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Nematicides Increase Grain Yields in Spring Wheat Cultivars and Suppress Plant-Parasitic and Bacterial-Feeding Nematodes

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Abstract: Grain yields of spring wheat (*Triticum aestivum* L. cvs. AC Barrie, AC Walton, AC Wilmot, Belvedere, Glenlea) in field plots over a 3-year period were increased ($P < 0.001$) by an average of 0.56 (25.1%) and 1.17 (52.5%) tonnes/ha in comparison to untreated check plots when aldicarb at 2.24 kg or fosthiazate at 13.5 a.i./ha, respectively, were broadcast and incorporated into the soil to suppress nematodes. The planned F test using orthogonal coefficients indicated that the mean response of grain yields to nematicide treatments of AC Barrie and Glenlea, which are grown primarily in the prairie provinces of Canada, was greater (48.5%) than the mean response of Belvedere, AC Walton, and AC Wilmot (33.7%), which are more common in the Maritime region of Canada ($P < 0.001$). Root lesion nematodes (primarily *Pratylenchus penetrans*) in wheat roots and in root zone soil at harvest were reduced by the nematicide applications ($P < 0.001$). Bacterial-feeding nematodes (primarily *Diplogaster lheritieri* (Maupas)) in root zone soil were also suppressed by fosthiazate ($P < 0.01$) but not by aldicarb. These data indicate that root lesion nematodes cause substantial yield losses in spring wheat in the Maritime region of Canada.

Key words: aldicarb, bacterial-feeding nematodes, fosthiazate, root lesion nematodes, spring wheat.

Diseases of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) in the Maritime region of Canada continue to be serious obstacles for growers (Clough and Johnston, 1978; Johnston and MacLeod, 1987). *Cochliobolus sativus* and *Stagonospora nodorum,* which are the causal agents of root rot and leaf blotch in wheat, respectively, are common fungal pathogens. However, several more recent field studies have indicated that root lesion nematodes, and in particular *Pratylenchus penetrans,* also can reduce yields substantially (Kimpinski et al., 1989, 1998; Kimpinski and Johnston, 1995). In those studies, information was obtained on both nematode and fungal pathogens and their interactions in disease complexes, but the most recent study (Kimpinski et al., 1998) indicated that the majority of the impact on grain yields of the wheat cultivar 'Belvedere' was due to *P. penetrans.*

The effect of nematodes on grain yields of wheat has not been determined in the major cereal-growing regions in western Canada. However, studies in other regions of the world have confirmed that the root lesion nematode species *P. neglectus* and *P. thornei* are important pathogens of wheat (Loof, 1991). For example, studies have shown that these two species cause substantial damage to susceptible wheat cultivars in Australia (Taylor et al., 1999; Thompson et al., 1995; Vanstone et al., 1998).

The objectives of this study were to observe the effects of nematicide treatments on grain yields of several wheat cultivars that are widely grown in Canada. The effects of these treatments on nematode populations also were noted.

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Materials and Methods

Study area: The field trials in each year were located on adjacent sites at the Harrington Experimental Farm of the Agriculture and Agri-Food Canada Crops and Livestock Research Centre on Prince Edward Island, Canada. The soil type was a fine sandy loam with 63% sand, 27% silt, 10% clay, 2.7% organic matter, and a pH range of 5.7 to 6.2. The previous crops for each experimental site were red clover (*Trifolium pratense* cv. Marino) followed by soybean (*Glycine max* cv. Proteus).

In spring 1999, 2000, and 2001, the sites were mouldboard-plowed 20 cm deep, tandem disced harrowed, and S-tine harrowed 15 cm deep. The nematicides were broadcast on 28 May 1999, 12 June 2000, and 30 May 2001, and the treatments were (i) untreated, (ii) aldicarb 15% granular applied at 2.24 kg a.i./ha, and (iii) fosthiazate 900 EC formulation broadcast at 13.5 kg a.i./ha. All plots were rototilled to a depth of 15 cm immediately following applications. Five wheat cultivars, AC Barrie, AC Walton, AC Wilmot, Glenlea, or Belvedere, were seeded immediately after the treatments at the rate of 350 seeds/m^2 at a depth of 2.5 cm in rows 18 cm apart in 6.5 × 1.8-m plots. Recommended cultural and fertilizer practices for wheat in the Atlantic region of Canada were followed in each year (Anonymous, 1991). The plots were harvested on 1 September 1999, 1 October 2000, and 12 September 2001.

