***Geocenamus brevidens* Associated with Reduced Yield of No-Till Annual Spring Wheat in Oregon**

Richard W. Smiley, Professor, and **Ruth G. Whittaker**, **Jennifer A. Gourlie**, and **Sandra A. Easley**, Faculty Research Assistants, Oregon State University, Columbia Basin Agricultural Research Center, P.O. Box 370, Pendleton 97801

ABSTRACT

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Associations between stunt nematodes and yield of no-till annual spring wheat (*Triticum aestivum*) were examined at two eastern Oregon locations. *Geocenamus brevidens* was the only species detected at one location and was mixed with *Tylenchorhynchus clarus* at another location. Six cultivars were planted with or without application of aldicarb during 2001. Inverse correlations between yield and stunt nematode density were significant at the *G. brevidens*-only site ($P = 0.04$) but not the *G. brevidens* + *T. clarus* site ($P = 0.44$). Yields were inversely correlated ($P < 0.01$) with stunt nematode populations at both sites during 2002. Aldicarb improved grain yields at both locations during 2001 (17 and 24%, $P < 0.01$) but not at the single location treated with aldicarb during 2002 (10%, $P = 0.06$). A lack of association between yield and *T. clarus* in 19 previously unreported experiments is discussed. Reduced wheat yield in response to stunt nematodes in Oregon is likely due to parasitism by *G. brevidens* and not *T. clarus*. This is the first report associating *G. brevidens* with suppression of wheat yield in the Pacific Northwest. Further studies are needed to define cropping systems and locations where *G. brevidens* may cause economic damage.

Additional keywords: direct-drill, *Heterodera avenae*, *Merlinius brevidens*, *Pratylenchus neglectus*

Stunt nematodes are migratory plant-parasitic nematodes cosmopolitan on roots of cereals, grasses, and many other plant species (6,8,13,28,31). The taxonomy of this group of obligate ectoparasites is complex and in a state of transition (1,4,5,9,29). Species in the genera *Geocenamus*, *Merlinius*, and *Tylenchorhynchus* are reported most frequently, and species in *Nagelus*, *Paratrophurus*, *Quinisulcius*, and other genera are reported infrequently. Identification of stunt nematode genera and species is difficult, as exemplified by more than 100 species differentiated in the genus *Tylenchorhynchus* (9). Although most stunt nematode species do not cause significant damage to plants, including the stunting symptom, all stunt nematodes feed on epidermal cells and root hairs mostly in the cell elongation region, and may cause roots to thicken and elongate at a reduced rate (19). Many species of stunt nematodes are multiplied efficiently into high populations without causing damage to wheat (21,41) and other crops (22).

Although stunt nematodes are not

among the species considered most important on cereals (20,26), wheat (*Triticum aestivum* L.) has been significantly damaged by several species within this group. The species most recognized for the potential to damage wheat is *Geocenamus brevidens* (Allen, 1955) Brzeski, 1991 (16,19,27); synonyms include *Merlinius brevidens* [Allen, 1955] Siddiqi, 1970, and *Tylenchorhynchus brevidens* Allen, 1955. This species has been associated with roots of many grass, cereal, vegetable, legume, brassica, fruit, and fiber crops (30), and was first reported in the United States on wheat in Texas in 1959 (21). Other species that have reduced wheat plant growth and yield include *T. brevilineatus* (39), *T. dubius* (12,28), and *T. vulgaris* (23,24). Wheat plants parasitized by stunt nematodes may exhibit a chlorosis of lower leaves and reduction in plant height, tillering, head size, and kernel size (19).

Peak stunt nematode population densities may occur at varying soil depths depending on tillage systems and crop rotations. Populations of *T. dubius* were highest in the surface 25 to 28 cm of soil, and the vertical distribution within this profile was relatively stable throughout the year (2,28). Detection of these ectotrophic species is most efficient by extracting juvenile and adult stages from soil. Eggs are released into soil as females feed on roots. A juvenile stage is released as the egg hatches, and each juvenile stage molts

three times before reaching the adult stage. As many as three reproductive cycles may occur each crop year. While mating requirements differ among species, certain species such as *G. brevidens* and *Tylenchorhynchus clarus* Allen, 1955 are nearly always extracted from soil only as females that reproduce by parthenogenesis. Males of both species are either absent or rare.

