EFFECTIVENESS OF METARHIZIUM ANISOPLIAE COMMERCIAL STRAIN F52 FOR SUGARBEET ROOT MAGGOT MANAGEMENT

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Introduction

Sugarbeet is an introduced cash crop which, in some areas of Red River Valley, can be completely devastated by a native insect pest species, *Tetanops myopaeformis* or the sugarbeet root maggot (SBRM), if chemical control measures are not taken. Yield losses from larval feeding on roots can average up to 40%. Organophosphate insecticides, represented by compounds such as terbufos and chlorpyrifos, were used to treat 90 to 100% of the sugarbeet acreage in North Dakota counties ravaged by the SBRM (Luecke et al. 2006). With such large-scale use of chemical insecticides, the danger of insecticide resistance development in SBRM populations is a real threat. A possible solution to avert resistance is the use of alternative control measures. The search for alternative SBRM control tools started in the early 1990s, and the use of insect pathogens such as bacteria (Smith 1990) and nematodes (Wozniak et al. 1993) topped the list at that time.

Due to the short environmental persistence and problems with pathogen delivery in those preliminary investigations, biocontrol research slowly shifted toward pathogenic fungi such as *Metarhizium anisopliae* var. *anisopliae*. Figure 1 shows two stages of infection of SBRM larvae caused by *M. anisopliae*. This pathogen penetrates larvae through the insect integument and rapidly proliferates inside the body of larvae, resulting in host death. All larval instars, as well as adult flies, can be infected by *M. anisopliae.* After a successful cycle of infection, the pathogen emerges out of the body of its dead host in the form of compact hyphal masses (Figure 1B). Smith et al. (1998) conducted the first field trials of *M. anisopliae* after establishing virulence of the strain ATCC62176 to SBRM larvae under laboratory conditions (Smith and Eide 1995). More recently, Jonason et al. (2005) and Campbell et al. (2006) have provided strong evidence regarding the effectiveness of *M. anisopliae* to SBRM larvae through replicated laboratory and field trials.

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Figure 1. Progression of *Metarhizium anisopliae* infection in sugarbeet root maggot (Illustrated by Ayanava Majumdar)

The possibility of an integrated SBRM management strategy incorporating the established practice of cover cropping was first tested in field by Carlson et al. (1997). A series of cover crop experiments where cereal cover crops were integrated with chemical insecticides was shown to be effective by Boetel et al. (2000-2002) and Dregseth et al. (2003). Those authors provided scientific evidence regarding the fact that cover crops can provide insect control apart from other advantages such as wind protection and soil erosion control early in the growing season. Cover crops were used by 31% of sugarbeet growers in a survey by Luecke et al. (2006); hence, there is potential for quick adoption of this practice for bio-based maggot control. Success of the first integrated biocontrol trials consisting of cereal cover crops and *M. anisopliae* was reported by Majumdar et al. (2003, 2004). The focus in those preliminary trials was on the strain ATCC62176 (or MA-1200 – a noncommercial strain of the fungus). Since 2005, the efforts have been on integrating a commercial strain (F52) of this fungus produced by Novozymes Biologicals, Inc., Salem, VA (previously Earth Biosciences, Inc., New Haven, CT), with cereal cover crops oat and rye at two seeding rates.

This unique cover crop + biocontrol fungus study aims at answering several questions through its intricate design and new research approach. The main objective was to assess the impact of two cereal cover crops at different seeding densities in conjunction with an effective strain of *M. anisopliae* for integrated management of the sugarbeet root maggot. Other objectives were to find the optimal deployment method for the biological insecticide by evaluating formulations, application techniques, and application timing. The current report summarizes findings from 2006 field trials and compares them to 2005 results to measure success of the study.

Materials and methods

A detailed account of experimental design and materials has been provided by Majumdar et al. (2006a). A few key details are provided in this report. Experiment sites were St. Thomas (Pembina Co.) and Minto (Walsh Co.) in 2005 and 2006. Table 1 provides the list of treatments included in the study. Fungus spores were mass produced and formulated at U. S. Department of Agriculture – Agricultural Research Service, Northern Plains Agricultural Research Laboratory, Sidney, MT. M. anisopliae strain F52 was applied at 3.23 x 10^{12} viable conidia/ac (2X rate) in the form of planting-time granules placed modified-in-furrow (MIF) or as a postemergence spray using modified field equipment. A planting-time application of terbufos 15G (Counter, AMVAC Chemical Corporation, Newport Beach, CA) at 10 lb product/ac served as the chemical standard in this study. The MIF placement of granules allowed separation of the active ingredients (chemical or biological insecticide) from the sugarbeet seed to prevent phytotoxicity. Cover crop varieties Newdak (oat) and Dacold (rye) were applied at 0 (no cover), 1.5 and 3.0 oat bushel equivalents (OBE) per acre; these seeding rates were equivalent to 0, 187, and 374 seeds/m^2. Sugarbeet variety BETA 3820 was planted after broadcast-planting and incorporation of cover crop seeds. Cover crops were removed chemically by using a grass herbicide when the plants achieved 7-inch height.

