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Application timing and efficacy of alternatives for the insecticidal control of *Tipula paludosa* Meigen (Diptera: Tipulidae), a new invasive pest of turf in the northeastern United States

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Abstract

BACKGROUND: Two invasive crane flies, *Tipula paludosa* Meigen and *Tipula oleracea* L. (Diptera: Tipulidae), were detected in New York State for the first time in 2004. Both are damaging pests of turfgrass and other horticultural systems in North America where establishment has already been documented. To develop management recommendations for the Northeast and define opportunities for preventive (autumn) and curative (spring) control, four insecticide trials targeting *T. paludosa* larvae were conducted over a 2 year period.

RESULTS: The most efficacious (≥70% control in both trials) products against early instars in autumn were bifenthrin, carbaryl, chlorantraniliprole, clothianidin and trichlorfon. Results varied for azadirachtin, *Beauveria bassiana*, cyfluthrin, dinotefuran, imidacloprid, imidacloprid + bifenthrin and indoxacarb. Clothianidin and dinotefuran were most efficacious against fourth instars in spring; results varied for imidacloprid, indoxacarb and trichlorfon.

CONCLUSION: Several insecticides offer alternatives for preventive and curative control of *T. paludosa*, but, because there is little overlap with application windows for scarab larvae pests, management may entail an entirely new insecticide treatment window, implying new economic and environmental burdens to the turfgrass industry. Moreover, curtailing the impact and spread of these invasives may be severely hampered because the best performing alternatives (clothianidin, dinotefuran) are not registered in New York.

Keywords: crane flies; golf courses; invasive species; leatherjackets; reduced-risk insecticides; *Tipula paludosa*

1 INTRODUCTION

Two species of exotic crane flies (Diptera: Tipulidae) were detected in western New York State in 2004.[1] This was the first report of *Tipula paludosa* Meigen, the 'European' crane fly, in the eastern United States, and the first record of *Tipula oleracea* L., the 'common' crane fly, in eastern North America. Both species are native to Europe, but are firmly established in three geographic regions of the United States after their accidental introduction.[2] In the Pacific Northwest, they are widespread and damaging to turfgrass, occurring from British Columbia south to California.[3–5] Both species are also established in eastern Canada where they are increasing in pest status on golf course turf in Quebec.[6,7] In Ontario, *T. paludosa* has been established since at least 1996.[8] Its presence and pest status in the Niagara Peninsula probably made its recent appearance in western New York inevitable. The origin of *T. oleracea* establishments in New York, and since 2005 in Michigan,[9] is unknown because this species was not reported from southern Ontario until 2007 (Charbonneau P, private communication).

Known as 'leatherjackets' for the tough pupal exuvia left behind by the emerging adult, larvae can be problematic in any grass-based system. They inhabit the top layer of the soil where they feed on root hairs, roots and crowns of their hosts.[10,11] By pruning and disrupting belowground portions of the plant, they cause damage in turfgrass akin to white grubs (Coleoptera: Scarabaeidae), which leads to severe thinning of the sward and extensive dieback when damaged turf is water stressed (Peck DC, unpublished). Larvae will also reside in the thatch, emerging at night to feed on aboveground portions of the stem and foliage. They will attack grasses

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across the full spectrum of management intensity, from home lawns to golf courses. Moreover, all turf (and forage) grass species appear to be susceptible because they are acceptable hosts for larvae.[12] New York State has 3.4 million acres of managed turfgrass,[13] and, because larvae are generalists, all of it may ultimately be susceptible as invasive *Tipula* spread across the state. A case in point is the Pacific Northwest, where leatherjackets are now the most serious insect pest in home lawns west of the Cascades. A 1999 report estimated that 46% of homeowners in western Washington treated their lawns with insecticides to target leatherjackets at an annual cost of \$12.9 million.[3] The present authors are aware of no studies from eastern North America that assess economic impact on the turfgrass industry, and accounts of crane fly outbreaks are largely anecdotal. In 2007, western New York experienced severe outbreaks of both species, with densities as high as 800–1300 larvae m^{-2} on severely damaged home lawns and golf course fairways (Peck DC, unpublished).

There is also cause for concern about the pest status of invasive *Tipula* in other horticultural and agricultural systems. In the Pacific Northwest, commercial peppermint fields,[14] seedling nurseries,[15,16] turnips, winter wheat (Rao S, private communication), grass seed production fields[17] and pastures and hayfields[3] have been affected by these pests. In native habitats of Europe, larvae of *T. paludosa* damage pastures and cereals, while those of *T. oleracea* are reported primarily as pests of winter cereals planted after oilseed rape crops.[18] Other crops reported as host plants in Europe include brassicas, clover, corn, lettuce, sugar beets, strawberries, turnips, other vegetables and ornamentals.[18,19] Because the Northeast has no experience with crane fly pests, there is an urgent need to establish control recommendations. Reporting information on the efficacy of insecticidal control products will arm golf course superintendents, lawn care providers, home owners and other turfgrass managers with the first tools to prevent or control outbreaks. While longer-term strategies need to be investigated in the near future (e.g. cultural and biological control), insecticidal alternatives may offer an effective temporary solution in the short term.

Several studies in the Pacific Northwest have previously examined the efficacy of older chemistries.[20–22] Among these, aldrin, azinphos-methyl, bendiocarb, chlordane, diazinon, ethoprop, isazophos, isophenphos and parathion-methyl were confirmed as alternatives. In the USA, however, none of these is currently available as an alternative in turfgrass owing to bans, phase-outs and other use restrictions. Other than a report by Simard and Dionne,[23] no studies on the insecticidal control of crane fly larvae have been published for eastern North America. While certain guidelines can be gleaned from experience developed in the Pacific Northwest, the Northeast will most benefit from recommendations established from studies conducted within the region because of significant differences in climate, weather patterns and agronomic practices.

Beyond information on insecticidal efficacy, recommendations must include information on the best timing of controls with respect to insect phenology. Preventive is herein associated with the autumn window of application when eggs and larvae are too difficult to scout in any practical way. This includes the period of oviposition and the first and second stadia. Curative is herein associated with the spring window of application when scouting is much more practicable given the large size of larvae during the third and fourth stadia. These designations are most specific to the phenology of *T. paludosa* (targeted in the following studies). *Tipula paludosa* is univoltine.[24] Adults emerge in the fall and lay eggs immediately, larvae achieve third instar before overwintering during the coldest months and fourth instars enter an inactive and non-feeding aestivation stage that lasts from early June until fall pupation. In contrast, *T. oleracea* is bivoltine.[18] Adult emergence and oviposition take place in both spring and fall, larvae overwinter as fourth instars and the life cycle lacks an aestivation stage. Although many other aspects of their natural history are similar, diverging voltinism and phenology will require that management strategies be tailored to the specific species present.