Stunt nematodes of undetermined identity were detected in 78% of southeastern Idaho fields (38) and 35% of eastern Oregon and Washington fields (34) planted to cereals. In a more comprehensive survey of southern Idaho and eastern Oregon counties, Hafez et al. (8) detected *G. brevidens* in 15% of fields planted to wheat and in 38% of all fields planted to field, pasture, vegetable, and horticultural crops (8). One or more of nine *Tylenchorhynchus* spp. also were detected in 10% of wheat crops and 15% of all fields sampled (8). Most fields sampled in the Oregon and Washington survey (34) were planted annually to no-till spring cereals, a cropping system that favors development of high populations of stunt nematodes (40). The population density for stunt nematodes in Oregon and Washington was as high as 2,430/kg of soil in fields planted to no-till spring cereals (34). While this population clearly exceeded damage thresholds reported elsewhere (16,19,24,28), the importance of stunt nematodes on field crops has not been investigated in the Pacific Northwest.

This paper reports relationships between stunt nematodes and wheat yields in four field experiments at two Oregon farms where soils were infested by *G. brevidens* and at one farm, also with *T. clarus*.

MATERIALS AND METHODS

Field experiments were performed during 2001 and 2002 on annually cropped fields at two farms in Union County, OR. The fields were at 825-m elevation in an area where annual precipitation averages 460 mm and mean air temperatures are -1°C in January and 18°C in July and August.

Experimental procedures. *Cuthbert Farm.* The Cuthbert Farm, 10 km northeast of La Grande, has a deep, well-drained Imbler fine sandy loam; a coarse-loamy, mixed, superactive, mesic Pachic Haploxerolls. The experiment was performed on a field that had been planted to winter wheat

Corresponding author: R. W. Smiley
E-mail: richard.smiley@oregonstate.edu

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during the autumn of 2000, after stubble of a perennial fine-leaf fescue crop was turned under with a moldboard plow. The field was fertilized (16-20-0, at 85 kg N/ha) and disked before winter wheat was planted on 18 October 2000. Winter wheat in the experimental area was killed by glyphosate herbicide on 21 March 2001. The experiment consisted of six spring wheat cultivars, Alpowa, Frame, Krichauff, Molineux, Penawawa, and Spear, planted with and without aldicarb (Temik 15G) and replicated four times in a two-way randomized complete block design. Wheat seed was treated with tebuconazole plus metalaxyl (Raxil XT) to suppress seed rot and seedling damping-off. The trial was planted into 1.5 × 6.1 m plots on 16 April 2001 at 270 seeds/m² using a drill with a cone-seeder and four hoe-type openers at 36-cm row spacing. Starter fertilizer (16-20-0, at 11 kg N/ha) was applied by banding 2.5 cm below the seed at planting. Aldicarb was dispensed with the seed through the cone at 4.2 kg a.i./ha to reduce initial nematode populations (2). The field was irrigated with a center-pivot system, and weeds were controlled by hand weeding. After cutting 1-m alleys, yield was determined for 7.7 m² plots by machine harvest at maturity during mid-August.

During 2002, a second experiment was performed in an adjacent field that had been fertilized and planted to winter wheat the previous autumn: October 2001. The experimental area was sprayed with glyphosate and uniformly planted into 36 plots of spring wheat cv. Zak on 19 April 2002 without additional tillage or application of fertilizer. Half of the plots were treated with aldicarb at planting. The field was not irrigated during 2002. Plots were sampled and harvested as described for experiments during 2001.

Wallender Farm. The Wallender Farm, 11 km east-southeast of La Grande, has a poorly drained Hooley silt loam; a medial over loamy, mixed over isolic, nonacid, mesic Typic Endoaquands. The experiment on a center-pivot irrigated field at the Wallender Farm during 2001 was similar to that at the Cuthbert Farm, except that the field at the Wallender Farm had been planted annually to no-till winter wheat. The same six cultivars were planted into an area where winter wheat was killed with glyphosate on 21 March 2001. There were four replications, with and without aldicarb, for a total of 48 plots planted as a two-way randomized complete block design on 16 April 2001. Starter fertilizer was banded below the seed, as previously described.

