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Root-lesion nematodes

Biology and management in Pacific Northwest wheat cropping systems

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Nematodes are tiny but complex unsegmented roundworms that are anatomically differentiated for feeding, digestion, locomotion, and reproduction. These small animals occur worldwide in all environments. Most species are beneficial to agriculture. They make important contributions to organic matter decomposition and to the food chain. Some species, however, are parasitic to plants or animals.

Plant-parasitic nematodes in the genus *Pratylenchus* are commonly called either root-lesion nematodes or lesion nematodes. These parasites can be seen only with the aid of a microscope. They are transparent, eel-shaped, and about 1/64 inch (0.5 mm) long. They puncture root cells and damage underground plant tissues, which reduces plant vigor, causes lesions, and predisposes plants to infection by root-infecting fungi. Root-lesion nematodes obtain sustenance only from living root tissues but may survive from crop to crop in dead root debris and in soil. They are capable of multiplying in a wide range of monocot and dicot host species.

Plant-parasitic nematodes are difficult to identify, to control, and to demonstrate as the cause of important crop damage. Root-lesion nematodes have been detected in approximately 90 percent of fields sampled in Idaho, Montana, Oregon, and Washington. Potentially damaging high population densities have been detected in as great as 60 percent of fields sampled in some regions. A particular challenge with root-lesion nematodes is that the symptoms on small grain cereals are non-specific and are easily confused with other ailments such as nitrogen deficiency, low water availability, and the root rots caused by fungi such as *Pythium*, *Rhizoctonia,* and *Fusarium*. Farmers, pest management advisors, and scientists routinely underestimate or fail to recognize the impact of root-lesion nematodes on wheat. It is now estimated that these root parasites reduce annual statewide wheat yields by about 5 percent in each of the Pacific Northwest (PNW) states of Idaho, Oregon and Washington. This generally unrecognized pest therefore reduces annual wheat profitability by about $51 million in the PNW.

Description

There are nearly 70 species in the genus *Pratylenchus*. At least eight of those species are parasitic to wheat. Four species (*P. crenatus*, *P. neglectus*, *P. penetrans*, and *P. thornei*) occur throughout the world in temperate cereal-producing regions. All four are present in the PNW but *P. neglectus* and *P. thornei* are the two species that are most prevalent and are also most often associated with yield losses in wheat fields. These two species are commonly the only *Pratylenchus* species in dryland wheat fields and are also present in many irrigated fields. They occur as mixtures of species in some fields but it is more common to detect only one or the other of these species in an individual field. *Pratylenchus neglectus* occurs more commonly than *P. thornei* and has caused losses up to 50 percent in Oregon. However, *Pratylenchus thornei* is generally considered more damaging than *P. neglectus* and has reduced yields as much as 85 percent in Australia, 70 percent in Israel, 50 percent in Oregon and 37 percent in Mexico. *Pratylenchus penetrans* is often the most prevalent species in irrigated sandy soils.

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Biology

Pratylenchus species have a vermiform (eel- or pencil-shape) body (Figures 1 and 2) that measures about 0.5 mm (1/64 inch) long and 0.02 mm (1/1000 inch) in diameter. For comparison, the diameter of a human hair is about five times (0.1 mm) greater than the diameter of a root-lesion nematode.

Root-lesion nematodes are classified as migratory endo- and ecto-parasites, meaning that they may become entirely embedded within root tissue ("endoparasitic") and migrate from cell to cell within that tissue, and that they also may feed on the root surface without actually moving from the rhizosphere into the internal root tissue ("ectoparasitic'). Root-lesion nematodes never lose the ability to leave the root to migrate back into soil. Root-lesion nematodes possess a stylet (Figure 1) that allows them to puncture, feed upon, and penetrate cells of the root epidermis and the root cortex. These nematodes have the ability to enter mature as well as immature segments of roots.

Root-lesion nematodes feed only on living root tissue but may deposit eggs in soil as well as inside root tissue (Figure 2). Females deposit about one egg per day and first-stage juveniles molt to become second-stage juveniles within the egg. One second-stage juvenile emerges from each egg about one week after the egg is deposited. Three additional molts within 35 to 40 days result in the adult stage. All juvenile and adult stages are parasitic. The number of nematodes in root tissue increases greatly during the growing season.

Pratylenchus neglectus and *P. thornei* are parthenogenic, meaning that females produce fertile eggs without copulation with a male. Populations of these two species are comprised nearly or entirely of females. In contrast, *P. penetrans* is an amphimictic species, meaning that a male and female must mate before fertile eggs are produced. Populations of *P. penetrans* therefore include nearly equal proportions of males and females.