Root rot severity assessment: Root rot severity was assessed visually on the subcrown internodes of plants at growth stage 70–72 (Zadoks et al., 1974). The disease ratings were healthy, slight, moderate, and severe (Ledingham et al., 1973). The fungal pathogens responsible for root rot were isolated from several host plants and identified.

Sampling and extraction of nematodes: Soil samples were taken from each plot just prior to the application of treatments in the spring and just prior to harvest in each year. Each sample consisted of 10 soil cores taken 1 m apart in a zigzag sampling pattern (Barker, 1985a) to a depth of 15 cm, using a 2.5-cm-diam. probe. A 50-g subsample was placed in a modified Baermann funnel (Barker, 1985b) for 7 days at 23 °C.

Just prior to harvest in each year, 10 root samples were collected 1 m apart in a zigzag sampling pattern (Barker, 1985a) from each plot. Each root sample was washed and a subsample of 5 to 10 g was placed in a mist chamber for 7 days at 23 °C (Hooper, 1986).

Root lesion nematodes recovered from the Baermann funnel and mist chamber methods were counted using a stereomicroscope (×80). Subsamples from each processed sample consisting of 50 g of soil and 10 g of roots were dried for 48 hours at 100 °C, and the data were expressed as numbers of nematodes per kilogram of dry soil or per gram of dry root. Individual specimens were examined using the oil immersion lens (×1000) of a compound microscope to confirm species identification.

Field design and statistical analysis: The field design in each year was a randomized complete block with four replicates per treatment. Analyses of variance were used to assess the effects of the nematicide treatments on grain yields and on nematode population density. Nematode data were transformed to $\log_{10}$ (x + 1) for analyses of variance (Snedecor and Cochran, 1989). Duncan's multiple-range test (SAS Institute Inc., 1985) and orthogonal comparison (Little and Hills, 1978; Steel and Torrie, 1960) were used for comparisons among treatment and cultivar means. Error variances were homogenous, and years were treated as fixed effects for the combined 3-year analyses of variance (Steel and Torrie, 1960).

Results

Grain yields: The applications of aldicarb and fosthiazate increased grain yields by 0.56 (25.1%) and 1.17 (52.5%) tonnes/ha, respectively, over the 3-year period when compared to untreated check plots ($P < 0.001$) (Table 1). Glenlea showed the largest average yield gain following nematicide applications, followed by AC Barrie, AC Walton, AC Wilmot, and Belvedere (derived from Table 1). AC Barrie produced lower grain yields than the other cultivars ($P < 0.001$). The orthogonal comparison indicated that the mean response of grain yield to the nematicide treatments of AC Barrie and Glenlea was greater (48.5%) than the mean response of Belvedere, AC Walton, and AC Wilmot (33.7%) ($P < 0.001$; derived from Table 1). There was also a cultivar by treatment interaction ($P < 0.001$).

Root rot severity: The incidences of root rot and leaf diseases in the wheat cultivars at the experimental sites were low in all 3 years, and these data are not presented.

Nematodes: The only plant-parasitic nematodes found within wheat roots were root lesion nematodes, and most of these were *P. penetrans,* though a few bearing the taxonomic characteristics of *P. crenatus* were detected. Root lesion nematodes were also the dominant plant-parasitic nematodes found in root zone soil. Other nematode groups found regularly in root zone soil were stunt nematodes (*Merlinius* spp. and *Tylenchorhynchus* spp.) and spiral nematodes (primarily *Helicotylehchus* spp.), but population densities were low (often < 500 nematodes/kg of dry soil in untreated plots). The dominant bacteria-feeding nematode species found in root zone soil was *Dipogaster lheritieri.*

The nematicide treatments reduced the numbers of root lesion nematodes in root zone soil and in roots (Table 2), fosthiazate being more effective than aldicarb ($P < 0.001$). Nematode population densities in both soil and roots were similar in all five cultivars, and there were no cultivar-by-treatment interactions. The fosthiazate treatment also reduced ($P < 0.001$) the numbers of bacteria-feeding nematodes in root zone soil, whereas aldicarb had no effect (Table 3). There was no cultivar effect on bacteria-feeding nematodes nor a cultivar by treatment interaction.

