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Root-lesion nematodes:

Biology and management in Pacific Northwest wheat cropping systems

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Nematodes are microscopic 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 are important members of the soil food chain. However, some species 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. Feeding by these nematodes 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 plant host species.

Plant-parasitic nematodes are difficult to identify and control. It is also difficult to show that they are the cause of crop damage. Root-lesion nematodes have been detected in as many as 90 percent of fields sampled in regions of Idaho, Montana, Oregon, and Washington. In some of these regions, potentially damaging, high population densities have been detected in as many as 60 percent of fields. A particular challenge with root-lesion nematodes is that the symptoms on small grain cereals are nonspecific and easily confused with other ailments such as nitrogen deficiency, low water availability, and 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 wheat yields by about 5 percent annually in each of the Pacific Northwest (PNW) states of Idaho, Oregon, and Washington. This generally unrecognized pest annually reduces wheat profitability by as much as $51 million in the PNW.

Description

There are nearly 70 species in the genus *Pratylenchus*, at least eight of which 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 most prevalent and most often associated with yield losses in wheat fields. The focus of this publication is on these two species, which are the only important *Pratylenchus* species that occur in dryland wheat fields and in many irrigated fields. *Pratylenchus neglectus* and *P. thornei* occur as a mixture in some fields, but it is more common to detect only one or the other species in an individual field. *Pratylenchus thornei* is generally considered more damaging than *P. neglectus*; it has reduced yields by as much as 85 percent in Australia, 70 percent

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in Israel, 50 percent in Oregon, and 37 percent in Mexico. *Pratylenchus neglectus* occurs more commonly than *P. thornei* and has also been shown to cause yield losses up to 50 percent in Oregon. *Pratylenchus penetrans* is often the most prevalent species in irrigated, sandy soils, but this species is seldom detected in non-irrigated soils.

Biology

Pratylenchus species have a vermiform (worm-shaped) body (Figure 1) that measures about $^{1}/_{64}$ inch (0.5 mm) long and $^{1}/_{1000}$ inch (0.02 mm) in diameter. For comparison, the diameter of a human hair is $^{1}/_{32}$ inch (0.1 mm), or about five times greater than the diameter of a root-lesion nematode. As with all plant-parasitic nematodes, root-lesion nematodes have a stylet (Figure 2) that allows them to puncture and penetrate cell walls, inject enzymes that liquefy the cellular cytoplasm, and ingest the cytoplasm. The stylet enables these nematodes to feed on cells of the root epidermis and the root cortex.

Root-lesion nematodes are classified as migratory ecto-endoparasites. Ectoparasitic activity describes feeding on root hairs and root epidermal cells without moving into the internal root tissue. This is characteristic of juvenile root-lesion nematode feeding behavior. Endoparasitic activity describes the ability of a nematode to penetrate and enter through the cell wall and become entirely embedded within a cell. As the nematode exhausts the supply of nutrients within a cell, it migrates to other cells of the root epidermis and root cortex. These nematodes have the ability to enter mature as well as immature segments of roots. Root-lesion nematodes never lose the ability to leave the root and migrate back into soil.

Root-lesion nematodes feed only on living root tissue and may deposit eggs inside root cells (Figure 1) as well as in soil. At appropriate soil temperatures, 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 capable of feeding on and entering plant roots. The number of nematodes in root tissue increases greatly during the growing season. Densities of several thousand nematodes per gram of dry root tissue are common. These nematodes destroy root cells and therefore reduce the capacity of the plant to extract water and nutrients from the soil.

Image courtesy of Dr. Vivien Vanstone, Western Australia Department of Agriculture, South Perth, Western Australia.

Figure 1. Adult female and eggs of a root-lesion nematode (*Pratylenchus neglectus*) in the root cortical tissue. The nematode and eggs are transparent but were stained blue to reveal their presence in the root. The length of the adult female is about $^{1}/_{64}$ inch (0.5 mm).

Image courtesy of Dr. Lynn Carta, USDA-Agricultural Research Service, Beltsville, MD.

Figure 2. A root-lesion nematode (*Pratylenchus neglectus*). The hollow, protrusible stylet is thrust in and out of the nematode body very rapidly to: 1) penetrate cell walls, 2) inject enzymes to liquefy the cytoplasm, and 3) extract the cytoplasm from the plant cell. The length of the stylet is about 0.005 inch (16 microns).