Table 1. Treatment list for sugarbeet root maggot biocontrol study, North Dakota, 2005 and 2006

Cover crop	Seeding rate (OBE)*	Insecticide (chem. / bio.)	Treatment rate	Application timing

OAT	1.5	Counter 15G	1.5# MIF**	Planting
OAT	1.5	*Metarhizium* F52	2X MIF	Planting
OAT	1.5	*Metarhizium* F52	2X spray	Postemergence
OAT	1.5	-----	----	----
OAT	3.0	Counter 15G	1.5# MIF	Planting
OAT	3.0	*Metarhizium* F52	2X MIF	Planting
OAT	3.0	*Metarhizium* F52	2X spray	Postemergence
OAT	3.0	-----	----	----
RYE	1.5	Counter 15G	1.5# MIF	Planting
RYE	1.5	*Metarhizium* F52	2X MIF	Planting
RYE	1.5	*Metarhizium* F52	2X spray	Postemergence
RYE	1.5	-----	----	----
RYE	3.0	Counter 15G	1.5# MIF	Planting
RYE	3.0	*Metarhizium* F52	2X MIF	Planting
RYE	3.0	*Metarhizium* F52	2X spray	Postemergence
RYE	3.0	-----	----	----
----	-----	Counter 15G	1.5# MIF	Planting
----	-----	*Metarhizium* F52	2X MIF	Planting
----	-----	*Metarhizium* F52	2X spray	Postemergence
----	-----	CHECK	----	----

*****Oat Bushel Equivalents (1 OBE = same seeding density per unit area as 1 bushel of oat seed)
** Modified In-Furrow # lb (AI)/ac 2X rate of *Metarhizium* = 3.23 x 10^{12} viable conidia/ac

Assessments of root maggot feeding injury were carried out by removing 10 roots per plot (from outer treated rows), washing them, and then assessing surface scarring on a 0 to 9 root injury (RI) scale developed by Campbell et al. (2000). A damage rating of 0 meant no scarring on root surface, and a 9 indicated scarring on 75% or more root surface. The two middle rows of each plot were mechanically harvested following defoliation and root yield was measured using a Dyna-Link digital scale attached to the collecting bin. Twelve to 14 medium-sized root samples were randomly collected and delivered to the American Crystal Sugar Quality Tare Laboratory, East Grand Forks, MN. Net recoverable sucrose yield was adjusted for sugar loss to molasses and tare weight. All root injury and yield data were subjected to the analysis of variance (ANOVA) using the general linear models procedure (SAS Institute 1999) and treatment means were compared using Fisher's protected least significant difference (LSD) test at P = 0.05.

Results

St. Thomas. There was a significant treatment effect on root injury and yield parameters in all trial years. Root injury in untreated check plots of 2005 was higher (RI = 6.50, Table 2) than that in 2006 (RI = 4.65, Table 3). Trials conducted in 2006 also had complexity arising from a significant wireworm infestation which reduced plant stand. Based on sugarbeet root injury, the trends seen in 2006 were consistent with trends seen in 2005. Nonintegrated fungus treatments consistently had uneven plant growth, moderate to high root scarring, and low root yield. There were no significant differences between in yield between F52 granules and the F52 spray. The effect of seeding rate was more evident when oat cover crop was integrated with F52 than with rye. For example, in 2006 (Table 3) plots that received oat 1.5 Bu + F52 spray had significantly less (17.4 T/ac) yield compared to plots that received oat 3.0 Bu + F52 spray (24.6 T/ac). A similar effect was seen if oat 3.0 Bu + F52 granular formulation is compared with oat 1.5 Bu + F52 granules. Increasing the seeding rate of rye in biological control integration did not provide such large differences.

