Economic Benefits of Additive Insecticide Applications for Root Maggot Control in Replanted Sugarbeet

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ABSTRACT
Multiple factors can necessitate replanting of sugarbeet, Beta vulgaris (L.). Later-established plants in replanted fields will typically be smaller and more vulnerable to herbivory by insect pests than those established at earlier, more conventional planting dates. A field study was conducted during 2004, 2007, and 2008 in Pembina County, North Dakota to determine if additive insecticide protection is warranted to manage sugarbeet root maggot (SBRM), Tetanops myopaeformis (Röder), in replanted sugarbeet fields initially protected by conventional at-plant insecticide applications. Replanting with supplemental at-plant applications of terbufos 15G and chlorpyrifos 15G reduced SBRM feeding injury and increased root yields by 8.4 to 11.9 Mg/ha. Replant applications of terbufos 15G, applied to plots initially established with at-plant chlorpyrifos 15G, resulted in 32.2% and 34.8% more root and sucrose yield, respectively, and generated $405 more gross economic return per hectare than the stand-alone at-plant application of chlorpyrifos 15G. Postemergence liquid insecticides provided slightly less consistent control and yield benefits than granular insecticides applied at replanting, although the disparities rarely involved significant differences in gross economic return. The results of this investigation show that additive insecticide applications in replanted sugarbeet provide significant reductions in SBRM feeding injury that translate to major increases in yield and economic return. This study also demonstrates the economic
The sugarbeet root maggot (SBRM), *Tetanops myopaemformis* (Röder), is the most important insect pest of sugarbeet (*Beta vulgaris* L.) in the Red River Valley of North Dakota and Minnesota. The SBRM was first observed damaging sugarbeet in North Dakota in 1947 (McBride et al., 1980), and it continues to be a significant management challenge on an annual basis for many Red River Valley growers. The insect also is an important pest in western sugarbeet-growing areas of the United States and the Canadian province of Alberta. Sugarbeet root maggot larvae injure the plant by rasping its root surface with paired oral hooks. Root maggot feeding injury can impair the sugarbeet plant’s ability to assimilate water and nutrients from soil. The impacts of SBRM feeding injury can be further exacerbated by other agronomic stressors such as drought. Heavy feeding injury resulting from high larval infestations under dry field conditions can be sufficient to cause plant mortality, thus leading to major stand reductions and significant yield losses. Campbell et al. (1998) demonstrated that 42% yield reductions can occur in the absence of SBRM control measures, and Blickenstaff et al. (1981) observed that the insect is capable of causing up to 100% yield losses in localized areas.

The most common SBRM management tactic in dryland sugarbeet production systems involves the prophylactic application of a granular soil insecticide at planting time (Peay et al., 1969; Yun and Sullivan, 1980; Bergen, 1984; Bergen et al., 1986). Granules are delivered in a swath over the row through either a conventional bander, an in-furrow tube, or a “spoon” placement device (Boetel et al., 2006).

Occasionally, extensive plant injury and stand loss can occur as a result of a late-spring frost event or from mechanical injury to fragile seedlings by high winds and associated blowing soil. Feeding injury by a variety of insect pests also can result in major plant stand losses (Hein et al., 2009). In some cases, stand losses are so severe that the grower must replant significant acreages or entire fields. Later-established sug-
The objective of this study was to determine if additive insecticide protection, in the form of either a supplemental planting-time application at replanting or a postemergence rescue treatment, is warranted for adequate plant protection in areas affected by moderate to high infestations of the sugarbeet root maggot.