Pratylenchus neglectus and *P. thornei* are parthenogenic, meaning females produce fertile eggs without mating with a male. Populations of these two species have few or no males. In contrast, *P. penetrans* is an amphimictic species, meaning that a male and female must mate before fertile eggs are produced.

Pratylenchus neglectus and *P. thornei* life cycles range from 45 to 65 days, depending on temperature, moisture, and other environmental variables. Reproduction of *P. neglectus* and *P. thornei* is greatest at temperatures between 68°F and 77°F (20°C and 25 °C) but may continue slowly at soil temperatures as low as 45°F (7°C). These species are therefore well adapted for reproducing during most of the year. For example, in Pendleton, Oregon, average monthly soil temperatures are above 65°F (18°C) at 4- and 8-inch depths for five months (May to September), and at 12- and 24-inch depths for four months (June to September). At each of these depths the mean monthly temperature is above 45°F (7°C) for eight months (April to December).

Pratylenchus neglectus and *P. thornei* are not strongly restricted by soil type and may attain damaging population levels in rainfed fields, even in low-precipitation regions. They have been detected in silt loam soils as well as in irrigated sandy loam soils. Large population densities have been detected throughout the depth of root growth in deep soils (Figure 3).

Pratylenchus neglectus and *P. thornei* are well adapted to survive between crop cycles in dead roots and in the soil. Nematodes survive through very dry conditions in an inactive, dehydrated state called anhydrobiosis. Individuals that enter living roots after emerging from anhydrobiosis often multiply more rapidly than those not 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 6 to 10 inches, particularly in fields where volunteer cereals or susceptible weed species establish and grow between the times of harvest and planting.

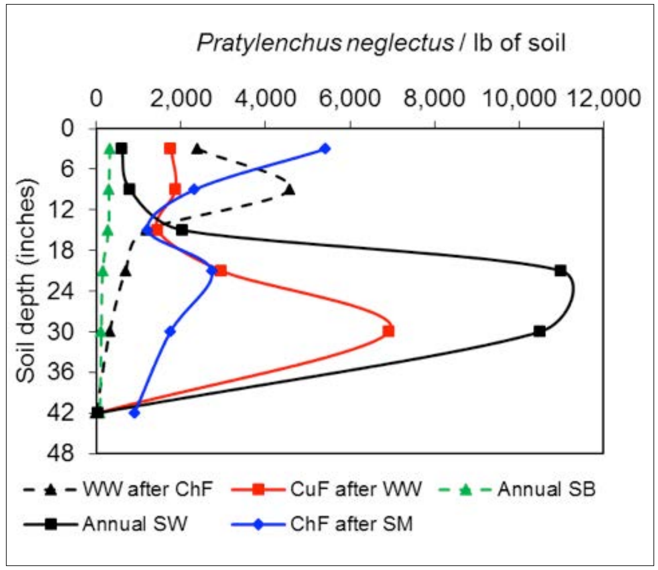

Figure 3. Variability of *Pratylenchus neglectus* density in soil profiles of five fields managed with different cropping systems in low-precipitation regions of Oregon. WW = winter wheat at Moro, SW = spring wheat at Moro, SB = spring barley at Moro, SM = spring mustard at Heppner, ChF = chemical fallow, CuF = cultivated fallow. Data markers are shown at the mid-point of each respective depth increment. Samples were collected at 6-inch intervals from 0- to 24-inch depths, and at 12-inch intervals from 24- to 48-inch depths. These profiles are used to illustrate the variability that may occur; this data does not necessarily represent the cropping systems from which this data were selected. In deep soils, the maximum nematode density may occur in the second or third foot of soil depth, which becomes important when determining the depth to which soils should be sampled for root-lesion nematodes.

Symptoms

Plants are not killed by *P. neglectus* and *P. thornei*, but destruction of root cells may occur throughout the life of the plant. Destruction of root cells by root-lesion nematodes greatly reduces the number of root hairs and the extent of root branching. Roots appear "thin" with few side branches from the main root axis (Figure 4, page 4). Plants with roots damaged by root-lesion nematodes exhibit nutrient and water stress earlier than undamaged plants, as damaged roots have a greatly reduced ability to extract water and nutrients from soil. Plants that become subjected to true drought stress late in the growing season are more likely to suffer yield loss because of prior root degradation by root-lesion nematodes. High densities of root-lesion nematodes in winter wheat roots may reduce the amount of water extracted from the soil by as much as 50 percent. The result is that more plant-available water remains in the soil and grain yields are more greatly reduced than if the same crop had been grown in the absence of root-lesion nematodes in the same field.