Table 2. Effect of bio-based sugarbeet root maggot management programs on root injury, root yield, and sucrose yield, St. Thomas, ND, 2005

Treatment	**Root injury (0 to 9 scale)**	**Root yield (T/ac)**	**Recoverable sucrose (lb/ac)**
Untreated check	6.50 a	10.9 f	2778 g
Metarhizium Granules (G)	3.90 bcd	14.5 a-e	3877 bcdef
Metarhizium Spray (S)	4.40 bcd	12.8 def	3271 efg
Terbufos	4.22 bcd	16.9 ab	4697 ab
Oat 1.5	3.90 bcd	15.3 abcd	4132 bcdef
Oat 1.5 + *Metarhizium* G	3.95 bcd	14.5 bcde	3897 bcdef
Oat 1.5 + *Metarhizium* S	3.65 cd	12.4 ef	3260 efg
Oat 1.5 + terbufos	2.92 d	17.3 a	5205 a
Oat 3.0	3.65 cd	15.3 abcd	4237 abcde
Oat 3.0 + *Metarhizium* G	3.87 bcd	16.5 abc	4392 abcd
Oat 3.0 + *Metarhizium* S	3.62 cd	14.9 abcde	3819 bcdef
Oat 3.0 + terbufos	3.47 d	16.6 abc	4617 abc
Rye 1.5	4.20 bcd	13.2 def	3592 defg
Rye 1.5 + *Metarhizium* G	5.37 ab	12.7 def	3236 efg
Rye 1.5 + *Metarhizium* S	4.35 bcd	14.0 cde	3646 cdefg
Rye 1.5 + terbufos	3.60 cd	16.1 abc	4382 abcd
Rye 3.0	5.02 abc	12.5 ef	3188 fg
Rye 3.0 + *Metarhizium* G	3.27 d	15.3 abcd	4084 bcdef
Rye 3.0 + *Metarhizium* S	3.20 d	14.4 bcde	4153 bcdef
Rye 3.0 + terbufos	3.12 d	15.4 abcd	4047 bcdef
Treatment Pr > $F_{19,57}$	0.0047	0.0005	0.0018
LSD (0.05)	1.52	2.76	1027.7

Metarhizium anisopliae strain F52 was applied as granules (modified in-furrow) or spray at rate of 3.23×10^{12} viable conidia/ac.

Oat and rye seeding rates are expressed as oat bushel equivalents (OBE)/ac.

Means within a column sharing a letter are not significantly (*P* = 0.05) different (Fisher's Protected LSD).

Table 3. Effect of bio-based sugarbeet root maggot management programs on root injury, root yield, and sucrose yield, St. Thomas, ND, 2006

Treatment	Root injury (0 to 9 scale)	Root yield (T/ac)	Recoverable sucrose (lb/ac)
Untreated check	4.65 a	17.8 f	4588 ef
Metarhizium Granules (G)	3.95 ab	17.8 f	4671 ef
Metarhizium Spray (S)	4.05 ab	17.9 f	4404 ef
Terbufos	2.75 d	29.9 ab	8204 a
Oat 1.5	3.77 bc	17.7 f	4582 ef
Oat 1.5 + *Metarhizium* G	3.82 bc	17.9 f	4593 ef
Oat 1.5 + *Metarhizium* S	3.95 ab	17.4 f	4137 f
Oat 1.5 + terbufos	3.35 bcd	30.0 a	7769 ab
Oat 3.0	3.47 bcd	22.3 def	5854 cde
Oat 3.0 + *Metarhizium* G	3.97 ab	24.3 cde	6276 bcd
Oat 3.0 + *Metarhizium* S	3.75 bc	24.6 cde	6325 bcd
Oat 3.0 + terbufos	3.05 cd	26.9 abcd	7335 abc
Rye 1.5	3.80 bc	19.7 ef	4923 def
Rye 1.5 + *Metarhizium* G	3.95 ab	20.5 ef	5237 def
Rye 1.5 + *Metarhizium* S	3.42 bcd	20.7 ef	5165 def
Rye 1.5 + terbufos	3.27 bcd	28.6 abc	7391 abc
Rye 3.0	3.72 bc	22.2 def	5625 def
Rye 3.0 + *Metarhizium* G	3.57 bc	21.0 ef	5466 def
Rye 3.0 + *Metarhizium* S	3.77 bc	21.2 ef	5531 def
Rye 3.0 + terbufos	3.87 ab	30.9 a	8485 a
Treatment Pr > F $_{19,57}$	0.0136	<0.0001	<0.0001
LSD (0.05)	0.78	5.37	1604.6

Metarhizium anisopliae strain F52 was applied as granules (modified in-furrow) or spray at rate of 3.23 x 10^{12} viable conidia/ac.