MATERIALS AND METHODS

Field experiments were carried out near St. Thomas (Pembina County) in northeastern North Dakota during the 2004, 2007, and 2008 growing seasons. Study sites had the following soil types: 1) Glyndon silt loam with 3.1% organic matter (O.M.) and 7.5 pH in 2004; 2) Glyndon silt loam with 3.2% O.M. and 8.1 pH in 2007; and 3) Neche silt loam with 3.1% O.M. and 8.3 pH in 2008. Sugarbeet varieties used in the experiments included Crystal 822 in 2004 and Van der Have 46519 in 2007 and 2008. The study was arranged in a randomized complete block design containing three replications. Individual plots were four rows (spaced 56 cm apart) wide and 10.7 m long. Two untreated buffer rows were planted between individual plots, and 7.6-m wide unplanted alleys were established between replicates. To simulate a replanting scenario for all plots in this experiment, seed was excluded when plots were initially established; however, a six-row planter was utilized to apply initial at-plant insecticides and simulate soil perturbation associated with a typical planting operation. The planter was also pulled through all no-insecticide controls without dispensing seed during simulated initial planting to ensure that all plots were subjected to the same level of disturbance and compaction from the tractor and planter. Plots assigned to receive a planting-time insecticide were established by using planter-mounted insecticide metering and placement devices, and passing the planter through the plots without seed in the same manner as was done in the control plots. At-plant insecticides included chlorpyrifos (Lorsban 15G [granular]; Dow AgroSciences, Indianapolis, IN) and terbufos (Counter 15G; Amvac Chemical Corp., Newport Beach, CA) which, according to Carlson et al. (2008), are the two most commonly used granular soil insecticide products applied by producers for root maggot management in the Red River Valley. Replanting scenarios were chosen in accordance with label restrictions, which preclude more than one application per year of either terbufos 15G or chlorpyrifos 15G. Management options in those scenarios involved either applying the alternate granular insecticide during replanting, applying a
postemergence liquid insecticide later in the season, or opting for no additive insecticide protection. Therefore, initially terbufos-treated plots slated to receive additive protection were either treated with chlorpyrifos 15G during simulated replanting or a postemergence spray application of chlorpyrifos (Lorsban 4E [emulsifiable concentrate]; Dow Agrosciences), whereas plots treated initially with chlorpyrifos 15G were “replanted” with an at-plant application of terbufos 15G or treated at postemergence with a spray application of chlorpyrifos 4E. The experiment was therefore comprised of the following treatments: 1) terbufos 15G at simulated initial planting; 2) terbufos 15G at simulated initial planting + chlorpyrifos 15G at replanting; 3) terbufos 15G at simulated initial planting + postemergence chlorpyrifos 4E; 4) chlorpyrifos 15G at simulated initial planting; 5) chlorpyrifos 15G at simulated initial planting + terbufos 15G at replanting; 6) chlorpyrifos 15G at simulated initial planting + postemergence chlorpyrifos 4E; and 7) a no-insecticide control.

Insecticide granules applied at simulated initial planting (28 April, 2004; 10 May, 2007; and 16 May, 2008) were delivered at the highest labeled rate for each material (i.e., 2.2 and 2.0 kg [a.i.]/ha for chlorpyrifos and terbufos, respectively) to reflect typical planting-time applications for SBRM control in dryland sugarbeet production systems. Noble™ metering units (Remcor, Inc., Howe, TX) mounted on a six-row John Deere™ (Deere & Company, Moline, IL) 71 Flex planter were used to regulate granular delivery rates, and all units were calibrated on the planter before treatment applications. The placement method used for initial at-plant applications of the two granular insecticides differed. Terbufos was applied via modified in-furrow (M) placement and chlorpyrifos 15G was applied in a band (B). Modified in-furrow placement involved dropping granules down conventional planter-mounted in-furrow application tubes that were positioned over the rows; however, the tubes were directed slightly backward from the seed drop zone and toward the rear press wheel to allow granule deposition into soil above the seed as the furrow closed, thus avoiding excessive insecticide contact with seed and minimizing the likelihood of insecticide phytotoxicity to sugarbeet seedlings. Banded applications consisted of 12.7-cm swaths of granules that were oriented perpendicularly to the row, delivered ahead of the planter’s rear press-wheels through planter-mounted Gandy™ row banders (Gandy Company, Owatonna, MN), and incorporated with drag chains.