A second experiment was performed at the same site during 2002. Volunteer wheat in the plot area was sprayed with glyphosate on 2 April 2002. Without tillage, the 48 plots were planted uniformly to spring wheat cv. Zak on 19 April 2002. Starter fertilizer (16-20-0, at 22 kg N/ha)

was applied by banding 2.5 cm below the seed at planting. Aldicarb was not applied during 2002. All plant and soil sampling, harvest measurements, and data analyses were performed to coincide with treatments applied to each specific plot during 2001.

Soil sampling and nematode extraction. Soil was collected before planting to assess plant-parasitic nematode populations in individual plots of all experiments. Soil was collected from marked plots usually within 2 days before being planted. Samples consisted of 15 to 20 cores (2.5 cm diameter × 20 cm deep) composited for each 10 m² plot. Samples were placed on ice in the field and in a refrigerated room (4°C) following collection and were stored for up to 14 days before being transported to the Oregon State University Nematode Testing Service at Corvallis.

Extractions of nematodes were performed using the standard "Whitehead-tray" method (10). Numbers of nematodes in each plant-parasitic genus or closely related genus complex were determined using standard morphological characteristics and measurements. Numbers are reported as nematodes per kilogram of oven-dry soil. During 2001 and 2002, the stunt nematode population density in each plot was not differentiated into specific genera or species. During 2003, a detailed identification of stunt nematode genera and species for each experimental location was performed by the Oregon State University Nematode Testing Service. The species identification was conducted on a composite sample for each location, derived by aggregating subsamples from every plot sampled at that location during April 2002.

Statistical analysis. Nematode populations were described as the range, mean, and standard deviations among plots in whole experiments or within cultivar and nematicide variables. Nematode populations were normalized by transformation ($\ln + 1$) prior to being subjected to analysis of variance using Co-Stat Statistical Software version 6.303 (CoHort Software, Monterey, CA). Nematode populations and grain yields were analyzed using the two-way randomized complete block model during 2001. When cultivar or aldicarb treatment effects were significant at $P < 0.05$, means were separated using the least significant difference test (LSD). The 2002 experiment at the Wallender Farm was also analyzed using the two-way randomized complete block model, based on potential residual effects from cultivars and aldicarb treatments applied during 2001, and planting a single wheat cultivar uniformly without additional treatment variables during 2002. The one-way randomized complete block model was used to analyze the nematicide variable at the Cuthbert Farm during 2002. During both years, associations between initial populations of nematodes and grain yields were evaluated by

regression analysis using a linear model for individual plots in whole experiments or within experimental variables. In selected instances, stepwise backward multiple regression analysis was utilized to determine if the association between yield and nematode population was strengthened by including multiple species of plant-parasitic nematodes in the analysis.

RESULTS

Cuthbert Farm. *G. brevidens* was the only stunt nematode species detected at the Cuthbert Farm. During 2001, the 48 plots had preplant populations ranging from 0 to 240/kg of soil; mean = 28 and standard deviation = 56. Populations did not differ for cultivar ($P = 0.84$) or nematicide treatment ($P = 0.43$). Grain yields averaged 4,003 kg/ha and did not differ among cultivars ($P = 0.09$) and were improved 17% by aldicarb treatment; 4,323 versus 3,682 kg/ha, $P = 0.0025$, $\text{LSD}_{0.05} = 258$. There was no significant interaction ($P = 0.16$) among cultivar and aldicarb treatments.

When wheat yield was regressed against initial nematode populations in all 48 plots, yield was weakly inversely correlated with *G. brevidens* ($P = 0.0350$, $r^2 = 0.09$) and *Pratylenchus neglectus* ($P = 0.0533$, $r^2 = 0.08$) but not *Heterodera avenae* ($P = 0.42$). When aldicarb-treated plots were analyzed separately, yield was not associated with populations of *G. brevidens* ($P = 0.97$), *H. avenae* ($P = 0.27$), or *P. neglectus* ($P = 0.40$). In control plots, wheat yield for the combined cultivars was more strongly inversely correlated with *G. brevidens* ($P = 0.0003$, $r^2 = 0.53$) (Fig. 1) than with *P. neglectus* ($P = 0.0467$, $r^2 = 0.18$) and was not associated with *H. avenae* ($P = 0.90$). The initial analysis showed the presence of two outliers in data presented in Figure 1. When outliers for *G. brevidens* populations exceeding 100/kg of soil were removed, the regression coefficient (r^2) was more modest; yield = $4,015 - 12.2x$; $r^2 = 0.21$, $P = 0.0315$, $n = 22$. When yields were regressed against multiple variables, the regression coefficient for *G. brevidens* alone (Fig. 1) was not improved by addition of other variables, such as *P. neglectus*.