The timing of control applications is further complicated by limitations imposed by cold winter weather, the occurrence of both species at the same site and the need to make control applications against other turf-infesting insect pests. Therefore, the main objective was to evaluate insecticidal control options for the preventive and curative control of *T. paludosa* in field trials. The study was also designed to measure variation in the efficacy of products between preventive and curative control windows. Emphasis was placed on reduced-risk and biological products that could supplant reliance on traditional chemistries with higher acute toxicity, namely the carbamates and organophosphates. Reduced-risk insecticides are those exhibiting relatively low use rates, mammalian toxicity, potential for groundwater contamination, impact to non-targets and risk for human exposure. By doing this, the authors sought to improve the precision of control product recommendations for the Northeast. They chose to work with *T. paludosa* because of the availability of field sites with reliable populations and an absence of *T. oleracea*. Although variation in the efficacy of control products across species has not been assessed, it is anticipated that the results will be largely transferable to the same phenological control windows for *T. oleracea*.

2 MATERIALS AND METHODS

2.1 Experimental design

Four experiments on the efficacy of insecticidal control products were conducted over a 2 year period from spring 2005 to autumn 2006. The experiments were done on rough-mown golf course turf at two sites in Niagara Co. located in western New York. These sites were amenable to the present studies because they had relatively high populations of *T. paludosa* but *T. oleracea* was absent, i.e. not detected in previous and concurrent surveys. At the Hyde Park Golf Course (HPGC, Niagara Falls), study sites were predominantly perennial ryegrass, *Lolium perenne* L. (65–90%), and Kentucky bluegrass, *Poa pratensis* L. (10–35%). At the Niagara Falls Country Club (NFCC, Lewiston), study sites included perennial ryegrass (50%), annual bluegrass, *Poa annua* L. (20%), tall fescue, *Festuca rubra* L. (15%), and Kentucky bluegrass (15%). Grass was maintained at a mowing height of 7.6 and 8.9 cm, respectively, at HPGC and NFCC.

Over the course of the four experiments, a total of 22 formulations of 14 active ingredients were tested, representing nine classes of compound and one combination (Table 1). The number of treatments evaluated in each experiment ranged from 13 to 22, including an untreated control where an equivalent amount of water was applied. Each experiment was arranged in a randomized complete block design with 3–6 replications per treatment. Treatment plots were 3 × 3 m, which included a treated buffer (0.3 m) where insect sampling did not take place. In both spring and autumn 2005, liquid and wettable powder formulations were applied in water (7.5 L) using a watering can. Granular formulations were applied using a shaker jar, followed by the same amount of water. In spring 2006, liquid and wettable powder formulations were applied using a 3.8 L hand-pumped pressurized sprayer unit at ~76 kPa through a flat-fan sprayer nozzle (Chapin Sure Spray Deluxe, Chapin International, Batavia, NY), followed by water (3.8 L) applied with a watering can. In autumn 2006 they were applied using a backpack carbon dioxide sprayer calibrated to deliver 2.6 L of material per 93 m^2 (1000 ft^2) at 207 kPa through two flat-fan sprayer nozzles (TeeJet 8002VS, Spraying Systems Co., Wheaton, IL). Granular formulations were applied with a handheld broadcast spreader. Owing to the wet conditions, no additional water was applied.

To evaluate larval populations, a standard golf course cup cutter of 10.2 cm (4 in) diameter was used to extract soil cores to a depth of 10 cm. Nine cores were taken from each plot in 2005, and six in 2006. To standardize insect evaluations, the authors chose to extract larvae from these cores in a battery of modified Tullgren funnels equipped with light bulbs (40 W). These conditions drove insects out of the soil into collecting cups beneath each funnel. Soil cores were extracted over 24–72 h depending on moisture levels corresponding to each sampling date. Until they could be processed, cores were stored in plastic bags at 4.5 °C. All cores from a single block were extracted simultaneously to control for any variation in extraction rate owing to time in storage or level of soil moisture.

2.2 Preventive applications

Preventive applications were made when target populations were mostly first and second instars, based on completion of the main period of adult emergence. All treatments were applied to out-of-play

Table 1. Insecticidal control products evaluated in field efficacy trials against *Tipula paludosa* larvae

Chemical class	Common name	Trade/code name	Producer	Test
Anthranilic diamide	Chlorantraniliprole	E2Y45 18.5SC	DuPont	Preventive, curative
Anthranilic diamide	Chlorantraniliprole	E2Y45 1.67SC	DuPont	Preventive
Botanical	Azadirachtin	Ornazin 3EC	SePro	Preventive, curative
Carbamate	Carbaryl	Sevin 43 SL	Bayer	Preventive, curative
Insect growth regulator	Halofenozide	Mach 2 1.5G	Dow	Preventive
Microbial	*Beauveria bassiana*	BotaniGard 11.3ES	Mycotech	Preventive, curative
Microbial	*Bt israelensis*	Gnatrol 6.38EC	Valent	Preventive, curative
Neonicotinoid	Clothianidin	Arena 50WDG	Arysta LifeScience	Preventive, curative
Neonicotinoid	Dinotefuran	Safari 20SG	Valent	Preventive, curative
Neonicotinoid	Imidacloprid	Merit 0.2G	Bayer	Preventive, curative
Neonicotinoid	Imidacloprid	Merit 0.5G	Bayer	Preventive, curative
Neonicotinoid + pyrethroid	Imidacloprid + bifenthrin	Allectus 0.81SC	Bayer	Curative
Neonicotinoid + pyrethroid	Imidacloprid + bifenthrin	Allectus 0.36G	Bayer	Preventive
Neonicotinoid + pyrethroid	Imidacloprid + bifenthrin	Allectus 9SC	Bayer	Preventive, curative
Organophosphate	Chlorpyrifos	Dursban 23.5EC	Dow	Curative
Organophosphate	Trichlorfon	Dylox 80WP	Bayer	Preventive, curative
Oxadiazine	Indoxacarb	Provaunt 1.25SC	DuPont	Curative
Oxadiazine	Indoxacarb	Provaunt 14.5SC	DuPont	Preventive, curative
Pyrethroid	Bifenthrin	Talstar PL 0.2G	FMC	Preventive, curative
Pyrethroid	Bifenthrin	Talstar 7.9ES	FMC	Preventive, curative
Pyrethroid	Cyfluthrin	Tempo Ultra 10WP	Bayer	Preventive, curative
Pyrethroid	Cyfluthrin	Tempo 20WP	Bayer	Preventive, curative

rough selected from areas of the course thought to have experienced high adult oviposition pressure. Because rapid knockdown is not critical during this control window, trials were assessed only once after treatment.