Life cycles range from 45 to 65 days depending upon temperature, moisture and other environmental variables. Reproduction of *P. neglectus* and *P. thornei* is greatest at temperatures between 68°F and 77°F but may continue slowly at soil temperatures as low as 45°F. These species are therefore well adapted for multiplication during most of the year, especially at soil depths greater

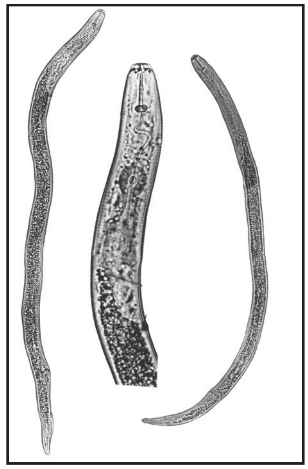

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Figure 1. (left) Photomicrograph of root-lesion nematodes. The center image, at higher magnification, shows the anterior end with the nematode's feeding stylet and esophagus. Figure 2. (right) The wheat root cortex tissue stained to reveal the presence of *Pratylenchus thornei* females and eggs.

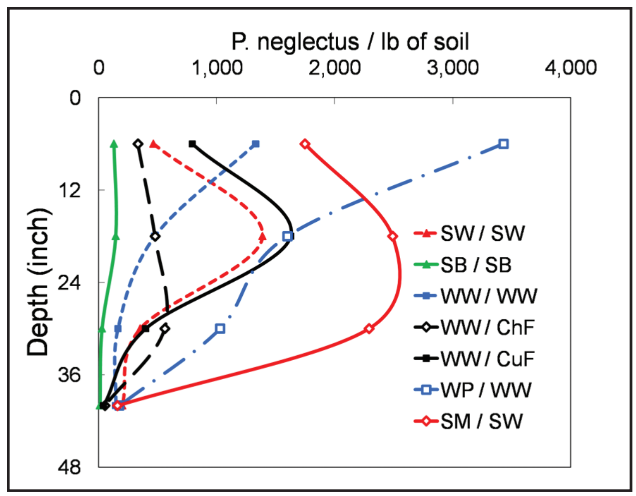

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Figure 3. *Pratylenchus neglectus* **population densities at 1-foot depth increments in soils after two years of selected treatments in a long-term experiment at Moro, Oregon; including no-till spring wheat (SW), no-till spring barley (SB), no-till winter wheat (WW), winter wheat rotated with winter pea (WP) or with cultivated (CuF) or chemical fallow (ChF), and spring wheat following spring mustard (SM).**

than one foot, where temperatures throughout the year are typically a rather constant 50°F to 55°F. Maximum population densities in fields with deep silt loams have been measured at soil depths as great as the third foot (Figure 3).

Pratylenchus neglectus and *P. thornei* are not strongly restricted by soil type and may attain damaging population levels even in the very driest (10-inch annual precipitation) of rainfed wheat fields. They have been detected in silt loams, clay loams, and irrigated sandy loams. Large population densities have been detected throughout the depth of root growth in deep soils. These nematodes are well adapted to survive between crops in the dead roots and in soil. Nematode survival through very dry conditions occurs in an inactive, dehydrated state called anhydrobiosis. Individuals that enter living roots after emerging from anhydrobiosis often multiply more rapidly than individuals that had not been subjected to this dormancy condition. Population levels of *Pratylenchus* often decline during long fallow periods between crops but high rates of survival have also been reported at soil depths greater than six to ten inches, particularly in fields where weeds or volunteer cereals (i.e., any green growth) are allowed to become established between the times of harvest and planting.

Symptoms

Root-lesion nematodes cause degradation of cells in the epidermis and cortex of underground plant organs (Figure 4). These activities reduce the amount of root branching and the ability of roots to absorb water and nutrients. Damaged wheat plants are less capable of extracting soil water and exhibit stress and wilting earlier than undamaged plants as soil moisture becomes limiting for plant growth. Experience in Oregon has shown that winter wheat may fail to extract all of the available soil water when roots are infested by high numbers of root-lesion nematodes. Plants that become subjected to true drought stress late in the growing season are even more likely to suffer yield loss.

Penetration of root tissues by root-lesion nematodes results in lesions that favor greater colonization by root-rotting fungi and by saprophytic bacteria, fungi, and nonparasitic nematodes. These secondary organisms cause more intense rotting and discoloration than that caused by the root-lesion nematode alone. Cortical degradation and reduced root branching often are not visible until plants are six or more weeks old, and these root symptoms are often confused with those caused by Pythium or Rhizoctonia root rot. Interactions of root-lesion nematodes, fungal pathogens, other plant-parasitic nematodes, and insect pests have been reported.

