

LABORATORY SCREENING OF INSECTICIDES FOR PREVENTING INJURY BY THE WIREWORM *MELANOTUS COMMUNIS* (COLEOPTERA: ELATERIDAE) TO GERMINATING SUGARCANE

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ABSTRACT

A laboratory bioassay was investigated for screening insecticides for preventing stand losses by the wireworm *Melanotus communis* (Gyllenhal) to germinating plant cane. For liquid materials, single-eye billets were dipped into different concentrations of a candidate insecticide and then planted in plastic containers of organic soil; wireworms were then introduced, airtight lids were placed onto the containers, and wireworm survival and damage were assessed 4 wk later. Tests with granular materials were similar except the containers were partially filled with untreated soil; 30 cc of soil treated with granular material were then added to the container; an untreated single-eye billet was placed onto this treated soil; an additional 30 cc of treated soil was then placed on and around the billet; and finally untreated soil was added to fill the container. Conditions inside the bioassay containers were suitable for germination and early growth of most cultivars. The airtight lids were advantageous from the standpoint of maintaining soil moisture.

Among six candidate insecticides studied, bifenthrin 2EC, thiamethoxam 25WG, thiamethoxam 2G, and tefluthrin 3G each reduced damage by wireworms to germinating eyes of seed cane planted in organic soils. Wireworms frequently survived in containers of seed-pieces treated with these materials yet did not damage eyes before germination, indicating the materials repelled wireworms. However, germinated shoots of billets treated with these materials were sometimes injured by the surviving wireworms.

INTRODUCTION

The wireworm *Melanotus communis* (Gyllenhal) (Coleoptera: Elateridae) is currently the single-most important insect pest of sugarcane in Florida based on economic damage potential, frequency of infestations, and money spent to prevent damage (Hall 2001). Preventing economic losses to *M. communis* using cultural tactics has historically been difficult particularly in a successive-plant situation, and biological control has offered little promise as a management tactic (Hall 2001). Two insecticides, ethoprop and phorate, are currently labeled and effective for reducing wireworm damage to newly-planted sugarcane. Additional insecticides for wireworm control in Florida sugarcane would be desirable, particularly since there is some concern that the sugarcane labels for ethoprop and phorate may eventually be cancelled.

To find new wireworm insecticides, candidate materials can be initially screened for efficacy under a laboratory setting and the most promising materials can later be field-tested.

Initial laboratory screenings of insecticides have traditionally involved topically applying technical grade materials directly to insects with subsequent assessments of mortality, the goal being to measure the relative toxicity of test compounds (e.g., Hall and Cherry 1985). Commercial pesticides available in liquid formulations can be substituted for technical grade materials in topical application assays on toxicity. A drawback to topical applications as an initial screening bioassay for wireworm pesticides is that such assays give no insight into how a material may perform in soil.

As an alternative to topical applications for initial screening of materials, wireworms can be introduced into soil treated with candidate materials (e.g., Cherry 2001). This treated-soil approach to screening materials gives insight into the relative toxicity of materials in soil. A disadvantage to both topical application and treated-soil assays is that they are biased toward finding toxic materials. Some materials might have little or no toxicity to wireworms but could still have value as a tool for wireworm control if they repel wireworms or stop wireworms from feeding. For example, Villani and Gould (1985) found that extracts from some plant species provided significant levels of feeding deterrence by *M. communis* in tests with treated potatoes. To simultaneously study both toxicity and repellency, single-eye sugarcane billets could be treated with candidate materials (liquids) and planted into containers of soil, wireworms would then be introduced into the containers, and the efficacy of the materials for killing wireworms or preventing damage would later be assessed. To screen granular materials, single-eye sugarcane billets could be planted in a small pocket of soil treated with a material within a container of untreated soil.

Presented here are the results of laboratory screenings on the efficacy of candidate materials for *M. communis* control in sugarcane using bioassays with single-eye billets planted in soil.