In 2005, three replications (blocks) were established on separate areas, one in HPGC and two in NFCC. Applications were made on 6 October (HPGC) and 7 October (NFCC). There were 22 treatments, representing 17 formulations (two at two rates, one at three rates) of 13 active ingredients (Table 2). At the time of application in HPGC and NFCC, respectively, average air temperature was 26.1 and 12.2 °C and average soil temperature was 22.2 and 15.6 °C (2.5 cm depth) and 20.6 and 16.7 °C (7.6 cm). Given the relative proximity of sites, the drop in temperature on the second date was attributed to a morning application after arrival of a cold weather front. Soil cores to assess the trial were collected 4 weeks post-treatment. All samples were at or near saturation point owing to the wet field conditions that prevailed.

In 2006, applications were made on 16 October to four replications established on separate areas of HPGC. There were 20 treatments, representing 14 formulations of 13 active ingredients (three at two rates, one at three rates) (Table 3). At the time of application, air temperature was 10.0–12.7 °C and soil temperature was 8.9–9.5 °C (2.5 cm) and 10.5–11.1 °C (7.6 cm). All soils were saturated because 5–7 cm of rain fell during the week prior to application. As a consequence, mowing had not taken place in over a week and grass height was 7.5–12.5 cm. Soil cores to assess the trial were collected 3 weeks post-treatment.

2.3 Curative applications

Curative spring applications were made when target populations were mostly late third or fourth (ultimate) instars. During this window, larvae were actively feeding in the period after overwintering and before aestivation. Because rapid knockdown may be critical at this control window, the experiment in spring 2006 was assessed at 1, 3 and 7 days after treatment (DAT) (this assessment was not contemplated in 2005).

In 2005, three replications were established on separate areas at HPGC and two at NFCC. Applications were made on 12 May, with the exception of azadirachtin, which was applied on 24 May. There were 17 treatments, representing 12 formulations of 11 active ingredients (two at two rates, one at three rates) (Table 4). At the time of application in HPGC and NFCC, respectively, average air temperature was 6.7 and 8.3 °C; soil temperature was not measured. Soil cores to assess the trial were collected 4 weeks post-treatment.

In 2006, six replications were established on separate areas at HPGC. Applications were made on 30 May. There were 13 treatments, representing nine formulations of nine active ingredients (one at two rates, one at three rates) (Table 5). At the time of application, average air temperature was 26.7 °C; average soil temperature was 32 °C (2.5 cm) and 29 °C (7.6 cm). Soil cores to assess the trial were collected 1, 3 and 7 DAT.

Table 2. Efficacy of insecticides applied on 6–7 October 2005 for the preventive control of first- and second-instar *Tipula paludosa* in golf course rough

Insecticide	Rate (kg AI ha^{-1})	Mean number of larvae m^{-2} (± SE)	Mean % larval reduction (± SE)[a]
Chlorantraniliprole (18.5SC)	0.25	0.0 (±0.0)	100 (±0.0)***
Clothianidin	0.38	0.0 (±0.0)	100 (±0.0)***
Dinotefuran	0.60	0.0 (±0.0)	100 (±0.0)***
Indoxacarb (14.5SC)	0.45	0.0 (±0.0)	100 (±0.0)***
Indoxacarb (14.5SC)	0.078	0.0 (±0.0)	100 (±0.0)***
Carbaryl	7.89	4.6 (±4.6)	97.2 (±2.8)***
Imidacloprid + bifenthrin (0.36G)	0.22/0.18	4.6 (±4.6)	94.4 (±5.6)***
Imidacloprid + bifenthrin (9SC)	0.083/0.067	4.6 (±4.6)	94.4 (±5.6)***
Azadirachtin	0.017	9.1 (±4.6)	94.4 (±2.8)***
Bifenthrin (PL)	0.45	9.1 (±9.1)	94.4 (±5.6)***
Chlorantraniliprole (18.5SC)	0.12	9.1 (±9.1)	94.4 (±5.6)***
Chlorantraniliprole (18.5SC)	0.49	9.1 (±9.1)	94.4 (±5.6)***
Imidacloprid (0.5G)	0.21	9.1 (±9.1)	94.4 (±5.6)***
Trichlorfon	9.16	9.1 (±4.6)	91.7 (±4.8)***
Imidacloprid (0.5G)	0.28	18.3 (±18.3)	88.9 (±11.1)***
Imidacloprid (0.2G)	0.18	13.7 (±7.9)	86.1 (±10.0)***
Beauveria bassiana	2.76	27.4 (±20.9)	83.3 (±12.7)***
Cyfluthrin (Ultra)	0.11	32.0 (±32.0)	80.6 (±19.4)***
Cyfluthrin (20WP)	0.15	36.6 (±19.9)	77.8 (±12.1)**
Bt israelensis	0.28	73.1 (±59.4)	58.3 (±29.3) NS
Halofenozide	2.24	64.0 (±50.9)	55.6 (±29.4)*
Untreated	0.0	137.1 (±27.4)	

[a] Means are significantly different from the untreated control at * 0.05, ** 0.01 and *** 0.001 (Dunnett's method).

Table 3. Efficacy of insecticides applied on 16 October 2006 for the preventive control of first- and second-instar *Tipula paludosa* in golf course rough

Insecticide	Rate (kg AI ha^{-1})	Mean number of larvae m^{-2} (± SE)	Mean % larval reduction (± SE)[a]
Clothianidin	0.34	0.0 (±0.0)	100.0 (±0.0)***
Bifenthrin (7.9ES)	0.45	10.3 (±5.9)	94.9 (±4.0)**
Chlorantraniliprole (1.67SC)	0.29	102.8 (±55.1)	80.4 (±7.4)*
Clothianidin	0.22	46.3 (±15.4)	79.0 (±10.1)*
Trichlorfon	9.16	149.1 (±135.8)	77.8 (±19.9)**
Imidacloprid + bifenthrin (9SC)	0.083/0.067	61.7 (±8.4)	73.5 (±9.4)*
Carbaryl	7.89	77.1 (±38.8)	70.1 (±23.5)*
Indoxacarb (14.5SC)	0.25	82.3 (±25.2)	63.6 (±21.3) NS
Beauveria bassiana	2.76	118.3 (±41.5)	63.6 (±21.9) NS
Dinotefuran	0.60	102.8 (±55.1)	62.5 (±21.7) NS
Imidacloprid (0.5G)	0.28	123.4 (±47.5)	57.3 (±20.0) NS
Chlorantraniliprole (1.67SC)	0.12	231.4 (±158.7)	46.4 (±27.0) NS
Imidacloprid + bifenthrin (0.36G)	0.22/0.18	493.6 (±386.7)	46.2 (±26.9) NS
Cyfluthrin (20WP)	0.15	195.4 (±56.6)	45.6 (±16.5) NS
Imidacloprid (0.5G)	0.18	138.8 (±39.7)	44.3 (±25.6) NS
Indoxacarb (14.5SC)	0.13	180.0 (±50.6)	44.0 (±17.7) NS
Azadirachtin	0.017	359.9 (±200.4)	39.6 (±22.9) NS
Imidacloprid (0.5G)	0.21	452.5 (±215.7)	31.5 (±15.0) NS
Bt israelensis	0.28	390.8 (±196.2)	25.0 (±25.0) NS
Untreated	0.0	375.4 (±147.0)	