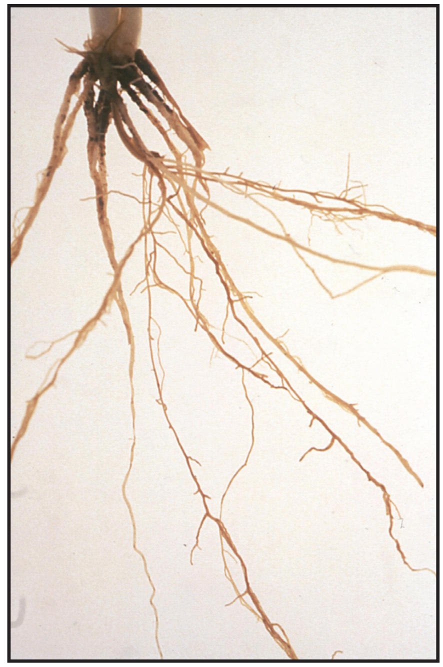

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Figure 4. Damage to wheat roots caused by root-lesion nematodes, showing a general absence of branch roots along the main root axis and a "thin" appearance of roots caused by degradation of the epidermal and cortical tissues.

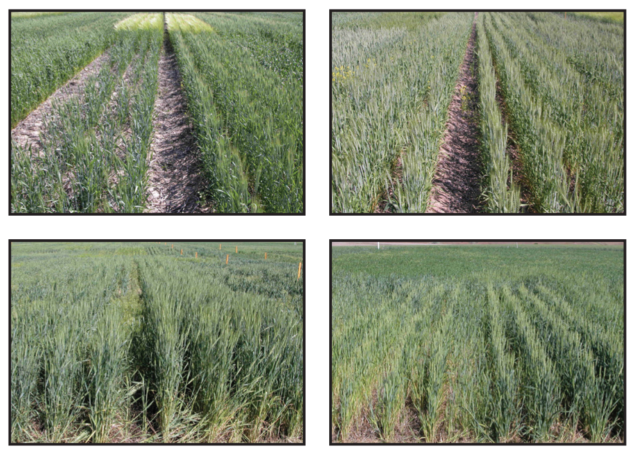

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Figure 5. Wheat growth and development in soils infested with *Pratylenchus* and either treated (drill strip on right) or untreated (drill strip on left) with an experimental nematicide at the time of planting; (top row) Alpowa (left) and Penawawa (right) spring wheat in *P. neglectus*-infested soil near Heppner, Oregon, and (bottom row) Weston (left) and Brundage 96 (right) winter wheat in *P. thornei*-infested soil near Pendleton, Oregon. Compared to plants in treated drill strips, plants in untreated drill strips were stunted, had fewer tillers that were less upright, and had smaller and later-emerging heads. Note also the chlorosis of lower leaves in untreated Brundage 96, and the uniform growth of Camas barley in both drill rows behind the Alpowa plots.

Foliar symptoms are non-specific (Figure 5). Intolerant plants with roots heavily damaged by root-lesion nematodes may exhibit yellowing and premature death of lower leaves, poor vigor, stunting, reduced tillering, reduced grain yield and grain quality, and an increased foliar temperature, reflecting impaired leaf cooling due to restricted water uptake. Affected areas of fields appear generally unthrifty, yellow (especially lower leaves), or droughty. Symptoms of nematode damage can easily be confused with symptoms of nutrient deficiency, drought, root disease, or barley yellow dwarf. For instance, fields with high populations of root-lesion nematodes often have plant canopies that are irregular in height and maturation, as also occurs in plants affected by Rhizoctonia root rot.

Yield Reduction

Yields of a single variety may be negatively correlated with the population density of root-lesion nematodes at the time of planting (Figures 6–8). It cannot be proven, however, that yield reductions are caused by root-lesion nematodes without the aid of a nematicide (Figures 9 and 10), soil fumigation, or wheat varieties that have consistently high levels of tolerance to the *Pratylenchus* species present in a particular field. Relationships between the number of root-lesion nematodes and the wheat yield potential are difficult or impossible to generalize over large regions because yield responses are influenced strongly by a multitude of interacting climate, plant, and soil factors.

Damage thresholds are commonly defined for insect pests but this crop management concept is affected too greatly by soil and plant factors to be of particular value for defining the potential for damage by a specific population level of a root-lesion nematode. For instance, the damage threshold for numbers of nematodes will be decreased when plant growth is stressed by drought, poor soil nutrition, impediments to root penetration, or adverse temperature. The threshold numbers will be increased by partial or full genetic tolerance reactions within a given cultivar and by a plentiful supply of water and nutrients. The economic threshold for damage is therefore expected to be lower for low-rainfall environments than for crops produced with supplemental irrigation or in areas of greater precipitation especially during the growing

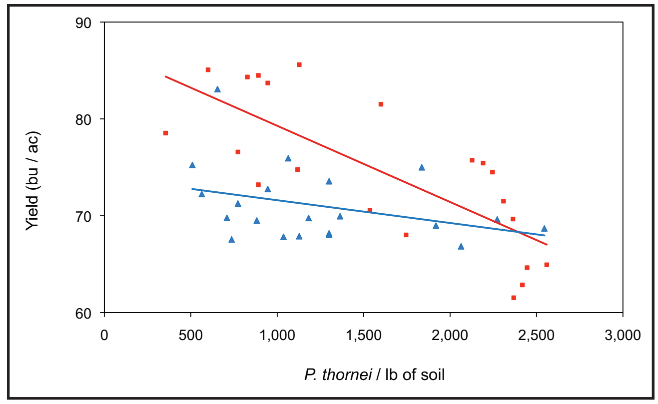

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Figure 6. Influence of *Pratylenchus thornei* on yield of Zak spring wheat in two experiments at Pendleton, Oregon.