Discussion

The 3-year average increase in grain yield when aldicarb or fosthiazate was applied indicated that root lesion nematodes were important factors in determining productivity. These results were similar to a previous

TABLE 1. Effects of nematicides on grain yields of spring wheat cultivars.[a]

	Grain yields (tonnes/ha)			
Cultivar	Untreated[b]	Aldicarb[b]	Fosthiazate[b]	Cultivar means[c]
Belvedere	2.46	3.13 (27.2)[d]	3.27 (32.9)	2.95a
AC Wilmot	2.46	3.06 (24.4)	3.45 (40.2)	2.99a
AC Walton	2.32	2.67 (15.1)	3.77 (62.5)	2.92a
Glenlea	2.04	2.76 (35.3)	3.66 (79.4)	2.82a
AC Barrie	1.87	2.33 (24.6)	2.83 (51.3)	2.34b
Treatment means[c]	2.23a	2.79b (25.1)	3.40c (52.5)	

[a] Data combined over 3 years.
[b] Standard error of the mean is 0.098 (*n* = 12, error d.f. = 112); nematicides applied just prior to seeding at 2.24 kg a.i./ha of aldicarb and 13.5 kg a.i./ha of fosthiazate.
[c] Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple-range test; standard errors of the mean are 0.066 (*n* = 36, error d.f. = 36) for cultivars and 0.040 (*n* = 60, error d.f. = 90) for treatments.
[d] Values in parentheses indicate percent increases in grain yields in nematicide-treated plots in comparison to grain yields in untreated plots.

TABLE 2. Effects of nematicides on the population densities of root lesion nematodes[a] in root zone soils and roots of different wheat cultivars.

Cultivar	Spring[b]	Untreated[c]	Aldicarb[c]	Fosthiazate[c]	Cultivar means[d]
Nematodes per kg of dry soil					
Belvedere	3.18 (1,510)[c]	3.23 (1,700)	3.16 (1,450)	2.72 (520)	3.04 (1,100)
AC Wilmot	3.21 (1,620)	3.43 (2,690)	3.01 (1,020)	2.85 (710)	3.10 (1,260)
AC Walton	3.31 (2,040)	3.28 (1,910)	3.04 (1,100)	2.89 (780)	3.07 (1,180)
Glenlea	3.19 (1,550)	3.11 (1,290)	3.00 (1,000)	2.59 (390)	2.90 (800)
AC Barrie	3.29 (1,950)	3.18 (1,510)	3.21 (1,620)	2.82 (660)	3.07 (1,180)
Treatment means[d]		3.25a (1,780)	3.08b (1,200)	2.77c (590)	
Nematodes per g of dry root tissue					
Belvedere		3.49 (3,090)	2.80 (630)	2.17 (150)	2.82 (660)
AC Wilmot		3.47 (2,950)	2.95 (890)	2.17 (150)	2.86 (720)
AC Walton		3.24 (1,740)	2.75 (560)	2.15 (140)	2.71 (510)
Glenlea		3.15 (1,410)	2.73 (540)	2.13 (130)	2.67 (470)
AC Barrie		3.20 (1,580)	2.96 (910)	1.98 (100)	2.72 (520)
Treatment means[d]		3.31a (2,040)	2.84b (690)	2.12c (130)	

[a] Primarily *Pratylenchus penetrans;* data combined over 3 years and presented as $\log_{10}$ means with back-transformed means in parentheses.
[b] Spring soil samples (no root tissue) collected from all plots just prior to nematicide treatments ($n = 36$, error d.f. = 36, standard error of the mean = 0.058); nematicides applied just prior to seeding at 2.24 kg a.i./ha for aldicarb and 13.5 kg a.i./ha for fosthiazate.
[c] Samples collected just prior to harvest; $n = 12$, error d.f. = 124 for both soil root data, and standard errors of the mean are 0.102 and 0.118 for soil and root data, respectively.
[d] Means followed by the same letter are not different ($P < 0.05$) according to Duncan's multiple-range test (letters omitted if not significant); standard errors of the mean for soil and root data are 0.060 and 0.071, respectively, for cultivars ($n = 36$, error d.f. = 36, spring sample excluded) and 0.050 and 0.051, respectively, for treatments ($n = 60$, error d.f. = 90.).

study in the region where the application of aldicarb in conjunction with fungicides led to an increase in grain yield of 50% (Kimpinski et al., 1998). In that study, most of the differences in grain yields were ascribed to differences in nematode numbers. It was also noted that AC Barrie and Glenlea, which are more common in the prairie provinces of western Canada, had a greater response to the nematicide treatments than Belvedere, AC Walton, and Wilmot, which are grown primarily in Atlantic Canada. However, the response of wheat cultivars to nematicide treatments under climatic conditions in western Canada has not been determined. Further, the nematode fauna in cereals in that region need further study.