METHODS AND MATERIALS

The basic assay used to screen candidate materials for preventing wireworm injury to germinating cane was as follows. For bioassays involving liquid materials, single-eye billets were dipped into different parts-per-million (ppm) concentrations of a material in distilled water; allowed to air dry under a fume hood for approximately 30 minutes; and then planted individually into 475 ml plastic containers (Fisherbrand #02-544-126, natural) partially filled with organic soil. Additional soil was then added to nearly fill each container; 2 – 3 ml of distilled water were pipetted onto the soil; and then an airtight lid was fitted onto each container. Bioassays with granular materials were similar except for the following. A bulk quantity (cc) of soil equal to 60 cc times the number of containers to receive a specific rate of material was calculated; the specific rate of material per container was multiplied by the number of containers to receive the rate, and the total amount of material needed for all of the containers was mixed into the bulk soil sample. Containers were then partially filled with untreated soil; 30cc of treated soil was placed into each container; a single-eye billet was placed onto this treated soil; 30cc of additional treated soil was placed on and around the billet; and then additional untreated soil was added to nearly fill each container. The specific per-container rate of a granular material was therefore applied in a total of 60 cc of treated soil per container. Test rates of granular materials were based on mg ai (active ingredient) per m² and were calculated based on the surface area of soil in

a container (9 cm diameter, 63.7 cm² surface area).

After setting up containers for a trial, three field-collected *M. communis* wireworms were introduced onto the soil surface of each container. The lidded containers were then placed either into an environmental chamber or onto a lab bench and checked every 1-2 days to determine when shoots emerged. When a shoot emerged, the contents of the container were emptied to assess wireworm survival and damage to the shoot. The bioassays were terminated after 4 wk, at which time each of the remaining containers was emptied to assess wireworm survival, damage to non-germinated buds and damage to germinated shoots. A wireworm was considered dead if it displayed no movement when prodded.

Most of the bioassays were conducted using sugarcane cultivar CL77-797, but other cultivars were utilized in some assays. Organic soil (55 to 80% organic matter, silica <5%, pH 7.5-7.9) obtained from sugarcane fields infested by wireworms was used in all trials. The soil was stored in sealed plastic bags in an air-conditioned lab until employed for the assays. By storing the fresh soil in sealed plastic bags, percentage moisture of the field-collected organic soil was maintained (50 to 55% by weight for the soil used in these trials). Prior to using the soil in an assay, it was forced through a 475 mm sieve to destroy clods and remove unwanted material. Wireworms used in the bioassays were collected from sugarcane fields during November-January and maintained in plastic boxes containing organic soil and pieces of carrots. Lids were placed onto these boxes, but the lidded boxes were not airtight. New carrots were placed into the boxes every 2-3 weeks and water was periodically added. The individual wireworms used in the assays were mid- to late-instar larvae generally weighing around 50 to 80 mg. *M. communis* wireworms in Florida sugarcane during December average 67.7 mg in weight (SEM 2.03, n=210) (Hall, unpublished). The bioassays were conducted at 20° to 24°C, as this range was representative of temperatures at planting during the fall in Florida.

Bioassays Without Insecticides

Two trials were conducted in which no wireworm control materials were tested. One of these was conducted during 2000 to evaluate germination of eight different sugarcane cultivars planted in the bioassay container (airtight lids, 55 day trial, no wireworms, 22°C, 9/12-11/6). Ten single-eye billets of each cultivar were studied, with 5 billets planted with the eye in an up position and 5 with the eye in a down position. The number of days from planting until emergence was recorded. At the end of the trial, all containers without emerged shoots were emptied and whether or not eyes had germinated was determined. Among plants which emerged, the average number of days from planting to emergence and percent emergence were determined for each cultivar. Also for each cultivar, the percentage of eyes which germinated was calculated. ANOVA was conducted to compare cultivars with respect to percent emergence and percent germination (percentages log-transformed); the ANOVA was based on two quasi replications, one for billets in an up position and one for billets in a down position, and mean comparisons were made using Duncan's multiple range test. In the second trial without insecticides, damage by wireworms newly-collected from a sugarcane field was compared to damage by wireworms which had been maintained in a laboratory for 50-54 wk (airtight lids, 61-620, billets planted with the eye in a side position, 30 replications per wireworm type, 4 wk test, 1 wireworm per container, 22°C).

Bioassays with Candidate Insecticides for Preventing Damage by Wireworms

Seven trials were conducted in which six candidate wireworm control materials were tested: bifenthrin 2 EC (Capture, 240 g ai/l, FMC), ethiprole 10EC (RPA 107382, 100 g ai/l, Aventis), tefluthrin 3G (Force, 3% ai, Zeneca), thiamethoxam 25WG (CGA293343, 25% ai, Syngenta), thiamethoxam 2G (CGA293343, 2% ai, Syngenta), and zeta-cypermethrin 0.8 EC (Fury, 96 g ai/l, FMC). Several of these compounds were screened simultaneously in some trials while other trials involved screening a single compound. The seven trials were conducted as follows.