Oat and rye seeding rates are expressed as oat bushel equivalents (OBE)/ac.

Means within a column sharing a letter are not significantly (*P* = 0.05) different (Fisher’s Protected LSD).

In both test years, oat 1.5 Bu + terbufos had one of the lowest (3.0 to 3.3) root injuries and highest root yields; the only bio-based treatments that matched performance were oat 3.0 + F52 granules (under high rainfall conditions in 2005, Table 2) or oat 3.0 Bu + F52 spray (under low rainfall conditions in 2006, Table 3).

Minto: Average root injury in the untreated check plots was higher (RI = 4.30, Table 4) in 2005 than in 2006 (RI = 1.70, Table 5). While the 2005 experiment indicated some success, the trial of 2006 was marked by uneven seed germination and poor plant stands that resulted from prolonged heat and dryness during May and June of that year. SBRM flies were seen ovipositing at the base of the plants in cracks and crevices of soil; however, many eggs could have died from lack of moisture, thus, resulting in negligible feeding activity in soil (AM, personal observation). Therefore, only the field trial of 2005 (Table 4) provided reliable estimate of treatment success in terms of root scarring and yield parameters. Similar to the trends observed at St. Thomas, the benefit of integrating an oat 3.0 Bu with F52 was also noticeable under the moderate insect pressure at Minto. Nonintegrated F52 plots also had high root injury (RI = 3.8 to 4.0), but the plots that were treated with oat 3.0 Bu + F52 spray had significantly lower (RI = 2.2) root injury compared to the stand-alone F52 plots. This finding is consistent with the St. Thomas data that indicate superiority of the oat cover crop at a high seeding rate.

Table 4. Effect of bio-based sugarbeet root maggot management programs on root injury, root yield, and sucrose yield, Minto, ND, 2005

Integrations	Root injury (0 to 9 scale)	Root yield (T/ac)	Recoverable sucrose (lb/ac)
Untreated check	4.30 ab	20.9 abcd	6133 bcdefg
Metarhizium Granules (G)	3.85 abcde	18.3 cdefg	5583 cdefg
Metarhizium Spray (S)	4.00 abc	17.0 g	5262 fg
Terbufos	3.00 efgh	22.9 ab	7154.0 ab
Oat 1.5	3.60 bcdef	20.9 abcd	6413 abcde
Oat 1.5 + *Metarhizium* G	3.25 cdefg	21.3 abc	6570 abcd
Oat 1.5 + *Metarhizium* S	3.07 cdefgh	20.3 abcdef	6333 abcdef
Oat 1.5 + terbufos	3.12 cdefgh	23.2 a	7281 a
Oat 3.0	2.25 h	20.7 abcde	6591 abcd
Oat 3.0 + *Metarhizium* G	2.87 fgh	20.9 abcd	6556 abcd
Oat 3.0 + *Metarhizium* S	2.20 h	20.5 abcdef	6241 abcdefg
Oat 3.0 + terbufos	2.35 gh	21.6 ab	6654 abc
Rye 1.5	4.62 a	17.4 fg	5151 g
Rye 1.5 + *Metarhizium* G	3.37 bcdef	17.8 defg	5358 efg
Rye 1.5 + *Metarhizium* S	3.97 abcd	18.2 cdefg	5534 defg
Rye 1.5 + terbufos	3.05 defgh	19.8 bcdefg	6281 abcdef
Rye 3.0	3.82 abcde	20.5 abcdef	6339 abcdef
Rye 3.0 + *Metarhizium* G	3.10 cdefgh	17.5 efg	5578 cdefg
Rye 3.0 + *Metarhizium* S	3.70 abcdef	19.8 bcdefg	6179 abcdefg
Rye 3.0 + terbufos	3.37 bcdef	20.9 abcd	6444 abcde
Treatment Pr > F $_{19,57}$	<0.0001	0.0058	0.0087
LSD (0.05)	0.94	3.26	1117.9