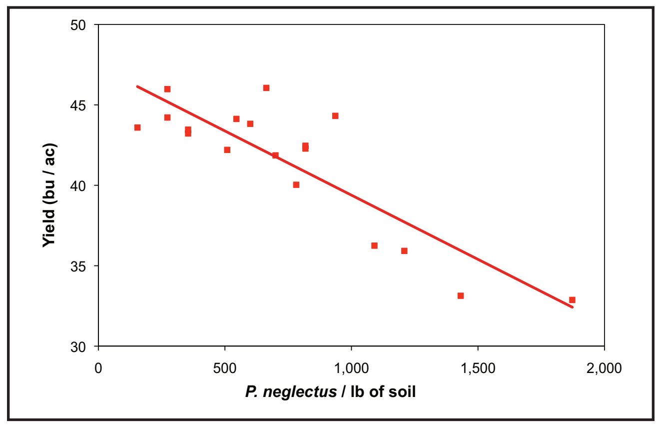

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Figure 7. Influence of *Pratylenchus neglectus* on yield of Zak spring wheat at Moro, Oregon.

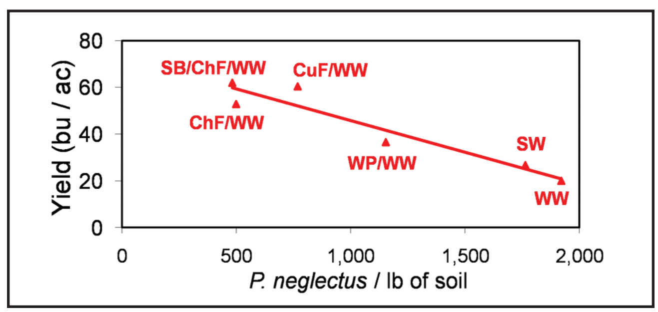

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Figure 8. Influence of *Pratylenchus neglectus* on the yield of winter wheat in seven crop-rotation and tillage-management treatments averaged over four crop years in a long-term experiment at Moro, Oregon; including no-till annual spring wheat (SW), no-till annual winter wheat (WW), winter wheat rotated with winter pea (WP/WW), winter wheat rotated with cultivated (CuF/WW) or chemical fallow (ChF/WW), and a no-till rotation of spring barley, chemical fallow and winter wheat (SB/ChF/WW).

season. Research in Oregon over the past decade has indicated that reduced wheat yields can generally be demonstrated wherever the root-lesion nematode density at any depth in the soil profile exceeds 1,000 nematodes per pound (quart) of soil (Figures 6–8). Limited surveys have found that these population densities are exceeded in as many as 60 percent of fields sampled in major wheat-producing regions of Idaho, Montana, Oregon, and Washington.

Damage caused by root-lesion nematodes is likely to be greater where there are limited rotation and cultivar selection options, a situation that is particularly acute in rainfed cereal monocultures, which by definition includes the "rotation" of winter wheat with summer fallow.

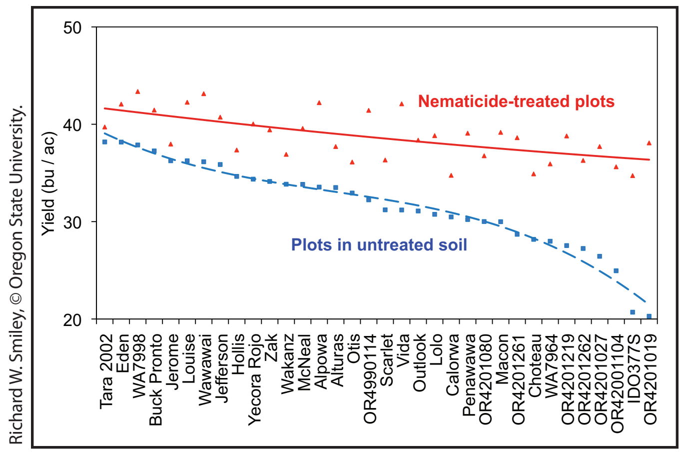

Figure 9. Grain yields averaged over two-years for selected spring wheat varieties and lines produced in a field infested with *Pratylenchus neglectus* near Heppner, Oregon (dotted line), as compared to adjacent plots of the same varieties and lines planted into soil that was treated with an experimental nematicide (solid line) to reduce numbers of the nematode.