For individual cultivars in control plots, significant negative correlations occurred between *G. brevidens* and yields of Alpowa ($P = 0.0103$, $r^2 = 0.98$) and Krichauff ($P = 0.0292$, $r^2 = 0.94$). These two varieties had initial *G. brevidens* mean populations of 35 and 60/kg of soil, with maximum densities of 140 and 240/kg, respectively. Yields of the other four cultivars were not correlated significantly with *G. brevidens*, and each was planted into plots with lower initial *G. brevidens* populations, with means <30/kg of soil and maximum populations <60/kg in individual plots.

During 2002, the *G. brevidens* population in 36 plots ranged from 0 to 380/kg of

soil; mean = 75, standard deviation = 101. Grain yield for this nonirrigated planting of spring wheat cv. Zak averaged 1,093 kg/ha and did not differ ($P = 0.06$) in aldicarb and control treatments; 1,146 and 1,040 kg/ha, respectively. Yield for all treatments was inversely correlated ($P < 0.0001$, $r^2 = 0.55$) with *G. brevidens*. Regression slopes for yield and *G. brevidens* populations differed ($P = 0.0315$) in aldicarb and control treatments (Fig. 2), indicating a greater impact of increasing *G. brevidens* population density in aldicarb-treated than in untreated soil. Yield was not correlated with *P. neglectus* in control ($P = 0.57$), aldicarb ($P = 0.18$), or combined ($P = 0.35$) treatments.

Wallender Farm. Stunt nematodes occurred as a mixture of 30% *G. brevidens* and 70% *T. clarus*. During 2001, the combined population ranged from 0 to 970/kg of soil; mean = 170, standard deviation = 245. Preplant populations differed significantly in plots subsequently divided into cultivar ($P = 0.0249$) but not aldicarb ($P = 0.38$) treatments. Mean populations were highest ($LSD_{0.05} = 194$) for plots planted to Krichauff (359) and Penawawa (236), intermediate for Molineux (188) and Spear (143), and lowest for Frame (78) and Alpowa (34).

Grain yields averaged 2,576 kg/ha and differed significantly among cultivar ($P = 0.0405$) and aldicarb ($P < 0.0001$) treatments. Plots treated with aldicarb yielded 24% more grain than the controls; 2,848 versus 2,304 kg/ha, $LSD_{0.05} = 173$. Average yields for Alpowa, Frame, Krichauff, Molineux, Penawawa, and Spear were 2,480, 2,362, 2,764, 2,530, 2,793, and 2,525 kg/ha, respectively; $LSD_{0.05} = 244$.

Yield for the combined cultivars was not correlated with *G. brevidens* plus *T. clarus* for the control ($P = 0.44$), aldicarb ($P = 0.15$), or combined ($P = 0.46$) treatments. Grain yield for Alpowa was significantly inversely correlated ($P = 0.0006$) with *G. brevidens* plus *T. clarus* (Fig. 3) when aldicarb and control treatments were grouped. Correlations were not significant for other cultivars, all of which had nematode population means and maxima higher than for Alpowa. Populations of *P. neglectus* were not significantly correlated with yields for any cultivar, and a very low population of *H. avenae* was detected in only one of 48 plots.

When individual cultivars were evaluated for aldicarb-treated plots, yields were not significantly correlated with the initial population of stunt nematodes; “*P*” values ranged from 0.18 to 0.96. When individual cultivars were evaluated for control plots, stunt nematodes were significantly inversely correlated with yield for Alpowa ($P = 0.0466$), Frame ($P = 0.0143$), and Spear ($P = 0.0432$), each of which had initial mean populations less than 100 nematodes/kg of soil; means and ranges were 40 (0–100), 88 (0–250), and 95 (0–

Fig. 1. Relationship between grain yield for six spring wheat cultivars and preplant population of *Geocenasus brevidens* in control plots (not treated with aldicarb) at the Cuthbert Farm during 2001.

