient: oxamyl, a conventional carbamate insecticide), Warrior II (active ingredient: lambda-cyhalothrin, a pyrethroid insecticide formulated with Zeon® U.V. protection), and all were compared with Lorsban Advanced (active ingredient: chlorpyrifos, an organophosphate) as a postemergence chemical insecticide standard. All postemergence sprays were broadcast-applied on 6 June (i.e., about 1 day before peak SBRM fly activity) by using a tractor-mounted, CO_2-propelled spray system equipped with an 11-ft boom that was calibrated to deliver a finished spray volume output of 10 GPA through TeeJet™ 110015VS nozzles. Water used for all postemergence liquid insecticide applications in Study I was adjusted to pH 6.0.

Study II: All insecticide treatments in Study II were planting-time applications. Counter 20G was included as a planting-time granular standard, and it was applied at it's a moderate rate of 7.5 lb product per acre as described above. Planting-time liquid insecticides in Study II included Bifender FC (bifenthrin, a pyrethroid insecticide), and Midac FC (imidacloprid, a neonicotinoid). All treatments involving Bifender and Midac were applied in a 20-GPA spray volume of 100% 10-34-0 (N-P-K) starter fertilizer solution through Teejet™ 650067 flat fan nozzles. Nozzle height was adjusted to achieve delivery of sprays in 3-inch bands over the open seed furrow. Dribble in-furrow applications were made directly into the open seed furrow through microtubes (1/4" outside diam.), and inline Teejet™ No.29 orifice plates were used to stabilize the spray volume output rate. To establish consistent fertility for all treatments, the same rate of starter fertilizer was also applied to Counter-treated plots and the untreated checks.

Root injury ratings: Sugarbeet root maggot feeding injury was assessed in this trial on 31 July by randomly collecting ten beet roots per plot (five from each of the outer two treated rows), hand-washing them, and scoring them in accordance with the 0 to 9 root injury rating scale (0 = no scarring, and 9 = over ¾ of the root surface blackened by scarring or dead beet) of Campbell et al. (2000).

Harvest: Treatment performance was also compared on the basis of sugarbeet yield parameters. Plots were harvested on 25 September. Foliage was removed from plots immediately before harvest by using a commercial-grade mechanical defoliator. All beets from the center two rows of each plot were extracted from the soil using a mechanical harvester, and weighed in the field using a digital scale. A representative subsample of 12-18 beets was collected from each plot and sent to the American Crystal Sugar Company Tare Laboratory (East Grand Forks, MN) for sucrose content and quality analysis.

Data analysis: All data from root injury ratings and harvest samples were subjected to analysis of variance (ANOVA) using the general linear models (GLM) procedure (SAS Institute, 2012), and treatment means were separated using Fisher's protected least significant difference (LSD) test at a 0.05 level of significance

Results and Discussion:

It is important to note that most of the insecticide entries in both of these trials were single-component (i.e., either at-plant-only or postemergence-only) control tools, which are not recommended in areas such as St. Thomas, where severe SBRM infestations are common. Another important aspect of these trials was that sugarbeet root maggot fly activity began exceptionally early in 2018. A count of 72 flies per sticky stake (well above the season-long cumulative economic threshold) was recorded on 25 May, and high activity continued for over three weeks thereafter. Thus, relatively high SBRM infestations were present for both of these experiments.

Study I: Sugarbeet root maggot feeding injury in the untreated check plots of Study I averaged 7.08 on the 0 to 9 scale of Campbell et al. (2000), which indicated the presence of a high SBRM infestation (Table 1). Entries that provided the greatest levels of root protection (i.e., lowest SBRM feeding injury ratings) included postemergence-applied Vydate C-LV (34 fl oz/ac) and the planting-time standard, Counter 20G, applied at its moderate rate of 7.5 lb product/ac. There was no significant difference in root protection between Vydate and Counter. Other entries that were not statistically outperformed by Counter in root protection included the following: 1) Endigo ZC applied at planting in a 3-inch T-band at 4.5 fl oz/ac; 2) Lorsban Advanced, applied as a postemergence broadcast at 1 pt product/ac; 3) Evergreen Crop Protection at 16 fl oz/ac as a postemergence broadcast; and 4) Dibrom, applied postemergence as a broadcast at 1 pt product/ac. The only treatments that significantly reduced SBRM feeding injury when compared to the untreated check were Vydate, Counter, Endigo, Lorsban Advanced, and Evergreen crop protection.