[a] Means are significantly different from the untreated control at * 0.05, ** 0.01 and *** 0.001 (Dunnett's method).

Table 4. Efficacy of insecticides applied on 12 May 2005 for the curative control of fourth-instar *Tipula paludosa* in golf course rough

Insecticide	Rate (kg AI ha^{-1})	Mean number of larvae m^{-2} (± SE)	Mean % larval reduction (± SE)[a]
Dinotefuran	0.60	2.7 (±2.7)	98.8 (±1.2)***
Clothianidin	0.37	2.7 (±2.7)	97.1 (±2.9)***
Indoxacarb (1.25SC)	0.49	5.5 (±3.4)	94.1 (±3.6)***
Indoxacarb (1.25SC)	0.078	21.9 (±9.3)	72.2 (±10.2)***
Trichlorfon	9.15	30.2 (±8.0)	69.1 (±7.5)**
Imidacloprid (0.2G)	0.28	30.2 (±2.7)	59.6 (±15.3)*
Chlorantraniliprole (18.5SC)	0.28	38.4 (±13.3)	56.8 (±19.2)*
Cyfluthrin (Ultra)	0.11	46.6 (±16.6)	50.7 (±17.7)*
Bt israelensis	0.30	87.8 (±47.0)	48.2 (±22.4)*
Imidacloprid + bifenthrin (0.81SC)	0.14/0.12	46.6 (±18.2)	45.8 (±16.4)*
Chlorantraniliprole (18.5SC)	0.14	52.1 (±15.9)	44.2 (±16.5) NS
Chlorantraniliprole (18.5SC)	0.56	52.1 (±15.3)	39.6 (±18.1) NS
Imidacloprid + bifenthrin (0.81SC)	0.23/0.18	65.8 (±10.1)	35.2 (±14.9) NS
Cyfluthrin (20WP)	0.15	71.3 (±20.1)	32.5 (±18.8) NS
Beauveria bassiana	2.88	63.1 (±15.4)	29.2 (±17.3) NS
Azadirachtin	1.78	90.5 (±17.7)	20.9 (±9.9) NS
Untreated	0.0	109.7 (±24.4)	

[a] Means are significantly different from the untreated control at * 0.05, ** 0.01 and *** 0.001 (Dunnett's method).

2.4 Data analysis

Data from each experiment were initially analyzed separately to test for significant effect of treatments with respect to the untreated control. For each treatment plot, an estimate of absolute larval density was made by pooling the counts across the soil core extractions. For each replication and treatment, population suppression was calculated with respect to the untreated control. These plot-level values were used to establish overall treatment means for density and population suppression. Dunnett's method[25] was used to test for significant differences between each treatment and the untreated control in terms of percentage larval reduction. In the 2006 curative experiment, data were pooled across all three sampling dates before means comparisons. Speed of kill was assessed for each treatment with analysis of variance (ANOVA) to test for an effect of time after treatment.

Data were also assessed for an effect of application window (preventive versus curative) on product efficacy. This was tested individually for the six products that were included in each of the four trials: clothianidin, dinotefuran, imidacloprid, imidacloprid + bifenthrin, indoxacarb and trichlorfon. In cases where more than one rate was tested, the products

Table 5. Efficacy of insecticides applied on 30 May 2006 for the curative control of fourth-instar *Tipula paludosa* in golf course rough

Insecticide	Rate (kg AI ha^{-1})	Mean number of larvae m^{-2} (± SE)	Mean % larval reduction (± SE)[a]
Dinotefuran	0.60	18.8 (±5.3)	83.7 (±5.9)***
Clothianidin	0.45	21.2 (±8.4)	78.6 (±6.5)***
Clothianidin	0.28	23.5 (±4.7)	70.9 (±10.1)***
Imidacloprid (0.5G)	0.44	38.8 (±6.3)	63.7 (±5.7)***
Trichlorfon	9.08	32.1 (±8.4)	61.6 (±13.3)***
Chlorpyrifos	1.12	40.0 (±9.3)	56.2 (±13.3)***
Indoxacarb (14.5SC)	0.49	44.3 (±13.1)	48.8 (±15.4)***
Carbaryl	8.97	74.4 (±17.0)	39.1 (±10.2)**
Indoxacarb (14.5SC)	0.24	74.1 (±21.4)	34.6 (±15.8)*
Imidacloprid + bifenthrin (9SC)	0.28/0.23	86.3 (±5.7)	25.1 (±9.3) NS
Indoxacarb (14.5SC)	0.12	87.4 (±14.5)	24.9 (±11.9) NS
Bifenthrin (PL)	0.11	113.0 (±18.3)	16.7 (±10.3) NS
Untreated	0.0	115.0 (±19.6)	

[a] Means are significantly different from the untreated control at * 0.05, ** 0.01 and *** 0.001 (Dunnett's method).

were examined three ways: with data from just the lowest rate examined in each trial, from just the highest rate and from all rates pooled. The dependent variable in the ANOVA was percentage larval reduction with respect to the untreated control; block and year were included as covariates.

An arcsine square-root transformation was used to stabilize the normality of the proportional data for the statistical analyses, while data for the ANOVAs were square-root transformed. All analyses were done using JMP software.[25] In the tables of results, formulations are specified only as necessary to distinguish among treatments applied over all four experiments. In the corresponding text, formulations and concentrations (kg AI ha^{-1}) are specified only as necessary to distinguish among treatments within each experiment.