Penetration of root tissues by root-lesion nematodes results in lesions that encourage colonization by root-rotting fungi, bacteria that feed on dead or decaying organic matter, and nematodes that are not parasitic to plants. These secondary organisms cause more intense rotting and discoloration than

Photo courtesy of Dr. Vivien Vanstone, Western Australia Department of Agriculture, South Perth, Western Australia.

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.

Photo courtesy of Dr. Alison Thompson, USDA-Agricultural Research Service, Maricopa, AZ.

Figure 5. Roots of three spring wheat varieties grown in small cones of soil infested with high numbers of *Pratylenchus neglectus*; 'Louise' (left), 'AUS 28451' (center), and 'Alpowa' (right). Roots of 'Louise' and 'Alpowa' are blackened because of multiplication and cellular damage by the nematode. Roots of 'AUS 28451' remained white because *P. neglectus* caused very little cellular damage. 'AUS 28451' is a crossing parent to introduce resistance into varieties that are agronomically adapted to the Pacific Northwest (see also Figure 14).

that caused by the root-lesion nematode alone (Figure 5). 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 root rot or Rhizoctonia root rot. Interactions between root-lesion nematodes, fungal pathogens, other plant-parasitic nematodes, and insect pests have been reported.

Foliar symptoms are nonspecific. Intolerant plants with roots heavily damaged by root-lesion nematodes may exhibit yellowing and premature death of lower leaves, poor vigor, slight stunting, reduced tillering, reduced grain yield and grain quality, and an increased foliar temperature resulting from impaired leaf cooling due to restricted water uptake. Affected areas of fields appear unthrifty or droughty, often with yellow lower leaves. Fields with high densities of root-lesion nematodes (as well as soilborne fungal pathogens that cause similar symptoms, either alone or in combination with the nematode) often have plant canopies that are very irregular in height and maturation (Figure 6). Symptoms of nematode damage can easily be confused with symptoms of nutrient deficiency, drought, or root diseases.

Photo: Richard W. Smiley, © Oregon State University.

Figure 6. Winter wheat growth and development during the spring in a field infested with *Pratylenchus thornei* as well as a fungal root pathogen (*Pythium* spp.). Both pathogens cause similar types of root degradation and, when both are present, their combined effects may be more damaging to the root system.

Photos: Richard W. Smiley, © Oregon State University.

Figure 7. Wheat growth and development in soils infested with root-lesion nematodes and either treated with an experimental nematicide at the time of planting (4-row drill strip, on right in each image) or untreated (4-row drill strip, on left). Top: Alpowa spring wheat in *P. neglectus*-infested soil. Bottom: Weston winter wheat in *P. thornei*-infested soil. Compared to plants in treated drill strips, plants in untreated drill strips were stunted, had fewer tillers, and had smaller and later-emerging heads. Grain yields were 25 percent to 30 percent higher in plots treated with a nematicide, as compared to untreated plots that would mimic what a farmer would experience in that field.

Yield Reduction

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 by interactions with climate, plant and soil factors, and the occurrence of soilborne plant-pathogenic fungi. Proving whether yield reductions are caused by root-lesion nematodes requires a side-by-side comparison of growth in untreated soil with growth in soil (in an adjacent plot) that has been treated either with a nematicide (Figures 7-9) or with soil fumigation.