Table 1. *Larval feeding injury* in an evaluation of experimental at-plant and postemergence sprays for sugarbeet root maggot control, St. Thomas, ND, 2018

Treatment/form.	Placement[a]	Rate (product/ac)	Rate (lb a.i./ac)	Root injury (0-9)
Vydate C-LV	1 d Pre-peak Broad.	34 fl oz	1.0	5.48 f
Counter 20G	B	7.5 lb	1.5	6.03 ef
Endigo ZC	3" TB	4.5 fl oz		6.25 de
Lorsban Advanced	1 d Pre-peak Broad.	1 pt	0.5	6.40 cde
Evergreen Crop Protection	1 d Pre-peak Broad.	16 fl oz		6.53 b-e
Dibrom	1 d Pre-peak Broad.	1 pt		6.68 a-e
Knack 0.86 EC	3" TB	10 fl oz		6.73 a-d
Captiva	1 d Pre-peak Broad.	2 pts		6.83 a-d
Larva Biocontrol + Spore Control + Spidermite Control	3" TB 1 d Pre-peak Broad.	5 fl oz 26 fl oz + 20 fl oz		6.90 a-d
Ecozin Plus 1.2% ME	1 d Pre-peak Broad.	56 fl oz		6.90 a-d
Veratran D	1 d Pre-peak Broad.	20 lb	0.04	6.90 a-d
Aza-Direct (0.0987 lb/gal)	3" TB	56 fl oz		6.90 a-d
Larva Biocontrol	3" TB	5 fl oz		7.03 abc
Check	---	---	---	7.08 ab
Warrior ll	1 d Pre-peak Broad.	1.92 fl oz	0.03	7.10 ab
Spore Control + Spidermite Control	1 d Pre-peak Broad.	26 fl oz/20 fl oz		7.20 a
LSD (0.05)				0.651

Means within a column sharing a letter are not significantly (P = 0.05) different from each other (Fisher's Protected LSD test).
[a]B = 5-inch band; 3" TB = 3-inch T-band

Yield data from Study I are shown in Table 2. The highest-yielding treatments, in relation to both recoverable sucrose yield and root tonnage, included the following: 1) Counter 20G, applied at a moderate rate of 7.5 lb product/ac; 2) Vydate C-LV, applied as a postemergence broadcast at 34 fl oz/ac; 3) Endigo ZC, applied at planting in 3-inch T-bands at 4.5 fl oz/ac; Lorsban Advanced, applied in a postemergence broadcast at 1 pt/ac; and 4) Ecozin Plus, which was applied as a postemergence broadcast at 56 fl oz/ac. However, the only treatments that produced significant increases in recoverable sucrose and root yields compared to the untreated check were Counter 20G and Vydate C-LV, both of which are conventional chemical insecticides.

Table 2. *Yield parameters* from an evaluation of experimental at-plant and postemergence sprays for sugarbeet root maggot control, St. Thomas, ND, 2018

Treatment/form.	Placement[a]	Rate (product/ac)	Rate (lb a.i./ac)	Sucrose yield (lb/ac)	Root yield (T/ac)	Sucrose (%)	Gross return ($/ac)
Counter 20G	B	7.5 lb	1.5	7353 a	22.3 a	17.55 a	990
Vydate C-LV	1 d Pre-peak Broad.	34 fl oz	1.0	7304 a	22.2 a	17.50 a	984
Endigo ZC	3" TB	4.5 fl oz		6954 ab	21.2 ab	17.55 a	933
Lorsban Advanced	1 d Pre-peak Broad.	1 pt	0.5	6672 abc	20.6 abc	17.40 a	882
Ecozin Plus 1.2% ME	1 d Pre-peak Broad.	56 fl oz		6554 a-d	21.3 ab	16.53 a	808
Evergreen Crop Protection	1 d Pre-peak Broad.	16 fl oz		6392 bcd	19.6 b-e	17.25 a	852
Dibrom	1 d Pre-peak Broad.	1 pt		6364 bcd	20.1 a-d	16.98 a	815
Check	---	---		6260 b-e	19.6 b-e	17.18 a	814
Larva Biocontrol	3" TB	5 fl oz		6205 b-e	19.4 b-e	17.15 a	809
Captiva	1 d Pre-peak Broad.	2 pts		6147 b-e	19.8 b-e	16.83 a	766
Aza-Direct (0.0987 lb/gal)	3" TB	56 fl oz		6000 cde	19.4 b-e	16.78 a	746
Larva Biocontrol + Spore Control + Spidermite Control	3" TB 1 d Pre-peak Broad.	5 fl oz 26 + 20 fl oz		5962 cde	18.7 cde	17.10 a	771
Spore Control + Spidermite Control	1 d Pre-peak Broad.	26 + 20 fl oz		5797 de	18.6 cde	16.80 a	729
Veratran D	1 d Pre-peak Broad.	20 lb	0.04	5764 de	18.1 de	16.90 a	743
Warrior ll	1 d Pre-peak Broad.	1.92 fl oz	0.03	5735 de	18.4 cde	16.70 a	718
Knack 0.86 EC	3" TB	10 fl oz		5475 e	17.6 e	16.75 a	685
LSD (0.05)				846.0	2.25	NS	