3 RESULTS

3.1 Preventive applications

In 2005, 100% control was attributed to five treatments: chlorantraniliprole (18.5SC, 0.25 kg AI ha^{-1}), clothianidin, dinotefuran and indoxacarb (0.078 and 0.45 kg AI ha^{-1}) (Table 2). Carbaryl gave 97% control. Nine other treatments gave ≥90% control: azadirachtin, bifenthrin, carbaryl, chlorantraniliprole (0.12 and 0.49 kg AI ha^{-1}), imidacloprid (0.5G, 0.21 kg AI ha^{-1}), imidacloprid + bifenthrin (0.15 and 0.40 kg AI ha^{-1}) and trichlorfon. Six other treatments also significantly reduced larval populations relative to the untreated check: *Beauveria bassiana*, cyfluthrin, halofenozide and imidacloprid (0.2G and 0.5G, 0.28 kg AI ha^{-1}). Only *Bt israelensis* did not significantly reduce populations.

There was no evidence for a positive rate response for the products evaluated at multiple rates: chlorantraniliprole (three rates, 94–100% control), indoxacarb (two rates, 100%) and imidacloprid (0.5G, two rates, 89–94%). A positive rate response may have been obscured by the relatively high control given by all products.

In 2006, significant control (>70%) was attributed to seven treatments, clothianidin (0.34 and 0.22 kg AI ha^{-1}), bifenthrin, chlorantraniliprole (0.29 kg AI ha^{-1}), trichlorfon, imidacloprid + bifenthrin (9SC) and carbaryl (Table 3). Although not statistically significant, four other treatments suppressed larval populations >50% with respect to the untreated control, including indoxacarb (0.25 kg AI ha^{-1}), *Beauveria bassiana*, dinotefuran and imidacloprid (0.28 kg AI ha^{-1}). All other treatments gave 25–46% suppression. Among the three rates tested, imidacloprid had inconsistent results, with 57.3, 44.3 and 31.5% control for the high, low and middle rates respectively. Clothianidin, chlorantraniliprole and indoxacarb, however, all showed a positive rate response.

Larval populations were 2.7 times higher in 2006 than in 2005, with means of 375.4 and 137.1 larvae m^{-2} in their respective untreated control plots. For the 12 treatments applied in both years, efficacy declined from 2005 to 2006 for all of them. For the treatments evaluated in each year, variation was relatively large. In order of least to most variation, these were trichlorfon (92/78%), *B. bassiana* (83/64%), imidacloprid + bifenthrin (9SC, 94/74%), carbaryl (97/70%), cyfluthrin (20WP, 78/46%), imidacloprid (0.5G, 0.28 kg AI ha^{-1}, 89/57%), *Bt israelensis* (58/25%), dinotefuran (100/62%), imidacloprid + bifenthrin (0.36G, 94/46%), azadirachtin (94/40%) and imidacloprid (0.5G, 0.21 kg AI ha^{-1}, 94/32%).

3.2 Curative applications

In 2005, best curative control (94–99%) was attributed to clothianidin, dinotefuran and indoxacarb (0.49 kg AI ha^{-1}) (Table 4). Indoxacarb (low rate), trichlorfon and imidacloprid gave ≥60% control. Chlorantraniliprole (0.28 kg AI ha^{-1}) and imidacloprid + bifenthrin (0.26 kg AI ha^{-1}) also gave significant control, but there was no evidence of a positive rate response for either product when the other rates were considered. One formulation of cyfluthrin (Ultra) showed significant control (58%), but the other (20WP) did not. *Bt israelensis* showed significant control (48%). No control was attributed to the other treatments evaluated (21–44% suppression).

In 2006, best control (71–84%) was attributed to dinotefuran and clothianidin (both rates), followed by imidacloprid (64%) and trichlorfon (62%) (Table 5). Significant control was also given by chlorpyrifos, indoxacarb (high rate) and carbaryl (39–56%). Indoxacarb showed a positive rate response, but the lowest rate (0.12 kg AI ha^{-1}) was not significantly different from the untreated control. Likewise, imidacloprid + bifenthrin and bifenthrin did not suppress populations relative to the untreated check.

In terms of speed of kill, sampling date did not have a significant effect on larval abundance for any treatment evaluated (df = 2, 10; $P > 0.05$) except carbaryl (df = 2, 10; $P = 0.036$). Carbaryl's efficacy increased with time and peaked at 62.7% at 7 DAT, at which point it was significantly different from the untreated check (Table 6). The overall efficacy of all other treatments was already manifest at 1 or 3 DAT.

Larval populations were similar between years with means of 109.7 and 115.0 larvae m^{-2} for 2005 and 2006 respectively. For the three treatments applied both years, variation was relatively small for dinotefuran (97/84%) and trichlorfon (69/62%) but much higher for indoxacarb (0.49 kg AI ha^{-1} 94/49%). The three rates of clothianidin tested over the 2 years gave consistently good results, ranging from 71 to 99%.

3.3 Preventive versus curative applications

A significant effect of application window was detected for dinotefuran ($F = 4.77$; df = 1, 12; $P = 0.050$) and imidacloprid + bifenthrin (pooled rates: $F = 6.04$; df = 1, 26; $P = 0.021$; low rates: $F = 3.64$; df = 1, 12; $P = 0.081$; high rates: $F = 2.96$; df = 1, 12; $P = 0.111$) (Fig. 1). Dinotefuran was significantly more effective when used as a curative than when used as a preventive, suppressing larval populations by a mean ± SE of 90.8 ± 8.49 versus $61.1 \pm 9.81\%$ relative to the untreated control. In contrast, imidacloprid + bifenthrin was significantly more effective as a preventive than as a curative, with reductions of 63.6 ± 7.80 versus $49.5 \pm 7.97\%$ respectively. There was no detectable effect of application window for clothianidin (pooled rates: $F = 0.059$; df = 1, 24; $P = 0.810$; low rates: $F = 0.41$; df = 1, 12; $P = 0.532$; high rates: $F = 0.17$; df = 1, 12; $P = 0.689$), imidacloprid (pooled rates: $F = 1.45$; df = 1, 30; $P = 0.238$; low rates: $F = 2.11$; df = 1, 12; $P = 0.172$; high rates: $F = 0.13$; df = 1, 12; $P = 0.723$), indoxacarb (pooled rates: $F = 3.07$; df = 1, 38; $P = 0.088$; low rates: $F = 0.55$; df = 1, 12; $P = 0.471$; high rates: $F = 1.79$; df = 1, 12; $P = 0.205$) or trichlorfon ($F = 0.15$; df = 1, 12; $P = 0.708$).

4 DISCUSSION

Based on the present results, there are highly efficacious products currently available for the insecticidal control of *T. paludosa* during both preventive and curative control windows. A synopsis of overall product acceptability with respect to window of application is summarized in Table 7. Other than the older standards (i.e. chlorpyrifos and carbaryl), some newer chemistries offer alternatives that are reduced risk owing to lower mammalian toxicity, lower rate of application or narrower spectrum of insecticidal activity.