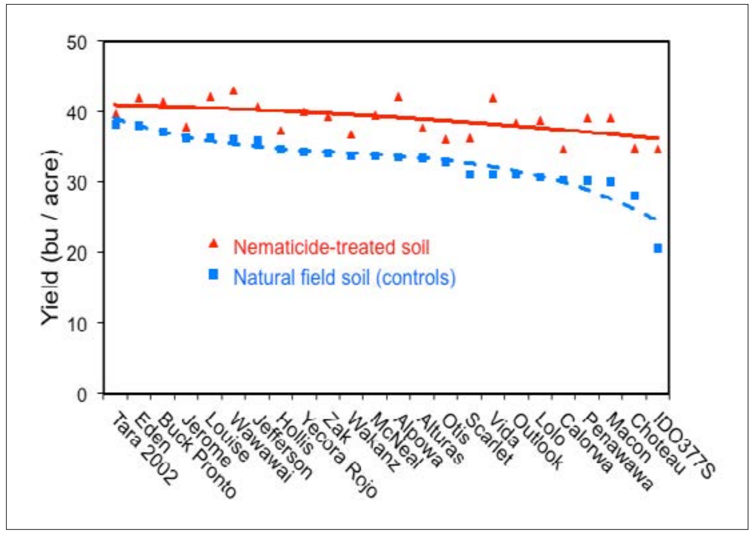

Figure 8. Grain yields averaged over two years for selected spring wheat varieties and lines produced in a field infested with *Pratylenchus neglectus* near Heppner, Oregon (dashed line), as compared to adjacent plots of the same varieties and lines planted into soil that was treated with an experimental nematicide (solid line) to reduce numbers of the nematode.

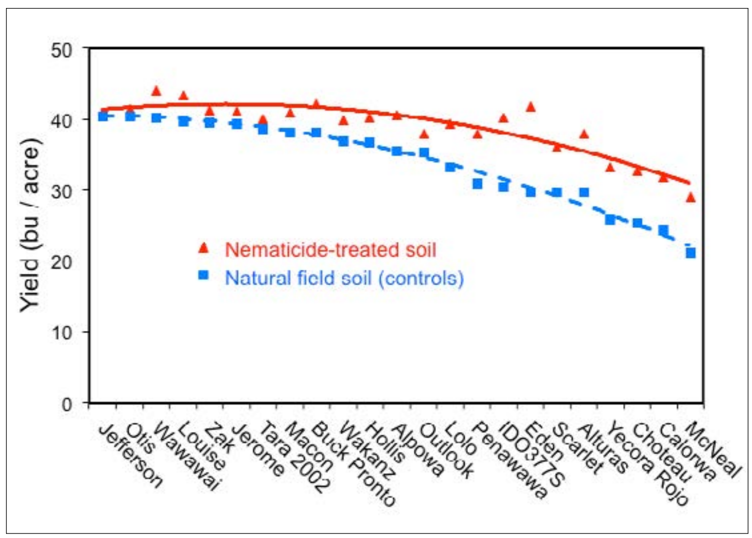

Figure 9. Grain yields averaged over two years for selected spring wheat varieties and lines produced in a field infested with *Pratylenchus thornei* near Pendleton, Oregon (dashed line), as compared to adjacent plots of the same varieties and lines planted into soil that was treated with an experimental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

Damage thresholds are commonly defined for insect pests. This approach, however, is not practical for defining damage by a specific population level of a root-lesion nematode because soil and plants are also factors. For instance, the damage threshold for numbers of nematodes will decrease when plant growth is stressed by drought, poor soil nutrition, impediments to root penetration, or adverse

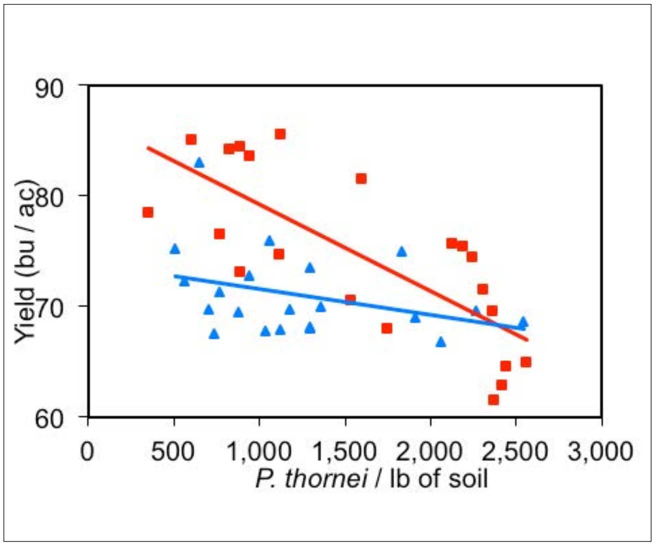

Figure 10. Influence of *Pratylenchus thornei* on yield of 'Zak' spring wheat in two experiments during 2003 in Pendleton, Oregon. The red line is an experiment in which spring wheat followed a previous crop of spring wheat, and the blue line is an experiment in which spring wheat followed chickpea.