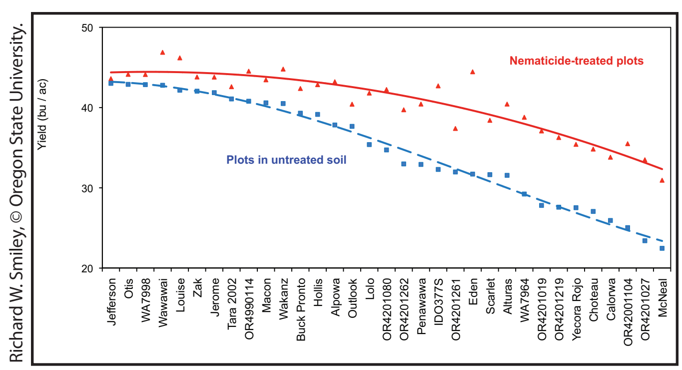

Figure 10. Grain yields averaged over two-years for selected spring wheat varieties and lines produced in a field infested with *Pratylenchus thornei* near Pendleton, Oregon (dotted line), as compared to adjacent plots of the same varieties and lines planted into soil that was treated with an experimental nematicide (solid line) to reduce numbers of the nematode.

Crop Management

Management of root-lesion nematodes includes an integration of field sanitation, crop rotation, genetic resistance, and genetic tolerance. *Pratylenchus neglectus* and *P. thornei* are often more damaging to crops in drier regions, and management options are also generally more limited in low-rainfall regions than in irrigated fields or high-rainfall regions.

Field sanitation during the fallow phase is as important as during the in-crop phase because root-lesion nematodes have a very broad host range. The *Pratylenchus* species that are dominant in the PNW multiply on many genera of broadleaf and grass weeds commonly occurring in the region. They also multiply very efficiently on volunteer oats, wheat, and triticale. The presence of a susceptible weed or crop species between planted crops allows *Pratylenchus* to increase population density over a greater interval of the cropping system. At least some grasses and forbs planted into fields as part of the Conservation Reserve Program (CRP) also serve as hosts for *Pratylenchus neglectus* but this relationship has not been examined for *P. thornei*. The hosting ability of individual weed species, CRP plants, and crops other than wheat has not been evaluated in the PNW but information from other countries suggests that most weeds and crop species in the PNW are likely to be susceptible and capable of maintaining or increasing the density of root-lesion nematodes in soil. Management of damage by crop rotation is possible only if resistant alternate crops such as flax, safflower, triticale, or barley are profitable for growers. However, results from the overseas studies have also indicated that the hosting ability varies among varieties of both legumes and cereals and for each variety, may differ for each individual *Pratylenchus* species. Therefore, very detailed studies of hosting ability must be conducted in the PNW before specific risk indices and management guidelines can be presented.

Successive or frequent crops of susceptible wheat varieties may elevate densities of *P. neglectus* and *P. thornei* and thereby increase the level of risk for damage to subsequently planted crops of intolerant species. Many varieties of mustard, canola, lentil, and chickpea also increase the population growth of *P. neglectus* or *P. thornei*, with multiplication capacities differing greatly for each combination of *Pratylenchus* species and host variety. Most growers in low-rainfall regions produce mostly winter or spring wheat under cultivated or direct-drill (no-till) conditions. Tillage has not had an appreciable effect on density of *Pratylenchus* in PNW soils. It appears that the greatest impact of conservation cropping systems is not associated with the presence, absence, or intensity of tillage but is more likely associated with the frequency and duration of growth by host crops and weeds or volunteer, as well as the time when crops are planted. Direct-drill systems are often planted later in the fall or earlier in the spring compared to cultivated cropping systems. Seedling roots of crops in cultivated soil are therefore subjected to longer periods of warmer temperature at shallow soil depth compared to seedlings planted without primary tillage. The rate of root-lesion nematode reproduction and the rate of nematode activities such as migration and root penetration are greater at warmer than cooler temperatures, as discussed earlier.

Damage by root-lesion nematodes is likely to become highest where susceptible and intolerant wheat varieties are produced annually or in rotation with summer fallow or susceptible crops such as canola, mustard, chickpea, field pea, or lentil. Likewise, root-lesion nematode population densities are likely to be increased when volunteer wheat and/or weed species are allowed to grow during the winter and early spring between spring wheat crops or during the sanitizing "fallow" interval of the winter wheat-summer fallow rotation. From the perspective of a root-lesion nematode, any susceptible plant that grows during the unplanted interval in a field converts a wheat-fallow system into an annual cropping system, and an annual spring cropping system into a double cropping system.