Fig. 2. Relationship between grain yield for spring wheat cv. Zak and preplant population of *Geocenasus brevidens* at the Cuthbert Farm during 2002; data are from aldicarb (a) and control (c) treatments, with slopes of regression lines differing at $P = 0.0315$.

Fig. 3. Relationship between grain yield for spring wheat cv. Alpowa and preplant population of *Geocenasus brevidens* (30%) plus *Tylenchorhynchus clarus* (70%) in plots subsequently treated with aldicarb (a) or left untreated (c) while planting at the Wallender Farm during 2001.

380), respectively. Stunt nematodes in the control plots were not significantly correlated with yield for Krichauff ($P = 0.58$), Molineux ($P = 0.50$), and Penawawa ($P = 0.57$), each of which had mean initial populations exceeding 100 nematodes/kg of soil and minimum numbers exceeding 60 nematodes/kg of soil; means and ranges were 527 (150–970), 110 (60–160), and 323 (160–400), respectively. When yields for each cultivar were regressed against populations of multiple nematode species, there was no relationship more significant than the association with the *G. brevidens* and *T. clarus* mixture.

During 2002, the mixed population ranged from 0 to 980/kg of soil, with a mean of 162/kg and standard deviation of 243. Following the treatments applied during 2001, there were no significant differences among nematode populations in plots treated with aldicarb ($P = 0.19$) or for cultivar variable ($P = 0.42$). Likewise, these variables did not have significant effects on the apparent reproductive ratio P_f/P_i , where P_f was the preplant population during 2002 and P_i was the preplant population in the same plots during 2001; $P = 0.20$ for cultivar treatments and $P = 0.25$ for aldicarb treatments. The P_f/P_i ratio was highest for plots that had the lowest initial populations during 2001, with the inverse correlation between P_f/P_i ratio and initial population significant at $P = 0.0503$.

Yield of Zak in this irrigated planting was very low (439 kg/ha) due to combined effects from two late-season frosts, one of which occurred immediately after an herbicide application that resulted in a pronounced phytotoxic response. Yield was inversely correlated with populations of *G. brevidens* plus *T. clarus* ($P = 0.0012$) (Fig. 4) but not *P. neglectus* ($P = 0.48$).

DISCUSSION

Yield of spring wheat was inversely correlated with populations of stunt nematodes at two locations during each of 2 years. *G. brevidens* was present at both

locations and was mixed with *T. clarus* at one location. No association between spring wheat yield and stunt nematode population was detected in 19 experiments of similar design at four locations where *T. clarus* was the only species of stunt nematode detected (unreported data). We conclude that *G. brevidens* but not *T. clarus* is responsible for suppressing yield of annual no-till spring wheat in eastern Oregon.

Four additional experiments, reported elsewhere (36,37), were also performed at the two *G. brevidens*-infested locations reported in this paper. Associations between stunt nematodes and yields were not detectable in the previously reported experiments, presumably because damage in those experiments was associated with the more aggressive plant-parasitic species *P. neglectus* (36) and *H. avenae* (37). Suppression of wheat yield by *G. brevidens* appeared to be detectable only when damage could not be associated with the more aggressive species.

Wheat yield was statistically ($P < 0.05$) greater (17 and 24%) following application of aldicarb in two of three experiments where the nematicide was applied while planting the current crop. Yield improvement (10%) in the third such experiment was significant at $P = 0.06$. At the single location where wheat was planted into the same experimental block during two consecutive years, and planted without application of additional variables during the second year, there was no detectable residual influence of aldicarb on the initial population of stunt nematodes prior to planting the second crop, one year following aldicarb application. Previous studies with aldicarb application have shown a near-tripling of yield at initial populations of 9,840 *T. vulgaris*/kg of soil (24).