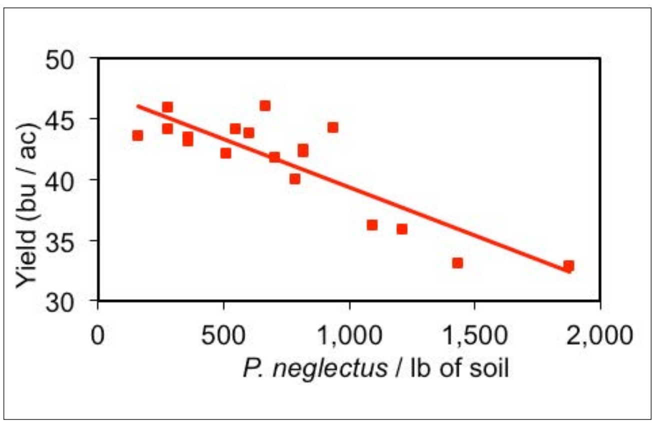

Figure 11. Influence of *Pratylenchus neglectus* on yield of 'Zak' spring wheat at Moro, Oregon.

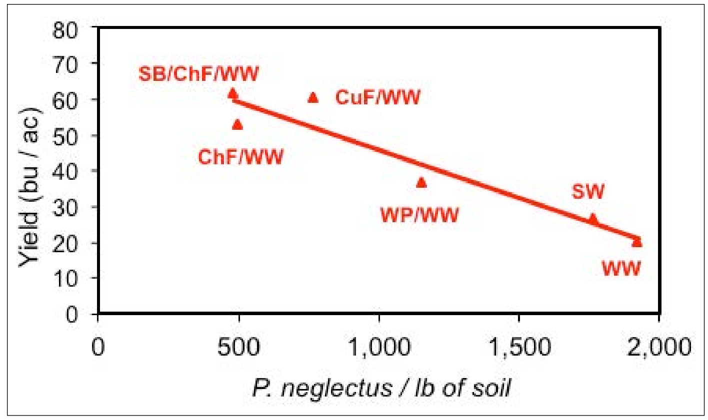

Figure 12. Influence of *Pratylenchus neglectus* on the yield of winter wheat in seven crop-rotation and tillage-management treatments averaged over four crop years in a long-term experiment at Moro, Oregon, including: no-till annual spring wheat (SW); no-till annual winter wheat (WW); winter wheat rotated 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).

temperature. The threshold numbers will increase if a variety has plentiful supplies of water and nutrients, particularly if it also has partial or full genetic tolerance. 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 late in the growing season. Research in Oregon 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 (about 1 quart) of soil (Figures 10-12). This relationship was determined by using small plots to associate grain yield with the nematode populations at the time the crop was planted. Limited surveys have found that in many fields in wheat-producing regions of Idaho, Montana, Oregon, and Washington, population densities exceed 1,000 nematodes per pound of soil at some portion of the soil profile.

Damage caused by root-lesion nematodes is likely to be greater where there are limited rotation and crop-variety options, which is particularly acute in rainfed cereal monocultures (e.g., the winter wheat-summer fallow "rotation"). Fields planted mostly with cereal crops, such as wheat, are often infested by fungal root pathogens as well as by root-lesion nematodes. Some combinations of fungal pathogens and nematodes can cause yield losses far greater than would be caused by each alone. Fields containing root-lesion nematodes and the fungi that cause Fusarium crown rot, Pythium root rot, and Rhizoctonia root rot are particularly common. A combination of *P. thornei* and *Fusarium culmorum* has been shown to cause reduction in the yield of dryland winter wheat (Figure 13, page 7) in an area of Iran, which has a climate similar to that of the inland PNW wheat-production region.