Trial 1 – Billets dipped in bifenthrin (24,000 ppm) or ethiprole (48,000 ppm), February 2001, wireworms collected 2-4 wk before the trial, CL61-620, 22°C.

Trial 2 – Billets dipped in ethiprole (24,000 or 48,000 ppm) or bifenthrin (12,000 or 24,000 ppm), February 2001, wireworms collected 6-10 wk before the trial, CL61-620, 22°C.

Trial 3 – Billets dipped in bifenthrin (1,500, 3,000 or 6,000 ppm), ethiprole (1,500 or 12,000 ppm), or thiamethoxam 25WG (12,000 or 24,000 ppm), April 2001, wireworms collected 11-18 wk before the trial, CP84-1198, 22°C.

Trial 4 – Billets dipped in ethiprole (12,000, 24,000 or 48,000 ppm) or thiamethoxam 25WG (12,000, 24,000 or 48,000 ppm), January 2002, wireworms collected 2-8 wk before the trial, CL77-797, 23.7°C (SEM 0.02°C).

Trial 5 – Billets dipped in zeta-cypermethrin (75, 100 or 125 ppm), March 2002, wireworms collected 8-12 wk before the trial, CL77-797, 23.2°C (SEM 0.01°C).

Trial 6 – Billets planted in a pocket of soil treated with tefluthrin 3G (2.75, 5.5 or 11.0 g/m²; 83, 165 or 330 mg ai/m²), January 2002, wireworms collected 4-6 wk before the trial, CL77-797, 23.6°C (SEM 0.01°C).

Trial 7 - Billets planted in a pocket of soil treated with thiamethoxam 2G (2.75, 5.5 or 11.0 g/m²; 55, 110 or 220 mg ai/m²), February 2002, wireworms collected 5-11 wk before the trial, CL77-797, 23.2°C (SEM 0.02°C).

Billets were planted with eyes positioned to the side in all trials. Twenty containers were tested for each rate of each test material except in trial two, where ten containers were tested for each rate of each material. For each trial, the containers of each treatment were randomly assigned to one of four replications (5 containers per replication) (exception, trial two consisted of only two replications). At the end of each trial, numbers of wireworms surviving, percentages of eyes germinated, eyes damaged before germination, and shoots damaged after germination were determined. The percentages of plants damaged before and after germination were added to obtain a total index of damage per container. ANOVA was conducted for each trial (log-transformed data for percentages), and means among treatments were compared using Duncan's new multiple range test.

RESULTS

Bioassays Without Insecticides

Among the eight cultivars tested, percent germination of single-eye billets planted in airtight containers ranged from 20 to 100% (Table 1). From 80 to 100% germination occurred for six of the cultivars, and 100% germination occurred for three cultivars. Percent germination of one cultivar (CP73-1547) was mediocre (60%) and of another (CL78-1600) poor (20%). With respect to speed of germination and emergence under the bioassay conditions, CL61-620, CP78-1628 and CP84-1198 developed the fastest; CL83-4266 and CP80-1743 were slower; and CL77-797 and CP73-1547 were slowest. CL78-1600 showed little development over the 55-day period. With eyes positioned down, plant emergence was delayed by more than 33 days for CL77-797 and by from 17 to 21 days for CL61-620, CL83-4266 and CP80-1743 (Table 2). Less of a delay was observed for CP73-1547 and CP79-1628 (with buds positioned down, plant emergence was delayed by only about 5 days). In the second trial, wireworms held for 2-3 wk before being used in the bioassay damaged 47% of the eyes while wireworms held for 50-54 wk damaged 20% of the eyes.

Bioassays with Candidate Insecticides for Preventing Damage by Wire worms

Ethiprole (48,000 ppm solution) and bifenthrin (24,000 ppm solution) appeared moderately toxic to wireworms in the first trial, each material causing a significant reduction in wireworm survival (Table 3). Low percent germination of CL61-620 billets dipped into the ethiprole treatment indicated the material may have been phytotoxic. Percent germination of billets dipped into the bifenthrin treatment was lower than expected but better than under the infested-check treatment. Wireworms caused considerable damage to seed under the infested-check treatment and some damage to eyes of billets treated with ethiprole, but no damage by wireworms occurred to the eyes of billets treated with bifenthrin. Although bifenthrin provided good protection of eyes from damage, the treatment did not prevent damage to some germinated shoots.