The neonicotinoids, clothianidin and dinotefuran, were the most effective overall, leading to high

Table 6. Speed of kill of insecticides applied on 30 May 2006 for the curative control of fourth-instar *Tipula paludosa* in golf course rough

		1 DAT		3 DAT		7 DAT	
Insecticide	Rate (kg AI ha^{-1})	Mean number of larvae m^{-2} (± SE)	Mean % larval reduction (± SE)[a]	Mean number of larvae m^{-2} (± SE)	Mean % larval reduction (± SE)[a]	Mean number of larvae m^{-2} (± SE)	Mean % larval reduction (± SE)[a]
Trichlorfon	9.08	19.9 (±8.9)	80.4 (±7.2)***	51.8 (±18.5)	55.1 (±18.5)*	19.9 (±15.4)	89.4 (±8.6)***
Clothianidin	0.28	23.3 (±9.5)	70.8 (±15.1)**	23.9 (±14.6)	75.7 (±19.1)***	19.9 (±10.9)	85.7 (±7.3)***
Dinotefuran	0.60	23.3 (±9.5)	67.3 (±15.2)**	19.9 (±6.2)	77.4 (±11.8)***	19.9 (±6.3)	85.2 (±5.8)***
Imidacloprid (0.5G)	0.44	39.9 (±13.6)	56.0 (±14.9)*	51.8 (±13.5)	53.7 (±11.0)*	31.9 (±8.0)	77.7 (±4.9)***
Chlorpyrifos	1.12	46.5 (±13.3)	46.7 (±17.7) NS	47.8 (±19.5)	54.0 (±17.9)*	31.9 (±20.5)	74.0 (±19.4)***
Clothianidin	0.45	10.0 (±10.0)	91.7 (±8.3)***	15.9 (±7.5)	84.1 (±7.7)***	43.9 (±20.3)	67.8 (±13.7)***
Carbaryl	8.97	113.0 (±35.9)	9.5 (±9.5) NS	63.8 (±16.0)	45.6 (±13.8) NS	51.8 (±21.5)	62.7 (±16.8)**
Indoxacarb (14.5SC)	0.49	39.9 (±13.6)	61.6 (±15.4)**	31.9 (±10.2)	64.6 (±12.0)**	63.8 (±25.5)	53.2 (±18.9)*
Indoxacarb (14.5SC)	0.12	66.4 (±16.8)	33.9 (±15.2) NS	111.6 (±18.5)	15.7 (±15.7) NS	95.7 (±32.4)	44.8 (±18.2) NS
Imidacloprid + bifenthrin (9SC)	0.28/0.23	73.1 (±29.0)	43.3 (±18.5) NS	111.6 (±21.5)	14.3 (±14.3) NS	91.7 (±16.2)	42.3 (±13.8) NS
Indoxacarb (14.5SC)	0.24	59.8 (±28.2)	48.1 (±17.8)*	79.7 (±30.2)	53.4 (±16.0)*	91.7 (±29.3)	41.4 (±18.0) NS
Bifenthrin (PL)	0.12	109.6 (±17.6)	23.4 (±10.9) NS	107.6 (±27.2)	24.3 (±15.9) NS	127.6 (±20.5)	20.1 (±5.5) NS
Untreated	0.0	103.0 (±25.9)		131.6 (±39.2)		159.5 (±31.5)	

[a] For each column, means are significantly different from the untreated control at * 0.05, ** 0.01 and *** 0.001 (Dunnett's method).

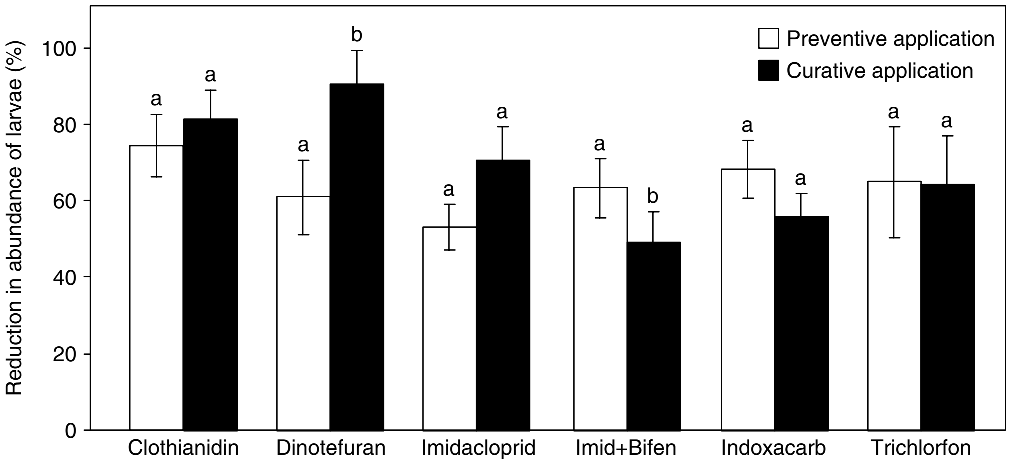

Figure 1. Efficacy of insecticidal control products against *Tipula paludosa* larvae with respect to control window. Preventive applications (white columns) targeted first and second instars in October, while curative applications (black columns) targeted third and fourth instars in May. For each treatment, columns with the same letter above them are not significantly different ($P > 0.05$), LSD.

Table 7. Efficacy of control products for *Tipula paludosa* in turfgrass with respect to window of application[a]

Application window	Acceptable	Variable	Unacceptable
Preventive	Bifenthrin Carbaryl Chlorantraniliprole Clothianidin Trichlorfon	Azadirachtin *Beauveria bassiana* Cyfluthrin Dinotefuran Imidacloprid Imidacloprid + bifenthrin Indoxacarb	*Bt israelensis*
Curative	Clothianidin Dinotefuran	Imidacloprid Indoxacarb Trichlorfon	Imidacloprid + bifenthrin

[a] Acceptable products are those with ≥70% control in each of two trials; unacceptable products are those with ≤50% control or non-significant control in each of two trials; variable products are those with mixed or intermediate results between two trials.

rates of suppression in both preventive (62–100%) and curative (71–99%) control windows. Given their efficacy, versatility and consistency, these two chemistries could be recommended for the control of early- and late-instar *T. paludosa* larvae, provided the insect is not targeted during the summer aestivation and pupation period (approximately early June to late August), or during winter when temperatures are too low. Dinotefuran gave significantly higher control as a curative (91%) than as a preventive (61%), suggesting that rapid foliar uptake or direct ingestion/contact by surface-feeding larvae might be involved.