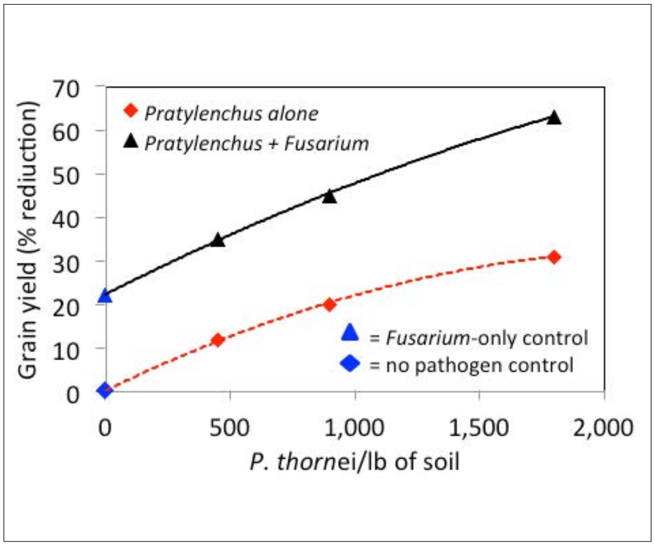

Figure 13. Percentage reduction in yield of winter wheat inoculated with *Pratylenchus thornei* (red dotted line) at four levels of initial inoculum density (0 to 1,800 nematodes/pound of soil) or inoculated with those same nematode densities plus a single rate of *Fusarium culmorum* (black solid line). The *F. culmorum*-alone control treatment is depicted as the blue triangle at the zero rate of nematode inoculation (e.g., a 22 percent reduction in yield of winter wheat by the fungal pathogen alone). Compared to pathogen-free soil (blue diamond), grain yield was reduced by 64 percent when the fungus and the nematode were both present at densities commonly encountered in PNW fields. Adapted from Hajihassani et al. (2013).

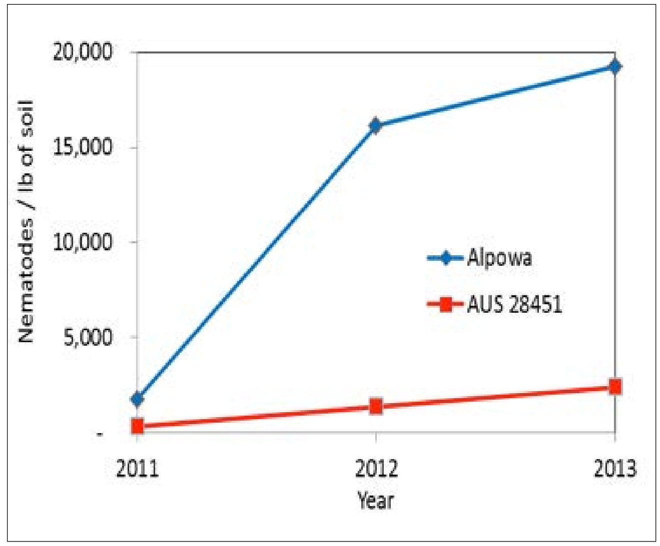

Figure 14. Density of the root-lesion nematode *Pratylenchus thornei* following harvest in a naturally infested field near Pendleton, Oregon. This chart compares nematode densities for replicated plots that were planted with either a susceptible spring wheat variety (Alpowa) or a breeding line (AUS 28451) that greatly reduces the rate of reproduction of this nematode.

Crop Management

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

Resistance and tolerance of wheat and barley

Resistance is a measure of the ability of nematodes to multiply in the roots. Roots of resistant plants are invaded and may or may not be damaged by the nematode but do not allow the nematode population to increase. Resistant plants, therefore, reduce the population density that may affect the health and yield of the next crop (Figure 14).

Tolerance is a measure of the ability of plants to yield acceptably, even when root-lesion nematodes are present. Tolerance measures the yield 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. Likewise, the 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.

Wheat varieties with both resistance and tolerance are being developed to increase the production efficiency in fields with high population densities of root-lesion nematodes. 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. Management of root-lesion nematodes will require development of wheat varieties that are both resistant and tolerant to both of the primary *Pratylenchus* species.

All spring and winter wheat varieties tested thus far in the PNW are susceptible to both *P. neglectus* and *P. thornei* (Tables 1 and 2). The wheat varieties allow these nematodes to increase in number with each crop cycle, until the nematode population reaches a plateau density, which varies based on the characteristics of the soil and climate. Most barley varieties do not allow the nematodes to reproduce as well as they do on wheat roots. Nevertheless, barley varieties are also variable in susceptibility to root-lesion nematodes (Table 3, page 9).