In the second trial, no significant reductions in numbers of live wireworms occurred in containers holding billets treated with 24,000 or 48,000 ppm solutions of ethiprole (Table 3). Billets of CL61-620 dipped into a 48,000 ppm solution of ethiprole had significantly poorer germination than billets dipped into a 24,000 ppm solution, but germination under the 48,000 ppm ethiprole treatment was generally better than in the first trial with this variety. A significant reduction in numbers of live wireworms occurred in containers holding billets treated with a 24,000 ppm solution of bifenthrin but not in containers holding billets treated with a 12,000 ppm solution. Good levels of germination occurred in containers holding billets treated with bifenthrin at each rate. No damage by wireworms was observed to eyes or germinated shoots under either bifenthrin treatment regardless of the presence of live wireworms.

Table 1. Germination of different cultivars in bioassay.^a

Cultivar	Mean (SEM) days to emergence	Mean percent emergence	Mean percent germination
CL61-620	18.4 (4.57)	70a	90ab
CL77-797	33.3 (4.33)	30b	80ab
CL78-1600	-	0c	20c
CL83-4266	25.6 (4.32)	100a	100a
CP73-1547	29.8 (3.65)	50ab	60b
CP78-1628	15.6 (1.38)	90a	100a
CP80-1743	24.9 (3.72)	80a	100a
CP84-1198	18.0 (2.51)	90a	90ab

^aMeans in the same column followed by the same letter are not significantly different ($\alpha=0.05$), Duncan's test.

Table 2. Germination of different cultivars in bioassay, billets planted with eyes in an up versus down position.

Cultivar	Eye position	Mean (SEM)	Percent emergence	Percent germination
		days to emergence		
CL61-620	Down	29.3 (6.17)	60	80
	Up	10.3 (1.44)	80	100
CL77-797	Down	-	0	80
	Up	33.3 (4.33)	60	80
CL78-1600	Down	-	0	20
	Up	-	0	20
CL83-4266	Down	36.0 (5.39)	100	100
	Up	15.2 (0.97)	100	100
CP73-1547	Down	32.5 (8.50)	40	40
	Up	28.0 (4.04)	60	80
CP78-1628	Down	18.3 (1.31)	80	100
	Up	13.4 (1.78)	100	100
CP80-1743	Down	35.7 (3.76)	60	100
	Up	18.4 (2.54)	100	100
CP84-1198	Down	23.0 (2.53)	100	100
	Up	11.8 (1.89)	80	80
Overall	Down	28.5 (2.20)	55.0	77.5
	Up	17.5 (1.58)	72.5	82.5

Table 3. Efficacy of different liquid treatments for preventing wireworm damage under the assay conditions.^a