Table 5. Effect of bio-based sugarbeet root maggot management programs on root injury,

root yield, and sucrose yield, Minto, ND, 2006

Integrations	Root injury (0 to 9 scale)	Root yield (T/ac)	Recoverable sucrose (lb/ac)
Untreated check	1.70	22.8 abcd	5931 abcdef
Metarhizium Granules (G)	1.55	22.3 abcde	6172 abcd
Metarhizium Spray (S)	1.32	22.5 abcd	6257 abcd
Terbufos	1.60	24.8 ab	6641 a
Oat 1.5	1.52	21.6 bcdef	5752 abcdef
Oat 1.5 + *Metarhizium* G	1.30	21.4 cdef	5603 cdef
Oat 1.5 + *Metarhizium* S	1.62	25.1 a	6582 ab
Oat 1.5 + terbufos	1.10	22.9 abcd	6392 abc
Oat 3.0	1.25	23.2 abcd	6164 abcd
Oat 3.0 + *Metarhizium* G	1.67	19.8 def	5180 ef
Oat 3.0 + *Metarhizium* S	0.92	20.6 cdef	5490 cdef
Oat 3.0 + terbufos	0.92	20.0 def	5565 cdef
Rye 1.5	1.17	23.7 abc	6244 abcd
Rye 1.5 + *Metarhizium* G	1.55	22.3 abcde	6019 abcde
Rye 1.5 + *Metarhizium* S	1.62	21.1 cdef	5679 bcdef
Rye 1.5 + terbufos	1.07	21.9 abcdef	5958 abcdef
Rye 3.0	1.25	22.2 abcde	5798 abcdef
Rye 3.0 + *Metarhizium* G	1.32	20.8 cdef	5346 def
Rye 3.0 + *Metarhizium* S	1.17	18.7 f	5122 ef
Rye 3.0 + terbufos	1.07	19.1 ef	5092 f
Treatment Pr > F $_{19,57}$	0.6662	0.0195	0.0179
LSD (0.05)	0.78	3.38	918.8

In Tables 4 & 5: *Metarhizium anisopliae* strain F52 was applied as granules (modified in-furrow) or spray at rate of

3.23 x 10^{12} viable conidia/ac.

Oat and rye seeding rates are expressed as oat bushel equivalents (OBE)/ac.

Means within a column sharing a letter are not significantly (*P* = 0.05) different (Fisher's Protected LSD).

Discussion

In 2006, dry weather and wireworms modified the testing environment at St. Thomas, and imposed inconsistencies in outcomes. Root maggot feeding injury was higher in 2005. Despite the sudden increase in root maggot populations in 2006 untreated check plots had moderate levels of injury (<5.0 on a 0 to 9 scale). Crop infestation by multiple insects highlighted the importance of direct root assessment of SBRM feeding in field trials; thus, yield characteristics alone are not sufficient to judge treatment success. The root feeding activity of wireworms was visible in the form of deep cavities created by large consumption of root tissues. SBRM larvae rarely cause such deep wounds because they move along the root surface scraping elongate wounds and feeding on the oozing sap. Thus, SBRM feeding scars are distinguishable from wireworm feeding injury. Overall, it appears that combining F52 spray applications with a high seeding rate of oat consistently reduced root scarring and increased yields comparable to chemical insecticides. The canopy provided by rye cover crop was thicker than oat cover crop at the same seeding rate. However, root protection from F52 + rye combinations was inconsistent. F52 did not control wireworms in 2006, and major stand reductions resulted.

The most important contribution of this study is that it demonstrates resilience of F52 under adverse weather conditions, such as low rainfall amounts and high solar radiation. The NDAWN weather information (Table 6) indicates that only 0.64 and 0.7 inch of rainfall were recorded at St. Thomas and Minto, respectively, during June of 2006; these rainfall amounts were about eight to nine times lower than in 2005. The months of May and June are crucial periods for maggot activity and all biocontrol control applications were conducted in those months. It is possible that the absence of moisture in the treatment zone inhibited or reduced the survival and activity of *M. anisopliae*. The cover crops further removed soil moisture which could have stressed the fungus despite other advantages (such as reduced wind movement and moisture loss in cover crop canopy). Total solar radiation received at St. Thomas and Minto in 2006 averaged about 474 Langleys higher than in 2005. Such high levels of solar radiation could have been sufficient to cause spore death and result in minimal root maggot control during the sugarbeet seedling stage. Average soil temperature also was five degrees higher in 2006 compared to 2005.