Spring wheat and spring barley varieties tested in the PNW vary in tolerance to *P. neglectus* and *P. thornei* (Table 4, page 9). Some varieties are tolerant or moderately tolerant to both *Pratylenchus* species, but other varieties are tolerant to only one of these nematode species. In particular, the barley varieties 'Camas' and 'Bob' are tolerant to both *Pratylenchus* species, and these varieties generally perform better than most spring wheat varieties. Distinguishing among tolerance levels in fall-planted

Table 1. Hosting ability ratings* of winter wheat varieties and lines

Winter wheat	*P. neglectus*	*P. thornei*
Hard red		
Bauermeister	VG	VG
Finley	VG	G
Weston	VG	VG
Hard white		
Gary	VG	VG
Golden Spike	VG	VG
MDM	VG	G
Soft white		
Bruehl (club)	VG	G
Brundage 96	VG	G
Cashup	VG	VG
Chukar (club)	VG	G
Coda (club)	VG	VG
Eltan	VG	VG
Finch	VG	VG
Gene	VG	VG
Goetze	VG	G
Idaho 587	VG	VG
Lambert	VG	VG
Madsen	VG	VG
Malcolm	VG	VG
Masami	VG	G
Moehler	VG	VG
ORCF-101	VG	G
ORCF-102	VG	G
ORSS-1757	VG	VG
Rod	VG	G
Simon	VG	G
Skiles	VG	VG
Stephens	G	G
Temple (club)	VG	VG
Tubbs	VG	VG
Tubbs 06	VG	VG
Weatherford	VG	G
Westbred 528	VG	VG

* Hosting ability ratings are based upon the reproductive factor (Rf) of the nematode as determined by replicated testing of each plant entry in greenhouse assays. The Rf is calculated as the final nematode density (Pf, nematodes/pound of soil) divided by the density of *Pratylenchus* initially added into soil (Pi, nematodes/pound of soil). Ranges of Rf values were then grouped to derive hosting ability ratings as follows; N = nonhost (Rf < 0.1), P = poor host (Rf = 0.1 to 0.9), M = minor host (Rf = 1.0 to 4.9), G = good host (Rf = 5.0 to 9.9), VG = very good host (Rf ≥ 10.0).

Table 2. Hosting ability ratings* of spring wheat varieties and lines

Spring wheat	*P. neglectus*	*P. thornei*
Hard red		
Buck Pronto	VG	M
Choteau	VG	M
Hollis	VG	M
Jefferson	VG	M
Jerome	G	M
McNeal	G	VG
Outlook	VG	G
Scarlet	VG	G
Tara 2002	VG	M
Vida	—	M
Yecora Rojo	VG	M
Hard white		
IDO377S	VG	M
Lolo	VG	G
Macon	VG	M
Soft white		
Alpowa	VG	M
Alturas	VG	G
Calorwa (club)	VG	M
Eden (club)	G	M
Louise	VG	G
Otis	VG	G
Penawawa	VG	G
Wakanz	VG	M
Wawawai	VG	VG
Zak	VG	VG

* Hosting ability ratings are as shown on Table 1.

cereals has been unsuccessful thus far. It is believed that varieties vary in tolerance but that the nematicide-comparison method used to estimate tolerance levels in spring cereals is not effective for winter cereals. This is likely because the growing season for spring cereals is only half as long as that for winter cereals, and the effect of a nematicide applied during the autumn does not last long enough to provide continuing protection against nematodes that invade roots during the spring. Additional research is needed to define tolerance differences among winter wheat varieties.

Landrace wheat lines (lines that are not adapted to local conditions) with resistance to both *P. neglectus* and *P. thornei* are important as crossing parents with agronomically adapted tolerant varieties (Figure 14). Landrace sources resistant to *P. neglectus* and *P. thornei* are being crossed with tolerant wheat varieties to achieve two objectives: resistance and tolerance to both nematode species. Varieties with resistance and tolerance to *P. neglectus* and *P. thornei* will reduce the nematodes' impact on yield and will eliminate the need for farmers to identify the *Pratylenchus* species present in a specific

Table 3. Hosting ability ratings* of barley varieties and lines

Feed barley	*P. neglectus*	*P. thornei*
2-row		
Baronesse	—	M
Bob	M	M
Camas	G	M
Luca	—	G
Merlin	—	M
Orca	—	M
Radiant	M	M
Waxbar	—	VG
6-row		
Doyce	—	VG
Hundred	G	M
Kold	G	G
Steptoe	—	VG
Strider	VG	G

Malting barley	*P. neglectus*	*P. thornei*
2-row		
Harrington	—	VG
6-row		
88 Ab 536	VG	VG
Eight-Twelve	G	M
J2-5-1	—	VG
J2-5-2	—	VG
S113/K50-21	—	M
Stab 113	VG	G
Stab 47/Kab 51-20	—	M
Stab 47/Kab 51-7	—	M
StabBC 182-6-5	—	M
StabBC 42-3-11	—	P
UTWB940628	—	M

* Hosting ability ratings are as shown on Table 1.