Means within a column sharing a letter are not significantly (P = 0.05) different from each other (Fisher's Protected LSD test).
[a]B = 5-inch band; 3" TB = 3-inch T-band; Broad. = Broadcast

Although few statistically significant improvements in yield parameters were observed in Study I, notable increases in gross revenue when compared to the untreated check were recorded for the following treatments (presented in descending order of gross revenue increase above the check): 1) Counter 20G ($176/ac); Vydate C-LV ($170/ac); Endigo ZC ($119/ac); Lorsban Advanced ($68/ac); and Evergreen Crop Protection ($38/ac).

It bears repeating that all insecticide-treated entries in Study I were single-application treatments, which is never recommended for SBRM management under the high to severe root maggot pressure that typically develops in the northern RRV. The overall goal of this experiment was simply to determine if any of the experimental insecticides tested have potential to provide a measurable level of root protection and associated yield benefits in relation to managing the sugarbeet root maggot. Once candidate insecticide materials with such potential are identified, future research will focus on integrating them into control programs that may include both planting-time insecticide protection (i.e., a granular, sprayable liquid, or seed treatment insecticide) and postemergence additive protection to optimize SBRM management methodology.

Study II:

Sugarbeet root maggot larval feeding injury rating data for Study II are presented in Table 3. Root maggot feeding injury in the fertilizer-only check (subsequently referred to as "check" or "untreated check") plots of this trial averaged 6.98 on the 0 to 9 scale of Campbell et al. (2000), which suggested the presence of a relatively high SBRM infestation for the experiment. All insecticide-based treatments in the experiment resulted in significant reductions in root maggot feeding injury when compared to the check. The lowest average SBRM feeding injury in Study II was observed in plots treated with Bifender FC at its higher (14.5 fl oz/ac) rate by using 3-inch T-band placement. Other entries in Study II that were not outperformed by this treatment included the following: 1) Counter 20G, applied as a 5-inch planting-time band at its moderate (7.5 lb product/ac) rate; 2) Midac FC, applied dribble in-furrow (DIF) at its high (13.5 fl oz/ac) rate; and 3) Midac FC, applied DIF at its low (6.9 fl oz/ac) rate.

Using a 3-inch T-band for placement of Bifender resulted in significantly greater root protection than when the product was applied at the same rate by using dribble in-furrow placement. Plots treated with the high rate T-banded application of Bifender at its high rate also had significantly less SBRM feeding injury than when it was applied either singly at its lower, 10.9 fl oz/ac rate, or when it was applied at the 10.9-oz rate and combined with Midac at 6.9 fl oz/ac as a tank mixture.

Although plots treated at planting time with Midac at its full (13.5 fl oz/ac) rate had numerically lower levels of SBRM feeding injury than those in which the lower (6.9 fl oz/ac) rate of Midac was used, there was no statistically significant difference in root protection between application rates of this product.

Table 3. *Larval feeding injury* in an evaluation of experimental at-plant sprays for sugarbeet root maggot control, St. Thomas, ND, 2018

Treatment/form.	Placement[a]	Rate (product/ac)	Rate (lb a.i./ac)	Root injury (0-9)
Bifender FC + 10-34-0	 3" TB	14.5 fl oz 5 GPA	0.19	4.80 e
Counter 20G + 10-34-0	B DIF	7.5 lb 5 GPA	1.5	5.03 de
Midac FC + 10-34-0	 DIF	13.5 fl oz 5 GPA`	4.28	5.20 cde
Midac FC + 10-34-0	 DIF	6.9 fl oz 5 GPA	2.14	5.33 b-e
Bifender FC + 10-34-0	 DIF	10.9 fl oz 5 GPA	0.14	5.55 bcd
Bifender FC + Midac FC + 10-34-0	 DIF	10.9 fl oz 6.9 fl oz 5 GPA	0.14 2.14	5.75 bc
Bifender FC + 10-34-0	 DIF	14.5 fl oz 5 GPA	0.19	5.88 b
Fertilizer check	DIF	5 GPA		6.98 a
LSD (0.05)				0.644