Material	Rate (ppm)	Mean number wireworms surviving	Mean germ. (%)	Mean plants killed before germ (%)	Mean plants killed after germ (%)	Mean total stand loss (%)
Trial 1: cultivar CL61-620						
ethiprole	48,000	1.5b	5.0b	20.0b	0.0a	20.0ab
bifenthrin	24,000	1.3b	45.0a	0.0c	15.0a	15.0b
infested check	-	2.4a	10.0b	70.0a	5.0a	75.0a
Trial 2: cultivar CL61-620						
ethiprole	48,000	1.9ab	20.0b	30.0a	0.0a	30.0a
ethiprole	24,000	2.7a	80.0a	0.0b	0.0a	0.0b
bifenthrin	24,000	1.1b	90.0a	0.0b	0.0a	0.0b
bifenthrin	12,000	2.1a	80.0a	0.0b	0.0a	0.0b
infested check	-	2.7a	60.0a	30.0a	20.0a	50.0a
non-infested check	-	-	90.0a	0.0b	0.0a	0.0b
Trial 3: cultivar CP84-1198						
ethiprole	12,000	2.4a	35.0b	15.0ab	5.0b	20.0ab
ethiprole	1,500	2.3ab	65.0a	5.0ab	10.0ab	15.0ab
bifenthrin	6,000	1.5c	75.0a	0.0b	5.0b	5.0b
bifenthrin	3,000	1.9abc	55.0ab	0.0b	5.0b	5.0b
bifenthrin	1,500	1.8bc	80.0a	0.0b	5.0b	5.0b
thiamethoxam	24,000	2.0abc	70.0a	0.0b	0.0b	0.0b
thiamethoxam	12,000	2.3ab	65.0a	5.0ab	0.0b	5.0b
infested check	-	2.0abc	65.0a	20.0a	25.0a	45.0a
non-infested check	-	-	85.0a	0.0b	0.0b	0.0b
Trial 4: cultivar CL77-797						
thiamethoxam	48,000	2.5b	70.0a	0.0c	0.0a	0.0d
thiamethoxam	24,000	2.9a	85.0a	0.0c	0.0a	0.0d
thiamethoxam	12,000	2.8a	90.0a	0.0c	0.0a	0.0d
ethiprole	48,000	2.8a	0.0b	20.0b	0.0a	20.0c
ethiprole	24,000	2.8a	0.0b	35.0ab	0.0a	35.0bc
ethiprole	12,000	2.9a	0.0b	40.0a	0.0a	40.0ab
infested check	-	3.0a	5.0b	75.0a	5.0a	80.0a
non-infested check	-	-	80.0a	0.0c	0.0a	0.0d
non-infested ethiprole	24,000	-	0.0b	0.0c	0.0a	0.0d
Trial 5: cultivar CL77-797						
zeta-cypermethrin	125	2.9a	40.0a	55.0a	20.0ab	75.0a
zeta-cypermethrin	100	2.7a	35.0a	55.0a	15.0ab	70.0a
zeta-cypermethrin	75	2.7a	60.0a	30.0b	10.0ab	40.0b
infested check	-	2.8a	45.0a	50.0ab	30.0a	80.0a
non-infested check	-	-	90.0a	0.0c	0.0b	0.0c

^aFor each trial, means in the same column followed by the same letter are not significantly different (a=0.05), Duncan's test.

No significant wireworm mortality occurred in containers of billets treated with ethiprole at either 1,500 or 12,000 ppm in the third trial (Table 3). With respect to bifenthrin, significant wireworm mortality occurred in containers with billets dipped into a 6,000 ppm solution. No significant wireworm mortality occurred in containers with billets dipped into thiamethoxam 25WG at either 12,000 or 24,000 ppm. Respectable levels of CP84-1198 germination occurred under all treatments except 12,000 ppm solutions of ethiprole. A low level of damage to eyes was observed under the 12,000 ppm ethiprole treatment, but not enough to account for the reduced germination; this rate of ethiprole may have been phytotoxic to CP84-1198. No damage to eyes occurred under any of the three bifenthrin treatments, but some young shoots were killed. A low percentage of eyes were damaged among billets dipped into a 12,000 ppm solution of thiamethoxam 25WG but not a 24,000 ppm solution. No young shoots were injured under either of the thiamethoxam treatments.

A small but significant reduction in wireworm survival occurred in containers of billets dipped into a 48,000 ppm solution of thiamethoxam 25WG in the fourth trial (Table 3). No significant mortality of wireworms occurred in containers of billets dipped into 12,000 or 24,000 ppm solutions of thiamethoxam 25WG nor into 12,000, 24,000 or 48,000 ppm solutions of ethiprole (Table 3). In spite of wireworm survival under the thiamethoxam treatments, good levels of germination occurred with no damage to either eyes or young shoots. No germination of CL77-797 occurred among billets dipped into the ethiprole treatments. The ethiprole treatments did not prevent wireworms from attacking eyes, although the percentages attacked were lower than under the infested-check treatment.

In the fifth trial, no significant wireworm mortality occurred in containers with billets treated with zeta-cypermethrin (Table 3). Significant percentages of eyes were damaged by wireworms before germination among billets treated with this material, and significant percentages of germinated shoots were injured by wireworms in spite of the zeta-cypermethrin treatments. For unknown reasons, damage by wireworms in containers of billets treated with 75 ppm zeta-cypermethrin was generally less than when billets were treated with 100 or 125 ppm.

No significant wireworm mortality occurred among containers in which billets were protected with tefluthrin 3G in the sixth trial (Table 4). A rate of 330 mg ai/m² provided good protection from wireworm injury to eyes before germination, but rates of 165 or 83 mg ai/m² did not. Wireworms tended to cause less damage to young shoots in containers treated with these rates of tefluthrin than in containers not treated.