The other neonicotinoid, imidacloprid, showed lower efficacy and was less consistent than the others. While rates from 0.18 to 0.28 kg AI ha^{-1} gave 86–94% control in one preventive trial, suppression fell to 32–57% in the second trial, which was not significantly different from the untreated control. A significant effect of imidacloprid as a curative was detected in both trials (60–64%). In a study by Stahnke *et al.*,[26] imidacloprid (0.28 and 0.39 kg AI ha^{-1}) gave 72–88% control applied in early autumn during oviposition. Those rates were not effective when applied in late autumn during the first and second stadia, although a higher rate (0.44 kg AI ha^{-1}) gave significant control (43%) in one of two trials. The other neonicotinoid tested in that study (thiamethoxam) was also effective in early autumn (72%), but not late autumn.

Among the older chemistries, efficacy of the carbamate, carbaryl, was confirmed in both preventive trials (70–97% control). It was not as effective as a curative, offering only low suppression (39%) and a slow speed of kill. Carbaryl's full effect was delayed until 7 DAT, whereas all other products reached full effect within 1 DAT. A week's delay in suppressing large larvae would probably be highly detrimental for a rescue treatment, i.e. an application made in response to the detection of damage. Stahnke *et al.*[26] confirmed the efficacy of carbaryl (9 kg AI ha^{-1}) as a curative against third instars (70–85% control), but did not test it as a preventive. Simard and Dionne[23] evaluated carbaryl as a late-May curative for fourth instars and showed 68–91% control regardless of AI concentration (14.5 or 20.0 mL 10 m^{-2}), spray volume (1000 or 300 mL 10 m^{-2}) and irrigation (0 or 63.5 L 10 m^{-2}).

Among the organophosphates, chlorpyrifos gave marginal suppression (56%) in the single curative trial. Stahnke *et al.*[22] found 86–100% control with chlorpyrifos (1.12 kg AI ha^{-1}) against third instars in spring, regardless of formulation (EC, FL, SC or WP). Stahnke *et al.*[26] showed 97–99% control in late autumn and 89–92% in early spring. Trichlorfon gave variable results as a preventive, from high to no suppression, but as a curative it gave consistent and marginal control (72%) across both trials. Stahnke *et al.*[26] showed no control in early autumn, 61% in one late-autumn trial but no control in the other (9.11 kg AI ha^{-1}). Trichlorfon is well known and widely used in the turf industry as a dependable late-season curative for suppressing white grubs.

The insect growth regulator, halofenozide, gave low efficacy in the single preventive trial; Stahnke *et al.*[26] showed no control in late autumn. It was included in these trials because of its widespread use and familiarity; halofenozide acts as an ecdysteroid mimic that induces premature and lethal molt with best activity against larvae of the Coleoptera, but also Lepidoptera.[27,28] This product is only labeled in turf for white grubs, weevil larvae and caterpillars.

Among the pyrethroids, bifenthrin was one of the best products evaluated for preventive control (94–95%). In contrast, it gave no significant suppression in the single curative trial. Anecdotal observations made after curative field applications on several golf courses, however, report it as efficacious, driving the larvae to the surface where they die (Peck DC, personal observation). Therefore, the curative use of bifenthrin should be examined further. Cyfluthrin gave mixed results as a preventive, from marginal to no significant suppression (46–81%). In the single curative trial there was low to no significant suppression. Stahnke *et al.*[26] showed that bifenthrin (0.25 and 0.45 kg AI ha^{-1}) gave 65–95% control in late autumn, 81–100% in early spring, and 67–86% in late spring (still third instars). Cyfluthrin gave 84% control in early autumn but no control in late autumn. Lambda-cyhalothrin gave significant control (60%) in one of two late-autumn trials and no control in late spring.

The turf industry's first anthranilic diamide, chlorantraniliprole,[29] was among the best preventive options. In the first trial, all three rates (0.12, 0.24, 0.49 kg AI ha^{-1}) gave >94% control, while in the second trial middle to low rates (0.29 and 0.12 kg AI ha^{-1}) gave marginal to no control (46–80%). It offered low to no control (19–50%) in the single curative trial. Another newer compound, the oxadiazine indoxacarb,[30] also showed promise for both preventive and curative control, but the results were variable between treatments. While low and high rates (0.078 and 0.45 kg AI ha^{-1}) gave 100% control in one preventive trial, two middle rates (0.25 and 0.13 kg AI ha^{-1}) gave no control (44–64%) in the second trial. In the curative trials, high rates (0.49 and 0.87 kg AI ha^{-1}) gave good control (72–94%), but lower rates in the second trial fell to low or no control (25–35%). A combination formulation of imidacloprid and bifenthrin gave marginal to good control as a preventive (73–94%), but this excludes one instance where a high rate gave no control (46%). As a curative, its efficacy was significantly less, with only marginal to no control (15–41%). For all three of these products, future trials will be needed for a better assessment of effective application rates for preventive and curative windows.

Among the microbials, *Bt israelensis* performed poorly, giving significant, but low, control in one trial (48%). However, as a compound with dipteran-specific activity,[31] this alternative should still be considered for its potential under different formulations or modes of application. Other strains of *Bt israelensis* are toxic to tipulid larvae;[32] in one European study, several Danish *Bt israelensis* isolates caused >40% mortality when tested against five-day-old *T. oleracea* larvae.[33] *Beauveria bassiana* showed marginal to high control in the preventive trials (82 and 68%) but no suppression in the single curative trial. Stahnke *et al.*[26] showed that *B. bassiana* (JW1, 3.71 and 7.42 × 10^{10}) gave no control in late autumn. Based on these results, it is proposed that this fungal entomopathogen be evaluated in additional preventive studies for its potential as an alternative to chemical insecticides. The botanical azadirachtin gave high control in one preventive trial (93%) but showed no control in the other preventive and the single curative trial. When targeting third instars in spring, Stahnke *et al.*[22] found no effect of a neem seed extract. Entomopathogenic nematodes are another biological alternative that should be further evaluated. Stahnke *et al.*[22] reported up to 56% control with *Steinernema feltiae* (Biosys '27' strain) and 41% with *Steinernema carpocapsae* ('A11' strain).