Wheat varieties with both resistance and tolerance are being developed to increase the production efficiency in fields with high numbers of root-lesion nematodes. Resistance is a measure of the ability of nematodes to multiply in the roots. Roots of resistant plants are invaded and damaged by the nematode but do not allow the nematode population to increase. Resistant plants therefore reduce the population density that may affect the following crop. However, roots of some resistant wheat varieties may be very sensitive (intolerant) to the initial invasion by the root-lesion nematode, resulting in reduced growth and yield. Resistant plants can therefore be either tolerant or intolerant because tolerance and resistance are genetically independent. Tolerance is a measure of the ability of plants to yield acceptably even when root-lesion nematodes are present. Tolerance therefore measures the yielding capacity of the current crop but has no bearing on the potential for damage to the following crop because tolerant plants can be either resistant or susceptible. When tolerant varieties are susceptible they may produce expected (normal) yields but allow the nematode to multiply and pose a higher risk to subsequent crops. Tolerance alone is therefore not considered an effective long-term management strategy. Management of root-lesion nematodes will require development of wheat varieties that are both resistant and tolerant. However, varieties with resistance to *P. neglectus* are not necessarily resistant to *P. thornei*, and vice versa. Likewise, varieties tolerant to *P. neglectus* are not necessarily tolerant to *P. thornei*, and vice versa. All combinations of resistance and tolerance are therefore possible within a collection of wheat varieties.

All wheat varieties tested thus far in the PNW are susceptible to both *P. neglectus* and *P. thornei* (Figure 11). They allow these nematodes to increase in number with each crop cycle. Sources of resistance to each *Pratylenchus* species have been identified and

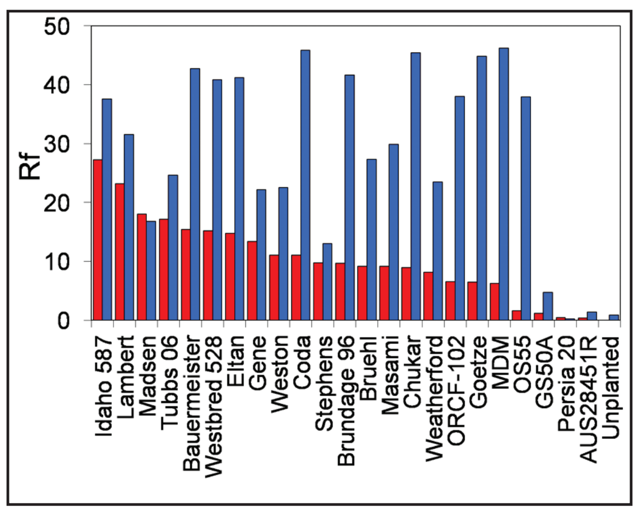

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Figure 11. Susceptibility of 20 Pacific Northwest winter wheat varieties to multiplication of *Pratylenchus thornei* (left) and *P. neglectus* (right), as compared to unplanted soil and three resistant lines (GS50A, Persia 20, and AUS28451R) being used in the breeding program; Rf is the 'reproductive factor' calculated from the ratio (Pf/Pi) of the final nematode population (Pf) after 16 weeks plant growth and the initial nematode population density (Pi) at the time when the seed was planted.

several lines are especially interesting because they exhibit resistance to both species (Figure 11). These sources of dual-species resistance have been crossed with PNW wheat varieties to eliminate in the future the need for farmers to identify *Pratylenchus* to the species level before selecting a variety with resistance and tolerance to a specific nematode species.

Spring wheat and barley varieties tested in the PNW vary in tolerance to *P. neglectus* and *P. thornei* (Table 1 and Figures 9 and 10). Varieties classed as tolerant or moderately tolerant to both *Pratylenchus* species in Oregon include Buck Pronto, Hollis, Jefferson, Jerome, and Tara 2002. Varieties classed as highly intolerant of one or both *Pratylenchus* species include Choteau, IDO377S, Lolo, McNeal, and Penawawa. Some varieties vary in response to invasion by these nematode species, as has been exemplified by the greater tolerance of Alpowa, Macon, and IDO377S to *P. thornei* than to *P. neglectus*, and of the much greater tolerance of Calorwa to *P. neglectus* than to *P. thornei*.

The barley varieties Camas and Bob are tolerant of both *Pratylenchus* species and these varieties generally performed better than most spring wheat varieties. Camas was clearly the most tolerant of barley varieties tested, and Radiant was the least tolerant of the spring barley varieties.

Distinguishing among tolerance levels in fall-planted cereals has been unsuccessful thus far. It is believed that varieties may actually vary in tolerance but that the method used to protect seedling roots and thereby differentiate tolerance levels among spring cereals is not effective for winter cereals, probably because the growing season for spring cereals is only half that for winter cereals. Additional research is needed to overcome this difficulty in defining tolerance differences among winter wheat varieties.