Treating the soil around billets with thiamethoxam 2G at rates of 55, 110 or 220 mg ai/m² resulted in no significant wireworm mortality during the seventh trial (Table 4). However, wireworms caused significantly less damage to eyes before germination under these treatments. The treatments did not prevent damage to shoots after germination.

Because ethiprole appeared phytotoxic in a number of trials, especially to CL77-797, a separate trial was conducted in which single-eye billets were dipped into five ethiprole solutions ranging from 100 to 40,000 ppm (two replications of five containers per ethiprole concentration, CL77-797, March 2002). These billets were planted in containers filled with organic soil and maintained with an airtight lid for 4 wk (no wireworms were introduced). Good germination of

Table 4. Efficacy of different granular treatments for preventing wireworm damage under the assay conditions.^a

Material	Rate (mg ai/m ²)	Mean number wireworms surviving	Mean percent germ.	Mean percent plants killed before germ.	Mean percent plants killed after germ.	Mean total percent stand loss
Trial 6: cultivar CL77-797						
tefluthrin 3G	330	2.6a	30.0a	10.0b	0.0a	10.0b
tefluthrin 3G	165	2.9a	50.0a	25.0a	5.0a	30.0a
tefluthrin 3G	83	2.8a	20.0a	45.0a	0.0a	45.0a
infested check	-	2.9a	20.0a	65.0a	15.0a	80.0a
non-infested check	-	-	70.0a	0.0c	0.0a	0.0c
Trial 7: cultivar CL77-797						
thiamethoxam 2G	220	3.0a	75.0a	0.0b	15.0a	15.0bc
thiamethoxam 2G	110	3.0a	80.0a	15.0b	25.0a	40.0ab
thiamethoxam 2G	55	2.9a	70.0ab	20.0b	25.0a	45.0ab
infested check	-	2.8a	35.0b	65.0a	20.0a	85.0a
non-infested check	-	-	85.0a	0.0b	0.0a	0.0c

^aFor each trial, means in the same column followed by the same letter are not significantly different ($\alpha=0.05$), Duncan's test.

root primordia and eyes occurred on billets dipped into solutions of 1,000 ppm or less but not at higher doses (Table 5).

Table 5. Germination of single-eye billets treated with ethiprole and planted in organic soil with airtight plastic containers, 23.2°C (SEM 0.01).^a

Ethiprole concentration (ppm)	Seed pieces with germinated root primordia (%)	Germination of buds (%)
0	100.0a	100.0a
100	100.0a	100.0a
1,000	100.0a	90.0a
10,000	10.0b	0.0b
20,000	0.0b	0.0b
40,000	0.0b	0.0b

^aMeans in the same column followed by the same letter are not significantly different ($\alpha=0.05$), Duncan's test.

DISCUSSION

The bioassay was a relatively easy approach for evaluating candidate materials for wireworm control. Airtight lids were advantageous from the standpoint of maintaining soil moisture. However, it remained possible that the efficacy of a material for wireworm control might appear different using an assay without airtight lids because air exchange could affect factors such as the persistence of insecticide odor. The assay could be conducted without lids, in which case water would have to periodically be added to each container. To determine how much water to add, a baseline initial weight could be determined for each container after it is set up, and then enough water to restore a container's weight back to the initial level could periodically be added to compensate for loss of soil moisture. A study comparing lidded versus non-lidded containers would be worthwhile. Soil moisture levels near 50% were suitable for wireworms in the particular organic soil used in the assays. In soils with lower than 50-60% organic matter, lower soil moisture levels by weight would be needed, with the particular moisture level being dependent upon suitability for wireworms.

The speed of germination of some cultivars is inherently slower than others. Most cultivars germinated normally under the bioassay conditions, but it is possible that some cultivars could perform better under the assay conditions than others. Based on the differences observed among the eight cultivars with respect to speed of germination and development, some cultivars may be better suited than others for a bioassay aimed at screening for materials to reduce stand losses by wireworms. For example, a cultivar intermediate or slow in germination rate may be advantageous with respect to giving wireworms ample time to attack a billet. As intuitively expected, plants emerged faster when billets were planted with eyes in an up position.