Although application rate and placement method varied between terbufos and chlorpyrifos for the simulated initial planting operation, they reflected respective label instructions for the two granular insecti-
cides. Insecticide rates and placement devices used in the experiment also represented the application methodology that is recommended by university extension personnel in the region and is most commonly used by Red River Valley sugarbeet producers. It should be noted that a priori comparisons chosen for this experiment were not intended to evaluate efficacy of one material or rate versus the other, but rather to determine the implications of additive insecticide applications on SBRM control for growers choosing either terbufos or chlorpyrifos as a preferred at-plant soil insecticide. Additional granules applied at simulated replanting (i.e., 18 May, 2004; 25 May, 2007; and 2 June, 2008) were all delivered via band placement at 1.7 kg (a.i.)/ha. Postemergence chlorpyrifos 4E was applied in 12.7-cm bands at 1.2 L product (i.e., 0.56 kg [a.i.]) per hectare in a finished spray volume of 93.5 L/ha through TeeJet 6501E nozzles on 21, 5, and 20 June in 2004, 2007, and 2008, respectively. Postemergence chlorpyrifos 4E applications were timed independently each study year in relation to the anticipated date of peak SBRM fly activity, which was projected by using a local degree-day-based forecast (R.B. Carlson, unpublished data).

Root maggot feeding injury was assessed in late July or early August each study year, depending on when larval feeding injury ceased. Assessments involved randomly collecting ten beet roots per plot (i.e., five from each of the outer two treated rows), hand-washing them, and rating them in accordance with the 0 to 9 root injury scale (0 = no scarring, and 9 = over 75% of the root surface blackened by scarring or a dead beet) of Campbell et al. (2000).

Treatments were also compared for impacts on sugarbeet yield parameters. Plots were harvested in mid- to late-September each year. Foliage was removed from all plots immediately before harvest by using a commercial-grade mechanical defoliator. Because border effects on sugar concentration and quality can occur in plants located near plot alleys due to reduced interplant competition, the crowns of the last two to four roots on both ends of each row were marked with spray paint after defoliation and before harvest. Painted roots from plot edges were included in total harvested weight measurements, but excluded from sucrose content and quality analyses to avoid variability due to potential edge effects. Immediately following defoliation, all beets from the center two rows of each plot were extricated from plots using a mechanical sugarbeet harvester. A harvester-mounted digital scale (Dyna-Link MSI-7200, Measurement Systems International, Seattle, WA) was used to measure pre-wash weight of all harvested roots immediately after harvesting each plot. A representative subsample of 12-20 unpainted beets was randomly collected from each harvested plot and sent to the
American Crystal Sugar Company Quality Tare Laboratory (East Grand Forks, MN) for sugar content and impurity analyses. Immediately before processing for quality analysis, all soil adhering to subsample roots was removed by washing and rinsing. Post-wash weight of each sample was recorded, and difference between pre- and post-wash weight (i.e., tare soil percentage) was deducted from total harvested weight to calculate net sugarbeet root yield for each plot. Net extractable sucrose per hectare was estimated by multiplying root weight by sugar concentration and subtracting the loss to molasses, which was based on concentrations of soluble non-sucrose components. Gross economic return from each treatment was calculated using a five-year average (2003-2007) of sugar processing variables used by a local sugar cooperative for determining shareholder payments. The value excluded grower input costs associated with insecticide purchase and application expenses, and it was calculated by using the following formula:

\[
\text{RETURN} = \text{YLD} \times (((\text{SUCR} - \text{LOSS}) \times \text{PRICE}) + \text{BYPR} - \text{COST})
\]

where \( \text{YLD} \) = harvested root yield, \( \text{SUCR} \) = sucrose concentration (%), \( \text{LOSS} \) = factory sugar loss (%), \( \text{PRICE} \) = sugar selling price, \( \text{BYPR} \) = processing byproducts revenue, \( \text{COST} \) = factory operating costs.