Table 6. Climatic differences between study years, St. Thomas and Minto, 2005 and 2006

			2005 vs. 2006		
St. Thomas	MAY	JUNE	JULY	TOTAL	AVERAGE
Soil temperature (^{o}F)	54 vs. 59	66 vs. 73	75 vs. 79		65 vs. 70
Solar radiation (Langley)	403 vs. 441	411 vs. 544	564 vs. 593	1378 vs. 1578	
Rainfall (inches)	3.58 vs. 0.90	5.15 vs. 0.64	2.53 vs. 1.34	11.26 vs. 2.88	
Minto	MAY	JUNE	JULY	TOTAL	AVERAGE
Soil temperature (^{o}F)	54 vs. 60	69 vs. 72	74 vs. 80		66 vs. 71
Solar radiation	399 vs.	399 vs.	496 vs. 581	1294 vs.	

(Langley)	462	525		1568
Rainfall (inches)	3.00 vs. 0.88	6.37 vs. 0.70	1.40 vs. 1.81	10.77 vs. 3.39

Laboratory bioassays of Jonason et al. (2005) conducted at 75°F and high humidity, demonstrated that a concentration of 2.6 x 10^7 viable *M. anisopliae* conidia/ml can cause 95% mortality in root maggot larvae in 15 d and ~100% mortality in 21 d. This information supports the hypothesis that soil moisture, rather than soil temperature, was a limiting factor in this field study. Although it is clear that no *M. anisopliae* strain tested thus far alone will be able to provide long-term SBRM suppression, the root yields provided by the cover crop + *M. anisopliae* compared closely with the chemical insecticide, thus indicating that bio-based integrated approach has potential as an alternative SBRM control method. This approach could have more likelihood for success under moderate to low maggot population levels such as those at Minto. Due to its biological nature, the fungus may need a period of activation if it is applied as soil-incorporated granule. A spray application of fungus should ideally be done after a few hours of humidification (i.e., exposing conidia to high humidity before spraying) so that infective fungus spores are deployed for speedy infection of root maggots. In other words, it appears that activation of *Metarhizium* is easier to achieve in spray formulations and could have been one of the reasons for their success in this study.

Many cover crop factors, such as cover type, plant phenology, seeding rate, and planting and removal techniques can greatly influence the success of this cultural control tactic. Cover crops can reduce wind velocity and provide shade to the ground. However, there could be a tradeoff between insect control benefits offered by cover crops and logistics involved in the use of ground cover. The amount of soil moisture removed by a cover crop appears to have no effect on *M. anisopliae* in a normal growing season. The effect of soil characteristics such as soil pH on persistence and virulence of F52 also need to be ascertained. Soil organic matter could determine soil microfauna which can inhibit introduced pathogens resulting in slow action of F52 in field soils.

The effects of diverse crop habitat on SBRM fly behavior also need further evaluation. Several hypotheses have been proposed by researchers in the last twenty years to explain insect behavior when they are exposed to host or nonhost plants, but none of the proposed concepts have been tested with SBRM flies. Preliminary cage studies indicate that SBRM female flies have a strong preference for sugarbeet plants for oviposition; however, they may oviposit few eggs at the base of a cover crop plant under a no-choice situation (AM, personal observation). In the field, SBRM flies spend a large amount of time assessing surface properties of plants upon landing and females usually continue exploratory searches until they locate a sugarbeet plant (AM, personal observation). Thus, cover crops may indirectly reduce crop injury by preventing or confusing the location for oviposition in the vicinity of a sugarbeet plant. SBRM fly behavior is an unexplored area of research which might answer some of the pertinent questions about the reported success of cover crops. Previous laboratory studies (Majumdar et al. 2006b) demonstrated that SBRM larvae have a strong preference for moist soil because it facilitates locomotion to find a host plant. SBRM larvae also aggregate at soil zones with optimum temperature and humidity. It is possible that low surface moisture could have forced larvae to move away from treated zones, resulting in an apparent failure of treatments. Larval escape behaviors need to be ascertained through laboratory experiments involving direct observations under specific environments. Further, rye and oat cover crops form dense root mat under the soil surface; the attractiveness or deterrence of maggots to substantial plant root mass has not been evaluated.

Most growers use cover crops for wind protection; however, the pest control potential of cover crops has probably not been fully realized. This biocontrol study, along with previous chemical insecticide studies incorporating cereal cover crops, provides strong evidence regarding the effectiveness of a combined strategy for SBRM management. Research is needed to determine the lowest seeding rates of various cover crops that can be integrated with virulent pathogen strains and chemical seed treatments for sustainable sugarbeet production in the Red River Valley.

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