Means within a column sharing a letter are not significantly (P = 0.05) different from each other (Fisher's Protected LSD test).
[a]B = 5-inch band; DIF = Dribble in-furrow; 3" TB = 3-inch T-band

Yield results from Study II appear in Table 4. Performance patterns with regard to sugarbeet root maggot management tool impacts on yield parameters in this trial corresponded closely with those observed in root injury rating results. Plots treated with the 3-inch T-banded application of Bifender FC at its high (14.5 fl oz/ac) rate produced the highest recoverable sucrose and root yields in the experiment, and generated $290/ac greater gross revenue than when the same rate of Bifender was applied by using dribble-in-furrow placement. Plots protected by this entry produced significantly more root yield than any other treatment in this study, except Midac at its high (13.5 fl oz/ac) rate. The T-banded application of Bifender at its high rate also resulted in significantly more recoverable sucrose yield than all other treatments, except the tank mixture of Bifender (10.9 fl oz/ac) plus Midac FC at 6.9 oz/ac, and the 13.5-oz rate of Midac alone. The following treatments generated the highest rates of gross economic return when compared to the fertilizer check: 1) the tank mixture of Bifender FC at 10.9 fl oz/ac + Midac FC applied DIF at 6.9 oz/ac ($267/ac above the check); 2) Bifender FC applied in a 3-inch T-band at 14.5 fl oz/ac ($261/ac above the check); 3) Midac FC at its high rate of 13.5 fl oz/ac ($233/ac above the check); and 4) Counter 20G applied at its moderate rate of 7.5 lb product/ac ($182/ac more than the check).

Table 4. ***Yield parameters*** **in an evaluation of experimental at-plant sprays for sugarbeet root maggot control, St. Thomas, ND, 2018**

Treatment/form.	Placement[a]	Rate (product/ac)	Rate (lb a.i./ac)	Sucrose yield (lb/ac)	Root yield (T/ac)	Sucrose (%)	Gross return ($/ac)
Bifender FC + 10-34-0	3" TB	14.5 fl oz 5 GPA	0.19	8304 a	26.4 a	16.85 a	1057
Bifender FC + Midac FC + 10-34-0	DIF	10.9 fl oz 6.9 fl oz 5 GPA	0.14 2.14	7818 ab	23.5 b	17.73 a	1063
Midac FC + 10-34-0	DIF	13.5 fl oz 5 GPA`	4.28	7806 ab	24.1 ab	17.28 a	1029
Counter 20G + 10-34-0	B DIF	7.5 lb 5 GPA	1.5	7180 b	21.6 bcd	17.75 a	978
Bifender FC + 10-34-0	DIF	10.9 fl oz 5 GPA	0.14	7103 b	22.0 bc	17.20 a	933
Midac FC + 10-34-0	DIF	6.9 fl oz 5 GPA	2.14	7062 b	22.1 b	17.13 a	914
Fertilizer check	DIF	5 GPA		6199 c	19.6 cd	17.05 a	796
Bifender FC + 10-34-0	DIF	14.5 fl oz 5 GPA	0.19	6035 c	19.2 d	16.90 a	767
LSD (0.05)				813.0	2.66	NS	

Means within a column sharing a letter are not significantly (P = 0.05) different from each other (Fisher's Protected LSD test).
[a]B = 5-inch band; DIF = Dribble in-furrow; 3" TB = 3-inch T-band

Future research on Bifender and Midac should focus more on applying these materials via T-band placement. Additional (i.e., higher) rates of these products should also be investigated, especially when both materials are incorporated into a single tank mixture. It is encouraging that several of the treatments involving either Bifender FC or Midac FC provided similar levels of root maggot control, in relation to both root protection from SBRM feeding injury and resulting yield, to that of the moderate rate of Counter 20G. At a minimum, this suggests that these new insecticides may have merit as SBRM management tools, either as stand-alone tools under moderate root maggot pressure, or as components of dual-insecticide programs for managing high SBRM infestations.

Although some of the experimental treatments tested in these experiments achieved comparable performance levels to those observed with either Counter 20G or Lorsban Advanced (the two conventional standards used in these studies), both of the conventional insecticides were applied at moderate rates, and not the maximum rates allowed on their respective labels. As such, further testing should be carried out on these and other experimental materials to identify potential alternatives to the currently used products. Alternative insecticide options could help prevent or delay the development of insecticide resistance in SBRM populations to currently used chemistries, and could also provide viable tools for growers to sustainably and profitably manage this pest if currently available conventional insecticides become unavailable due to regulatory action.

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