Detection of plant damage by stunt nematodes is difficult. At high levels of parasitism, plants may become chlorotic and stunted, may produce fewer tillers and heads, and may tend to be aggregated into distinct patches (16,19). We did not observe definitive symptoms in the plant

canopy during experiments reported here. Plants parasitized by *G. brevidens* are also characterized as having fewer and shorter roots but no distinct lesions or premature necrosis of root tissue (16,19). Roots in our experiments were excavated to evaluate symptoms of diseases caused by soil-borne root-infecting fungi (25). During the course of those evaluations (unreported data), there were no distinct abnormalities noted on roots that could be definitively attributed to damage by *G. brevidens*, but we did not attempt to quantify possible differences in root diameters or lengths.

Studies of stunt nematodes on wheat have shown a large divergence in apparent damage threshold, presumably depending on differences in local characteristics of soil, plants or plant cultivars, experimental conditions, and possibly also the aggressiveness of different populations. In controlled-environment experiments, a population density of approximately 1,200 *G. brevidens*/kg of soil reduced weights of wheat roots and shoots by 40% (19). In a similar experiment, a population of about 660 *G. brevidens*/kg did not cause stunting, whereas populations greater than 2,000/kg were associated with severe plant stunting and reduced wheat yield (16). In field studies, populations exceeding 2,000 *G. brevidens*/kg were associated with plant stunting and reduced grain yield (13). Wheat growth was reduced by 40 and 24% in the presence of *T. dubius* at 67/kg of soil (28) and 5,000/kg of soil (12), respectively. The damage threshold for *T. vulgaris* on wheat occurred between 200 and 1,500/kg of soil (24).

In our studies, inverse associations between wheat yield and population densities of *G. brevidens* appeared to occur at very low initial population densities. During 2001, a *G. brevidens* population exceeding 30 to 50/kg of soil was associated with yield suppression in the sandy loam at the Cuthbert Farm. Populations higher than 100 to 200/kg appeared necessary to suppress yields at the same location during 2002. In the silt loam at the Wallender Farm, correlations between yield and populations of the *G. brevidens* + *T. clarus* mixture occurred only when the initial population was between 0 and 60/kg and did not occur when the initial population was higher than 60/kg. Although reasons for this observation are unclear, it appears that in this soil, under the restricted crop growth conditions experienced during 2001, initial mean populations of stunt nematodes higher than 100/kg may have induced a uniform suppression of wheat growth in a manner suggestive of a saturation response. It is also possible that this observation may have been an anomaly resulting from the spatial heterogeneity which led to significant differences in preplant populations in plots planted to individual cultivars at the Wallender Farm during 2001. This appears likely because

Fig. 4. Relationship between grain yield for spring wheat cv. Zak and preplant population of *Geoclenamus brevidens* (30%) plus *Tylenchorhynchus clarus* (70%) at the Wallender Farm during 2002.

yield of a single cultivar at the same site during 2002 was negatively correlated with increasing populations of the *G. brevidens* plus *T. clarus* mixture over the full range of initial population densities. Additional research in the Pacific Northwest is required to examine this possibility and particularly to establish more precise estimates of thresholds for economic damage.

Patel and Thakar (24) suggested that wheat cultivars differed in tolerance to parasitism by *T. vulgaris*. In our experiments with six cultivars during 2001, the cultivar Alpowa was significantly negatively correlated with stunt nematode populations in control plots (without aldicarb treatment) at both locations. Additionally, the cultivar Krichauff was also negatively correlated with *G. brevidens* population at the Cuthbert Farm but not with the mixed population of *G. brevidens* and *T. clarus* at the Wallender Farm. In contrast, in addition to Alpowa, cultivars negatively associated with *G. brevidens* plus *T. clarus* at the Wallender Farm but not the Cuthbert Farm included Frame and Spear. Differences in response of the six cultivars at each location appeared to relate more to heterogeneity in initial density of stunt nematodes in individual plots than to genetic traits for the cultivars examined in these experiments. Nevertheless, these experiments were not adequately replicated over locations and years to identify possible differences in cultivar responses to damage by *G. brevidens*.

Langdon et al. (16) reported that damage caused by *G. brevidens* alone was less severe than when soils were infested with both *G. brevidens* and *Olpidium brassicae*, an obligate parasitic protista (fungus-like organism). Boag et al. (3) also concluded that yield reductions were more likely from combined populations of *Pratylenchus*, *Tylenchorhynchus*, and other genera than from individual genera of plant-parasitic nematodes. When we regressed yield against multiple measures of root damage attributable to various soilborne plant-pathogenic fungi (unreported) and populations of all extractable plant-parasitic nematode genera, we found no association that was more important than for stunt nematodes alone.