All data were subjected to analysis of variance using the general linear models procedure (SAS Institute, 2001), and treatment means for the response variables of root maggot feeding injury, sugarbeet root yield, net extractable sucrose yield, and gross economic return were separated by using Fisher’s protected least significant difference (LSD) test at a 0.05 level of significance. Initial analyses generated nonsignificant \( (P > 0.05) \) treatment \( \times \) year interactions for all response variables, which permitted our use of combined analyses for all three years of data.

RESULTS

SBRM feeding injury.

Results from root injury assessments are presented in Table 1. Moderately high root maggot feeding pressure occurred throughout this three-year experiment. Root injury observed in the no-insecticide control plots averaged 6.0 on the 0 to 9 rating scale when averaged across study years. Root rating data also showed that all insecticide treatment regimes imparted significant \( (P < 0.05) \) reductions in SBRM feeding injury when compared with the injury that occurred in the no-insecticide control plots. Applying chlorpyrifos 15G at simulated replanting

<table>
<thead>
<tr>
<th>Treatment regime</th>
<th>Simulated 1st planting</th>
<th>Replanting</th>
<th>Postemergence spray</th>
<th>Root Injury (0-9)†‡</th>
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<tr>
<td><strong>Treatment/form.</strong></td>
<td>Rate (kg a.i./ha)</td>
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Means within a column sharing a letter are not significantly different (P > 0.05) from each other (Fisher’s protected least significant difference test).

† Root injury ratings are based on the 0 to 9 scale of Campbell et al. (2000).

‡ Root injury rating data from 2004, 2007, and 2008 were pooled due to a nonsignificant (P > 0.05) treatment × year interaction in the original analysis.
to plots initially treated with terbufos 15G resulted in a significant increase in protection from root maggot feeding injury when compared to the stand-alone, at-plant treatment of terbufos 15G. However, applying a postemergence application of chlorpyrifos 4E to plots initially treated with at-plant terbufos 15G did not significantly improve the level of root protection when compared with that provided by the single at-plant application of terbufos.

When chlorpyrifos 15G was used as the initial planting-time insecticide, an additive at-plant application of terbufos 15G at simulated replanting resulted in significantly less root maggot feeding injury than that sustained in the stand-alone at-plant chlorpyrifos 15G plots (Table 1). The margin of improvement provided by the replant application of terbufos 15G in this scenario amounted to nearly two points less feeding injury on the 0 to 9 rating scale. Postemergence applications of chlorpyrifos 4E, applied two to four days before peak SBRM fly activity, also resulted in significant improvements in root protection when compared with stand-alone at-plant applications of chlorpyrifos 15G; however, the chlorpyrifos spray was not as effective as the replant application of terbufos 15G.

Yield parameters.

Results of yield comparisons corresponded closely with root injury rating data. Significant increases in both root and sucrose yields resulted from all insecticide treatment regimes when compared to yields from the no-insecticide controls (Table 2). In plots that received terbufos 15G as the at-plant insecticide at simulated first planting, additive applications of at-plant chlorpyrifos 15G provided 8.4 and 1.0 Mg/ha greater sugarbeet root yields and extractable sucrose yields, respectively, than stand-alone at-plant applications of terbufos. Significant increases in root and extractable sucrose yields also were achieved by adding a postemergence application of chlorpyrifos 4E to plots initially established with an at-plant application of terbufos 15G. There was no statistical difference between the additive replant application of chlorpyrifos 15G and postemergence chlorpyrifos 4E for either yield parameter when terbufos 15G was used as the initial at-plant material.