Other management practices are less effective in managing *Pratylenchus* populations. These nematodes are transmitted in all manners in which soil is moved from location to location. Common means of transport are with soil adhering to equipment, vehicles, animals, humans (boots), and plant products. *Pratylenchus neglectus* and/or *P. thornei* have been detected in approximately 90 percent of the fields sampled throughout the PNW. Field sanitation will provide some level of protection to fields not already infested by these parasites but the value of field and equipment sanitation is limited.

Table 1. Yields and tolerence ratings for common varieties

	Percent yield increase†		Tolerance rating‡	
Variety or line	*P. neglectus*	*P. thornei*	*P. neglectus*	*P. thornei*
Camas §	7.1	3.9	T	VT
WA8569-99 §	9.9	10.8	T	MT
Buck Pronto	12.9	9.3	MT	T
Hollis	12.6	11.7	MT	MT
Tara 2002	13.3	5.5	MT	T
Bob §	14.0	4.3	MT	VT
WA15279-00 §	14.4	9.1	MT	T
Jerome	14.9	7.1	MT	T
WA7998	15.5	9.5	MI	T
WA10701-99 §	15.5	14.4	MI	MT
Jefferson	15.8	5.6	MI	T
Louise	18.0	17.0	MI	MI
Wawawai	18.1	8.9	MI	T
Zak	18.6	6.3	MI	T
Otis	18.7	8.8	MI	T
Radiant §	19.5	17.8	MI	MI
Wakanz	20.5	14.1	MI	MT
Scarlet	26.6	17.6	MI	MI
OR4990114	26.6	14.9	MI	MT
Macon	26.7	8.5	MI	T
Eden	26.6	33.3	MI	I
Yecora Rojo	26.9	26.1	MI	MI
Vasco	28.1	24.8	MI	MI
Pelsart	28.6	10.0	MI	T
Calorwa	29.2	29.6	MI	MI
Vida	29.9	9.6	MI	T
Alpowa	31.7	10.6	I	MT
WA7964	33.2	25.8	I	MI
Outlook	33.2	19.6	I	MI
Alturas	33.7	24.8	I	MI
Krichauff	35.2	39.1	I	I
OR4201080	35.6	16.4	I	MI
Penawawa	35.8	22.1	I	MI
Choteau	36.0	29.6	I	MI
OR4201261	37.0	13.7	I	MT
Lolo	38.9	19.5	I	MI
OR4201262	41.5	15.2	I	MI
Sunvale	48.1	23.5	I	MI
McNeal	49.9	28.2	I	MI
OR4201219	55.1	29.3	VI	MI
OR4201027	55.4	35.9	VI	I
OR42001104	57.6	38.5	VI	I
Machete	61.2	39.0	VI	I
IDO377S	83.0	27.6	VI	MI
OR4201019	98.7	33.6	VI	I
$LSD_{0.05}$	35.4	17.1		

† Comparison of yields in nematicide-treated versus untreated plots in naturally infested soils; yield increase = 100 × (yield in soil treated with nematicide – yield in untreated soil) / yield in untreated soil). Data are means of two years of testing for *P. neglectus* and three years for *P. thornei*.

‡ Tolerance rating, based upon yield response to nematicide application: VT = very tolerant (<5% yield response), T = tolerant (5-10%), MT = moderately tolerant (10-15%), MI = moderately intolerant (15-30%), I = intolerant (30-50%), VI = very intolerant (>50%).

§ Barley varieties or lines (6); all others are spring wheat.

There are no chemicals or biological agents currently available to control damage caused by root-lesion nematodes in wheat. Chemical nematicides are effective and are widely used in research but are currently not economically feasible, registered, or environmentally appropriate for managing these parasites on wheat. Biological control agents are also not commercially available for *Pratylenchus* species on wheat. Additional research is being performed to determine if chemical or biological options can be developed as components of integrated management tactics in the future.

Green-manure crops are used as bio-fumigants to sanitize soils in regions where water is not a limiting factor for wheat growth. When green tissue from a bio-fumigation crop is macerated and incorporated into soil the toxic products generated during the degradation of that tissue in soil are often capable of reducing the nematode density in soil. However, several *Pratylenchus* species are capable of multiplying in roots of potential bio-fumigant crops such as sudan grass and mustard. If these crops are grown to maturity for seed or forage harvest, as often occurs in low-rainfall environments, populations of root-lesion nematodes may remain high or even become elevated during the production of those crops.

Sampling

Nematode detection and identification requires the services of a professional nematologist. Samples must be collected and handled carefully because the diagnostic procedure in some labs is based upon the collection of living nematodes that migrate from moist soil or moist roots into a container, from which they are identified and quantified. These nematodes can be killed by improper handling, such as over-heating the samples by leaving them for short periods in direct sunlight or in a car trunk. Population densities of root-lesion nematodes are determined by extracting the nematodes from root segments as well as from soil.