4.1 Preventive versus curative control

Best IPM practices would be favored theoretically by the curative control of *T. paludosa* larvae, especially since insecticidal options are available. Owing to their small size, scouting for first and second instars in autumn is not feasible under most circumstances, but, in the spring, third and fourth instars are large enough for sampling programs to assess densities through the visual inspection of soil cores. Application decisions could then be made on the basis of action thresholds. In addition, this approach would allow natural population regulation to take place over the winter. Regulators include environmental factors such as harsh winters[24] and vertebrate predation. Reductions of 30–40% in larval populations are reported between late autumn and early spring without treatment, largely attributed to bird predation.[26] Treatment thresholds of 160–270 m^{-2} (15–25 ft^{-2}) in turf are recommended in the Pacific Northwest,[34] and these have been adopted in Ontario until accurate thresholds can be determined (Charbonneau P, private communication).

While this approach is appropriate for *T. paludosa*, it may not be relevant for *T. oleracea*. Adult *T. oleracea* emerge in the autumn, coincident with *T. paludosa*, and therefore larval phenology of the two species should be similar with respect to preventive applications. However, *T. oleracea*'s shorter developmental time leads it to complete the fourth instar in early spring and would make it refractory to any insecticides once pupation began. It is still unclear whether *T. oleracea* causes meaningful damage in early spring and, if so, whether fourth instars could be targeted in the window after cold temperatures and before pupation. In western New York, adult emergence takes place from late April to mid May (Peck DP, unpublished). Therefore, preventive control might be the best approach in areas that harbor *T. oleracea* alone or together with *T. paludosa*. This underscores the importance of species differentiation, not only to distinguish between native and exotic species but also to distinguish between *T. paludosa* and *T. oleracea*, before deciding on the best control window.

Beyond phenological considerations of the target pests, tailoring the best control to each species will depend on studies that better define the time of insecticide application and the speed of kill. Owing to climate conditions, late-autumn and early-spring control windows in the Northeast may be far narrower and less predictable than in the Pacific Northwest. With respect to preventive control, crane fly management would therefore profit from studies designed to test the best timing of applications. The window of adult emergence, for example, could help signal when applications need to be made, but it is necessary to determine if that time is coincident with adult emergence or delayed 1, 2 or more weeks to be most effective. When Stahnke *et al.*[26] conducted autumn trials at the time of oviposition and at the time of first to second instars (~7 weeks later), suppression by cyfluthrin, imidacloprid and thiamethoxam fell from significant to non-significant.

With respect to curative control, studies on the speed of kill would be critical. For instance, all products that were tested reached full effect within 1–3 DAT, with the exception of carbaryl, the full effect of which was delayed until 7 DAT. A week's delay in suppressing large larvae would probably be highly detrimental for a rescue treatment, i.e. an application made in response to the detection of damage. Nevertheless, the variable temperatures experienced in early spring and late fall are likely to influence insecticide performance in terms of speed of kill as well as efficacy. Degree day accumulations were 22 $DD_{(10\,^{\circ}C)}$ the first week after application in 2005, but were 126 $DD_{(10\,^{\circ}C)}$ in 2006. Under those conditions, speed of kill might have been greatly reduced in 2005.

4.2 A new control application window

Beyond turfgrass injury, a major consequence of these invasives becoming established in the Northeast is that their management may entail an entirely new insecticidal control window in susceptible turf. Up to now, insect pest management in home lawns and golf courses generally has not involved late-autumn or early-season applications. The main exception would be spring control of the annual bluegrass weevil (*Listronotus maculicollis* Dietz) on the peripheries of golf course playing surfaces.[35,36] The early-spring and late-autumn windows for *T. oleracea* and *T. paludosa* control fall outside of that for white grubs, the most widespread and problematic turfgrass pests in the Northeast. This complex includes a series of previously introduced exotics: the Asiatic garden beetle [*Maladera castanea* (Arrow)], European chafer [*Rhizotrogus majalis* (Razoumowsky)], Japanese beetle (*Popillia japonica* Newman) and oriental beetle [*Exomala orientalis* (Waterhouse)].[10] For those pests in the Northeast, preventive control (e.g. imidacloprid) is recommended around the time of oviposition and early larval development (mid-June to mid-August, depending on the grub species), after which a curative control (e.g. trichlorfon) remains an option through early September[37] (Peck DC, personal observation). While the newest long-residual soil insecticides to emerge (e.g. clothianidin, dinotefuran, thiamethoxam) harbor possibilities for white grub control with applications as early as May, it remains to be tested how early a spring application could be made for curative control of *T. paludosa* and still offer residual control of subsequent white grub infestations. If not, the arrival of this exotic will mean additional insecticide inputs, implying a costly new economic and environmental burden to the turfgrass industry. Research must also be conducted for better definition of action thresholds so that turfgrass managers have the informational tools necessary to make the best decisions about what areas need protection. On a golf course, for instance, this means determining whether just greens need to be protected or whether tees and fairways should be included, and when/if applications are necessary for the rough areas.

The neonicotinoids evaluated here are normally recommended for the control of turf insects early in the life cycle. Because of their relatively long residual and uptake through the roots of the grass, they offer targeted and almost 'season-long' control of white grubs and other troublesome root-feeding insects. Best results are achieved when these insecticides are applied around the time of oviposition to allow time for activation and uptake, and to target the more susceptible early stages of the insect. None is recommended as a late-season curative for white grubs or other insects. Nevertheless, the present results revealed high efficacy against large (third- or fourth-instar) *T. paludosa* larvae. Combined with the rapid speed of kill, it is suggested that the potential of neonicotinoids for the curative control of crane fly larvae be further investigated. Rapid knockdown means that the insect may not be exposed to the insecticide as a systemic. Since larvae will feed on the surface, it may be that they ingest or come into contact with the product when active aboveground.

More applied research is urgently needed in order to prevent outbreaks, reduce the impact and curtail range expansion of invasive crane flies across New

York and into the broader regions of the Northeast. Impact in other horticultural systems, such as forage grasses,[3,18] may also be inevitable. Recommendations for the insecticidal control of invasive *Tipula* larvae are the cornerstone of an initial response to their establishment and range expansion in the Northeast. Insecticides thereby represent the first, not the only, tools to arm golf course superintendents, lawn care providers, home owners and others against outbreaks. Longer-term and alternative strategies will need to be investigated in the future. In the area of cultural control, for instance, it may be possible to exploit the extreme dependence of eggs and first instars on moisture[38,39] through the practice of deficit irrigation. In the area of biological control, the role for fungal entomopathogens and entomopathogenic nematodes needs to be further investigated. Finally, given the active range expansion of these two species, it would be valuable to understand how the susceptibility of a habitat to invasion[40,41] is affected by management practices and other ecological and environmental variables. Moreover, curtailing the impact and spread of these invasives across the East may be severely hampered by lack of access to the best interventions in their current areas of establishment. Unlike most other states, some of the best new chemistries for crane fly control (clothianidin, dinotefuran) are not registered in New York.

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