In plots established with an initial application of chlorpyrifos 15G at simulated first planting, a replant application of terbufos 15G resulted in a 32.2% (i.e., 11.9 Mg/ha) increase in sugarbeet root yield over that of the initial stand-alone chlorpyrifos 15G treatment. Chlorpyrifos 4E appeared to have a slightly positive impact on root yield. Plots initially established with at-plant chlorpyrifos 15G averaged 3.6 Mg/ha (i.e., 9.8%) more sugarbeet root yield when they received an additive poste-

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<tr>
<th>Treatment regime</th>
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<th>Extractable sucrose yield Mg/ha †</th>
<th>Gross economic return/ha ‡</th>
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† Root yield, extractable sucrose yield, and gross economic return data from 2004, 2007, and 2008 were pooled due to a nonsignificant (P > 0.05) treatment × year interaction in the original analysis.

‡ Gross economic return excludes pesticide purchase and application costs. It is based on a five-year average (Fiscal Years 2003-2007) of gross revenue rates per unit harvest weight after deducting storage losses and processing costs, and adding factory by-product revenue for a local sugar cooperative.
mergence spray of chlorpyrifos 4E. Despite that trend being consistent across study years, the difference was not statistically significant in the combined analysis.

Gross economic return.

All insecticide regimes provided major improvements in gross economic return when compared to the no-insecticide control plots. Overall, insecticide-treated regimes resulted in between $251 and $656/ha more gross economic return than the controls. A significant (P < 0.05) increase in gross economic return, which amounted to $317/ha, was achieved when a postemergence application of chlorpyrifos 4E was applied at two to four days before peak SBRM flight activity in plots initially protected by an application of terbufos 15G at simulated first planting. Plots that received terbufos 15G at the simulated first planting, followed by a replant application of chlorpyrifos 15G, averaged $219/ha more in gross economic return than those that did not receive the replant application; however, the difference was not statistically significant.

The highest economic return in this experiment was from the treatment comprised of chlorpyrifos 15G at simulated first planting, followed by a replant application of terbufos 15G. The gross return from this combination was significantly greater than that from the stand-alone at-plant application of chlorpyrifos 15G, and it produced a revenue increase of more than $400/ha. There also was a consistent trend over the three years of this experiment in which plots treated with an additive postemergence spray application of chlorpyrifos 4E averaged about $210 greater gross economic return per hectare than plots treated with the single at-plant application of chlorpyrifos 15G, although the difference was not statistically significant (P = 0.0727).

DISCUSSION

Insect damage, frost or freeze events, high winds, or blowing soil can cause major seedling stand losses and occasionally cause enough damage for growers to consider replanting sugarbeet. Replanting of sugarbeet can be an expensive management endeavor because of the costs of replacement seed, fuel, wear-and-tear on equipment, and labor. In sugarbeet production, additional costs associated with replanting sugarbeet can also be incurred in the form of yield losses because later-emerging plants in replanted fields tend to produce less root yield and lower sucrose concentrations than those in early planted fields. Plants in replanted fields also tend to have smaller tap roots and are therefore,
more vulnerable to attack by insect pests such as the sugarbeet root maggot. Because sugarbeet is a tap root crop, extensive feeding injury to its root system can result in severing of the root and, ultimately, plant mortality and associated yield loss. This is especially likely if other stressors such as drought, disease, or herbicide injury are negatively impacting plant development.

The findings of this three-year study, conducted in sites with moderate to high SBRM infestations, indicate that additive insecticide applications in replanted sugarbeet fields are likely to result in major reductions in sugarbeet root maggot feeding injury, as well as significant increases in root yields, extractable sucrose yields, and gross economic returns. Additive applications of granular insecticides at replanting in this investigation were generally more consistent at providing improvements in root protection from SBRM feeding injury to initial at-plant treatments than were postemergence spray applications of the liquid insecticide, chlorpyrifos 4E. Replant applications of granular insecticides improved root yields by 8.4 to 11.9 Mg/ha and increased extractable sucrose yields by 1.0 to 1.6 Mg/ha. Improvements in root tonnage and extractable sucrose yields from additive insecticide applications via a second at-plant granular material led to increases in gross economic return that ranged from $219 to $405/ha, which would easily justify the additional insecticide cost. Moreover, applying a second at-plant granular material during replanting operations would not involve added application cost because the required equipment is mounted on the planter needed for both planting operations. An additional benefit of such an application would be that the producer could achieve excellent SBRM control without having to attempt achieving an optimally timed postemergence rescue insecticide application.