The greater efficacy of fosthiazate in comparison to aldicarb may have been due to the long-term (since 1986) use of aldicarb on potatoes at the Harrington Experimental Farm. Such long-term usage produces a selection or adaptation pressure for soil microorganisms that can rapidly degrade carbamate pesticides such as aldicarb (McLean and Lawrence, 2003; Read, 1987). The organophosphate, fosthiazate, has had a much shorter history of prior use at the site.

The effect of the nematicides on bacteria-feeding nematodes (Tahseen et al., 1996a, 1996b) is similar to that reported for plant-parasitic nematodes (Spurr, 1985). However, the root lesion nematodes in this study were more affected by the nematicides than were the bacteria-feeders; on the latter, aldicarb had no effect. We speculate that this was related to the ability of the bacteria-feeding nematodes to reproduce more rapidly than the root lesion nematodes after the nematicide treatments. For example, the generation times of *P. penetrans* and *D. lheritieri* under favorable conditions are estimated at about 30 days and 3 days, respectively (Mai et al., 1977; Nicholas, 1984). Secondly, the endoparasitic root lesion nematodes were exposed to systemic action of the nematicides within wheat roots as well as to the direct contact in the soil at the beginning of the season, whereas the bacteria-feeding nema-

TABLE 3. Effects of nematicides on the population densities of bacteria-feeding nematodes[a] in root zone soils.

Cultivar	Spring[b]	Untreated[c]	Aldicarb[c]	Fosthiazate[c]	Cultivar means[d]
Numbers per kg of dry soil					
Belvedere	3.66 (4,570)	3.66 (4,570)	3.57 (3,720)	3.23 (1,700)	3.49 (3,090)
AC Wilmot	3.56 (3,630)	3.63 (4,720)	3.39 (2,450)	3.39 (2,450)	3.47 (2,950)
AC Walton	3.47 (2,950)	3.52 (3,310)	3.66 (4,570)	3.11 (1,300)	3.43 (2,650)
Glenlea	3.55 (3,550)	3.63 (4,270)	3.50 (3,160)	3.19 (1,550)	3.44 (2,750)
AC Barrie	3.64 (4,370)	3.39 (2,450)	3.60 (3,980)	3.21 (1,620)	3.40 (2,510)
Treatment means[d]		3.57a (3,720)	3.54a (3,470)	3.23b (1,700)	

[a] Primarily *Diplogaster lheritieri;* data combined over 3 years and presented as $\log_{10}$ means with back-transformed means in parentheses.
[b] Spring soil samples (no root tissue) collected from all plots just prior to nematicide treatments ($n = 36$, error d.f. = 36, standard error of the mean = 0.067); nematicides applied just prior to seeding at 2.24 kg a.i./ha for aldicarb and 13.5 kg a.i./ha for fosthiazate.
[c] Samples collected just prior to harvest; $n = 12$; error d.f. = 110, standard error of the mean = 0.107.
[d] Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's multiple-range test (letters omitted if not significant); standard errors of the mean are 0.071 ($n = 36$, error d.f. = 36) for cultivars (spring sample excluded) and 0.043 ($n = 60$, error d.f. = 90) for treatments.

todes would be exposed primarily to direct contact (Bunt, 1987).

The main result of this study was the substantial increase in grain yield for the five wheat cultivars when nematicides were applied. This result agreed with previous work in this region (Kimpinski et al., 1998) and was similar to studies in Queensland and South Australia where grain yields increased by 23% (Taylor et al., 1999) and 42% (Thompson et al., 1995) when aldicarb was used to suppress *P. thornei* and *P. neglectus* in nematode-susceptible wheat cultivars. These observations indicated that root lesion nematodes are important factors in reducing grain yields in the Maritime region and that all the cultivars used in this study were intolerant to *P. penetrans*.

Nematicides are too costly for use in wheat and are not environmentally desirable. However, alternative methods of nematode management are currently being developed. These include predicting the effect of nematode populations at planting on grain yields of different cultivars (Nicol et al., 1999; Vanstone et al., 1998), crop rotations (Hollaway, 2002; Taylor et al., 2000), and development of nematode-resistant cultivars (Vanstone et al., 1998). Application of these procedures may lead to significant monetary gains for Canadian producers in the maritime provinces as well as in the prairie provinces where wheat is grown over a large area.

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