The data indicated it may be disadvantageous to hold *M. communis* for a long period of time before screening a material for wireworm control because a reduction in wireworm damage may be mistaken as control. If wireworms stored for a long time had to be used in an assay, greater numbers of wireworms could be introduced per billet. *M. communis* is thought to have one annual generation in southern Florida, with most wireworms pupating during early to mid spring (e.g., late March to early May). Wireworms are relatively easy to collect from cane stubble soon after harvest during late October – March. When wireworms are collected during the winter and maintained in containers of soil with carrots as a food source on a laboratory bench, few wireworms pupate even if they are held for more than a year. It is possible such wireworms may feed less because they have completed development and are simply waiting for environmental cues to pupate. If so, it may be disadvantageous to utilize wireworms collected during October-January after around the following March.

Relatively little wireworm mortality occurred in most of the trials regardless of which insecticide was tested, yet little damage to eyes prior to germination often occurred. Wireworms in containers with billets not treated with insecticides usually caused substantial injury. Therefore, wireworms in containers with treated billets may have simply avoided the billets due to repellency of the insecticides (e.g., odor or other characteristics which deterred feeding). Insecticides may vary in both toxicity and repellency (Silverman and Liang 1999). Working with *M. communis* in North Carolina, Villani and Gould (1985) found that five extracts from four plant families significantly reduced wireworm feeding damage to potato. It is possible that a

nontoxic material which repels wireworms from germinating eyes of sugarcane could be useful for reducing damage before germination, but developing shoots might still be subject to attack.

At the rates studied, bifenthrin, thiamethoxam 25WG, thiamethoxam 2G, and tefluthrin 3G each appeared to have value as materials for reducing damage by wireworms to germinating eyes of seed cane planted in organic soils. However, germinated shoots of billets treated with these materials were sometimes injured by wireworms, usually some distance away from the billet itself. Some seed-piece treatments may protect eyes from wireworm injury during germination but not young shoots. Overall, the most promising material based on these limited data appeared to be thiamethoxam 25WG with respect to reducing damage to both germinating eyes and young shoots. Ethiprole was phytotoxic to CL77-797, at least at concentrations above 1,000 ppm, and may have been somewhat phytotoxic to CL61-620 and CP84-1198. A granular formulation of ethiprole might be less toxic to cultivars such as CL77-797. Little wireworm mortality occurred in containers of billets treated with ethiprole at any rate, but surviving wireworms frequently caused injury to the billets. Zeta-cypermethrin appeared to have little value as a wireworm control material at the rates studied, which were comparatively much smaller than the rates tested of the other liquid materials. Higher rates of zeta-cypermethrin might be more effective.

Since the Florida sugar industry currently uses granular formulations of either ethoprop 20G or phorate 20G for wireworm control, alternative pesticides in granular formulations would be more convenient substitutes than liquid pesticides. The recommended application rate of phorate 20G, 1 kg per 300 row meters, equates to approximately 10.9 g product/m² or 2.2 g ai/m² when applied in a 30-cm band. The recommended application rate of ethoprop 20G, 0.6 to 1.3 kg per 300 row meters, equates to 6.8 to 13.7 g per m² or 1.4 to 2.7 g ai/m² when applied in a 30-cm band. With respect to g ai/m², my test rates of thiamethoxam 2G (0.055 to 0.220 g ai/m²) and tefluthrin 3G (0.083 to 0.330 g ai/m²) were much lower than the recommended rates of phorate 20G and ethoprop 20G; higher rates of the two candidate alternatives might have been more effective for killing wireworms in organic soil. Other granular pesticides which could be investigated for wireworm control include Deltagard 0.1%G, Talstar PL-GR (0.2%) and Aztec 2.1%G (Cherry 2001). The Florida industry could consider liquid alternatives to ethoprop 20G and phorate 20G. Ethoprop EC (6 lb per gal) was once registered for wireworm control in Florida sugarcane, with recommended application rates of 100 to 250 g ai/300 row meters (at spray volumes of 4 to 6 l per 300 row meters, solutions of around 15,000 to 60,000 ppm).

The bioassay could be standardized using initial screening rates of 100, 1,000, 10,000 and 50,000 ppm solutions of liquid materials, or rates of 100, 1,000, 2,000 and 4,000 mg ai/m² for granular materials, with 20 containers per rate and 3 wireworms per container. Larger numbers of containers per rate would be advantageous for statistical comparisons.

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