Postemergence sprays of chlorpyrifos 4E in this study were slightly less consistent than granular insecticides at providing significant improvements in root protection and yield parameters. This disparity could have been associated with occasional differences between anticipated and actual timing of peak SBRM fly activity, which can vary as a result of wind and rainfall events because inclement weather typically delays or reduces insect flight activity. It also is possible that the occasional lack of significant differences could have been associated with the minimal number (i.e., three) of replications used in this study. It should be noted that, while postemergence spray applications did not always result in significant improvements in efficacy, they were not statistically inferior to additive at-plant granular insecticide applications with respect to gross economic return.

Plots treated with postemergence sprays of chlorpyrifos 4E as the
additive insecticide in replanted sugarbeet produced revenue increases that ranged between $210 and $317/ha. These returns, similar to those from supplemental granular applications made at sugarbeet replanting, would also easily justify the investment in additive insecticide and associated application costs. Despite being slightly less consistent than additive applications of granules at replanting, the strategy of using rescue applications of postemergence materials, applied on an as-needed “prescriptive” basis, should remain as a viable option because it allows the producer to determine if fly populations justify the treatment before deciding to make the investment. This scenario is attractive from an environmental stewardship standpoint because it embodies one of the fundamental tenets of pest management, which advocates that intervention with an insecticide should be reserved for cases where the application is justified based on economic decision indices associated with a pest’s population level.

The focus of this study was on sugarbeet root maggot management in replanting situations where an at-plant insecticide was applied during the initial planting operation. Our results clearly demonstrate the importance of insecticidal protection of late-planted sugarbeet fields in maggot-infested areas. These findings also could be applied to late-planted sugarbeet fields that occur for other reasons, such as excessive spring soil moisture that delays field preparation and planting. Additionally, our findings also could have implications for SBRM control in seasons where extended cool weather or dry soils delay emergence and development of sugarbeet seedlings, thus rendering plants smaller and more susceptible to attack during the sugarbeet root maggot larval feeding period.

In addition to the demonstrated impact of postemergence insecticide sprays in this study, the efficacy provided by replant applications of terbufos 15G and, to a lesser extent chlorpyrifos 15G, suggest that the granular insecticides also could have potential as postemergence rescue tools for SBRM management. This contention is supported by the work of Bergen and Whitfield (1987) that indicated both liquid and granular formulations provide effective avenues for postemergence delivery of chemical insecticides to control the sugarbeet root maggot. Those findings, combined with the results of the current study, suggest that postemergence banded applications of either the liquid or granular insecticides used herein would probably fit well as control tactics in areas affected by moderate to high SBRM infestations. Additionally, postemergence applications of these insecticides would likely serve as excellent additive management tools for producers choosing to adopt seed treatment insecticide technology which, according to Boetel et al.
(2008) should not be used as stand-alone tools for control of the high SBRM infestations that commonly plague producers in northern portions of the Red River Valley. It should be noted that preharvest interval restrictions appearing on labels of some granular insecticides could, however, preclude their use as postemergence tools in some years.

The results of this three-year investigation also demonstrate that moderate to high infestations of the sugarbeet root maggot are capable of causing major revenue losses. A 45.2% loss in gross economic return was observed in the no-insecticide control plots when compared with that achieved by using the most efficacious insecticide treatment combination in the experiment. This corresponded closely with the results of Campbell et al. (1998), who observed 42% yield reductions in untreated control plots. The combined results of these studies clearly underscore the significance of the sugarbeet root maggot as a serious economic pest of sugarbeet, and thereby demonstrate the importance of using efficacious tools for its management.

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LITERATURE CITED