Distribution of *G. brevidens* in the Pacific Northwest has not been reported. Identifications of stunt nematode species were not performed during surveys of plant-parasitic nematodes in Idaho (38) and in Oregon and Washington (34). Stunt nematode species identified in a survey of Idaho and eastern Oregon (8) were reported by crop association but not geographic location. In our experiments in eastern Oregon, *G. brevidens* was detected in an area characterized by fewer growing-degree days and lower January temperatures than for four locations where *T. clarus* but not *G. brevidens* was detected. These temperature characteristics are ma-

jo determinants for distinguishing geoclimatic zones in the western United States (11). The region where *G. brevidens* was detected has a 30-year mean average 820 growing-degree days (0°C base) from 1 January to 1 May (calculated from <http://pnwpest.org/wea/>, Integrated Plant Protection Center, Oregon State University, Corvallis), which is comparable to the range of values (417 to 964) occurring in locations where *G. brevidens* was detected by Hafez et al. (8). We detected only *T. clarus* at four locations characterized by an average of 1,100 to 1,250 growing-degree days from 1 January to 1 May. Minimum and maximum mean daily January temperatures are several degrees lower in the area where we detected *G. brevidens* compared to *T. clarus* (calculated from <http://www.ocs.oregonstate.edu/prism/>; 7). These distinctions are of interest because maximum multiplication rates for *G. brevidens* (18) occur at lower temperatures (10 to 20°C) than for *T. clarus* (20 to 35°C). By applying these growing-degree-day and temperature calculators to areas where *G. brevidens* has been detected in this and previous studies, it is clear that this species causes economic damage in regions characterized by colder (6,14), equally cold (16,17,27), and warmer (15,19,21,31,40) winters than those where *G. brevidens* was or was not detected in Oregon. Additionally, distribution maps for these species in California (31) indicate that the occurrence of *G. brevidens* extends into colder regions than *T. clarus* in California, and that each species is distributed throughout warmer regions of that state. It therefore appears that temperature relationships detected in our study are unlikely to be a major single determinate of the distribution of *G. brevidens* in Oregon or elsewhere in the Pacific Northwest. More likely, the distribution pattern we observed was an artifact relating to site-selection criteria designed to examine damage relationships for *H. avenae* (37), *P. neglectus* (36), and *P. thornei* (35).

Crop management practices that minimize damage from *G. brevidens* have not been studied in the Pacific Northwest. Crops that favor efficient multiplication of this species include wheat, barley, oats, and field pea (17). Poor hosts include alfalfa, potato, and sugar beet (17). Populations of *G. brevidens* decline rapidly in the absence of a host (19), indicating that populations may be expected to be higher in annual crops than in 2-year rotations of winter wheat with summer fallow. Also, populations become higher and potentially more damaging in no-till than in cultivated fields (40). Management of *G. brevidens* population density is particularly important during the seedling growth stage (19). Aldicarb and other nematicides are not registered for this use on wheat in the United States.

Soil samples for this investigation were collected to a depth of 20 cm, consistent

with shallow depths (15 to 25 cm) reported previously (12,14,21,28) but not as deep (50 to 150 cm) as for some studies (2,8,40). Stunt nematodes are vertically distributed to considerable depth in soil, but their population is generally greatest in the upper 25 cm (2,12,28). Sampling protocols in our experiments were considered adequate for characterizing relative differences in nematode species and populations in large numbers of plots.

This paper presents the first evidence that *G. brevidens* is associated with suppression of wheat yield in the Pacific Northwest. This report supplements previous evidence that wheat is damaged by *H. avenae* (33,37), *P. thornei* (35) and *P. neglectus* (36), and a complex of fungi (*Fusarium*, *Pythium*, *Rhizoctonia*, and *Gaeumannomyces* spp.) in the Pacific Northwest (25,32). Additional research is needed to more fully describe the importance of *G. brevidens* in the complex of root- and crown-infecting fungi and plant-parasitic nematodes affecting wheat in the northwestern United States.

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