Samples for root-lesion nematodes must be taken to a depth of at least 12 inches in deep silt loams because these nematodes may be found as deep as six feet and the maximum population density may vary from the first to the third foot of depth, depending upon variables such as intensity of surface cultivation, type of crop, and seasonal rainfall. Sampling to a depth of 18 inches provides a more precise evaluation than samples collected to 12-inch depth. If unfamiliar with nematode sampling procedures, one should contact the nematode testing lab for instructions on how to collect and handle samples.

Two commercial and two university labs that provide nematode testing services in the PNW are shown below.

Nematode Identification

Identification of *Pratylenchus* to the species level is currently an essential prerequisite for a control tactic that is based upon selection of a tolerant variety. However, identification is difficult because there are few morphological characteristics of taxonomic value for rapidly and accurately differentiating the *Pratylenchus* species present in most PNW soils. Diagnostic labs therefore usually identify *Pratylenchus* nematodes only to the genus level and do not differentiate species as a regular component of the testing service. Molecular procedures using a single DNA extract from soil will soon be available to precisely differentiate and quantify individual species of root-lesion nematodes. One of the commercial nematology labs listed here is already using this advanced diagnostic technique to differentiate species of other parasitic nematodes and fungal pathogens.

Nematode Testing Labs

1. Kuo Testing Labs (2 locations), 1300 6th Street, Umatilla, OR 97882 and 337 South 1st Avenue, Othello, WA 99344. 800-328-0112. http://kuotesting.com
2. OSU Nematode Testing Service, 1089 Cordley Hall, Corvallis, OR 97331. 541-737-5540. http://www.science.oregonstate.edu/bpp/Nematodes/contact.htm
3. University of Idaho, Parma Research and Extension Center, Parma, ID 83660. 208-722-6701.
4. Western Laboratories, 211 Highway 95, Parma, ID 83660. 208-722-6564. http://www.westernlaboratories.com

For More Information

Castillo, P., and N. Vovlas. 2007. *Pratylenchus*, Nematoda, Pratylenchidae: Diagnosis, biology, pathogenicity and management. *Nematological Monographs and Perspectives* 6:1–530.

Hafez, S.L., A.M. Golden, F. Rashid, and Z. Handoo. 1992. Plant-parasitic nematodes associated with crops in Idaho and Eastern Oregon. *Nematropica* 22:193–204.

Handoo, Z.A., and A.M. Golden. 1989. A key and diagnostic compendium to the species of the genus *Pratylenchus Filipjev*, 1936 (lesion nematodes). *Journal of Nematology* 21:202–218.

Johnson, W.A. 2007. Discovery and distribution of root lesion nematode, *Pratylenchus neglectus*, in Montana. M.S. Thesis. Montana State University, Bozeman.

Mai, W.F., H.H. Lyon, and K. Loeffler. 1996. *Plant-parasitic Nematodes: A Pictorial Key to Genera*, 5th ed. Ithaca, NY: Cornell University Press.

Smiley, R.W., K. Merrifield, L.-M. Patterson, R.G. Whittaker, J.A. Gourlie, and S.A. Easley. 2004. Nematodes in dryland field crops in the semiarid Pacific Northwest USA. *Journal of Nematology* 36:54–68.

Smiley, R.W., J.G. Sheedy, and S.A. Easley. 2008. Vertical distribution of *Pratylenchus* spp. in silt loam soil and Pacific Northwest dryland crops. *Plant Disease* 92:1662–1668.

Smiley, R.W., R.G. Whittaker, J.A. Gourlie, and S.A. Easley. 2005. *Pratylenchus thornei* associated with reduced wheat yield in Oregon. *Journal of Nematology* 37:45–54.

Smiley, R.W., R.G. Whittaker, J.A. Gourlie, and S.A. Easley. 2005. Suppression of wheat growth and yield by *Pratylenchus neglectus* in the Pacific Northwest. *Plant Disease* 89:958–968.

Smiley, R.W., and S. Machado. 2009. *Pratylenchus neglectus* reduces yield of winter wheat in dryland cropping systems. *Plant Disease* 93:263–271.

Smiley, R.W. 2009. Root-lesion nematodes reduce yield of intolerant wheat and barley. *Agronomy Journal* 101:1322–1335.

Smiley, R.W., and J.M. Nicol. 2009. Nematodes which challenge global wheat production. p. 171–187 in *Wheat Science and Trade*, B.F. Carver (ed.), Wiley–Blackwell, Ames, IA.

Strausbaugh, C.A., C.A. Bradley, A.C. Koehn, and R.L. Forster. 2004. Survey of root diseases of wheat and barley in southeastern Idaho. *Canadian Journal of Plant Pathology* 26:167–176.

Yan, G.P., R.W. Smiley, P.A. Okubara, A. Skantar, S.A. Easley, J.G. Sheedy, and A.L. Thompson. 2008. Detection and discrimination of *Pratylenchus neglectus* and *P. thornei* in DNA extracts from soil. *Plant Disease* 92:1480–1487.

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