Table 4. Tolerance ratings* for spring wheat and spring barley varieties planted into fields infested with either *P. neglectus* or *P. thornei*

Crop and variety	*P. neglectus*	*P. thornei*
Barley		
Camas	T	VT
Bob	MT	VT
Radiant	MI	MI
Wheat		
Buck Pronto	MT	T
Hollis	MT	MT
Tara 2002	MT	T
Jerome	MT	T
Jefferson	MI	T
Louise	MI	MI
Wawawai	MI	T
Zak	MI	T
Otis	MI	T
Wakanz	MI	MT
Scarlet	MI	MI
Macon	MI	T
Eden	MI	I
Yecora Rojo	MI	MI
Vasco	MI	MI
Calorwa	MI	MI
Vida	MI	T
Alpowa	I	MT
Outlook	I	MI
Alturas	I	MI
Penawawa	I	MI
Choteau	I	MI
Lolo	I	MI
McNeal	I	MI
IDO377S	VI	MI

* Tolerance rating, based upon yield increase when varieties were planted side-by-side in replicated plots that were either treated with nematicide to reduce the influence of root-lesion nematodes, or were not treated with nematicide to determine what the farmer would experience in that field: VT = very tolerant (<5% yield increase from nematicide application), T = tolerant (5-10%), MT = moderately tolerant (10-15%), MI = moderately intolerant (15-30%), I = intolerant (30-50%), VI = very intolerant (>50%). Ratings were based upon results of two years of testing for *P. neglectus* (near Heppner, Oregon) and three years for *P. thornei* (near Pendleton, Oregon).

field, which is currently necessary before selecting a variety tolerant to a specific nematode species.

Resistance of other crops

Many varieties of mustard, canola, lentil, and chickpea also increase the population densities of *P. neglectus* or *P. thornei*. The reproduction capacity of root-lesion nematodes differs greatly for each combination of *Pratylenchus* species and plant variety (Table 5). Most growers in low-rainfall regions produce mostly winter or spring wheat under cultivated or direct-drill (no-till) conditions. 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 fields are therefore subjected to longer periods of warmer temperature at shallow soil depth compared to seedlings planted without primary tillage. As discussed earlier, the rates of root-lesion nematode reproduction and activities, such as migration and root penetration, are greater at warmer temperatures than at cooler ones. Damage by root-lesion nematodes is likely to become highest where susceptible and intolerant wheat varieties are produced annually or in rotation with susceptible crops such as canola, mustard, chickpea, field pea, or lentil.

Table 5. Hosting ability ratings* of crops other than wheat and barley

Crop	Variety	*P. neglectus*	*P. thornei*
Canola (spring)	Hyola 401	VG	M
Canola (spring)	Goldrush	VG	P
Canola (winter)	Amanda	VG	M
Canola (winter)	Dwarf Essex	VG	P
Canola (winter)	Salut	VG	M
Mustard (brown)	Pacific Gold	G	P
Mustard (yellow)	IdaGold	VG	M
Camelina	Yellowstone	VG	P
Camelina	Blaine Creek	VG	P
Camelina	Calena	G	M
Chickpea	Sierra	G	M
Chickpea	Myles	G	VG
Chickpea	Dwelley	M	M
Pea (green)	Journey	M	VG
Pea (yellow)	Universal	P	G
Pea (yellow)	Badminton	P	M
Pea (Austrian winter)	Granger	M	VG
Lentil (winter)	Morton	G	G
Lentil (spring)	Athena	G	VG
Lentil (spring)	Skyline	M	VG
Safflower (winter)	KN 144	M	M
Safflower (spring)	Gila	M	P
Safflower (spring)	Girard	M	P
Sunflower	2PD08	M	M
Flax	Pembina	P	P
Eastern gamagrass	Pete	P	P
Switchgrass	Blackwell	P	P
Sudangrass	Piper	VG	M
Sorghum/Sudangrass cross	Greentreat Plus	G	M
Oats	Monida	G	VG
Alfalfa	Don	M	M
Alfalfa	Ladak-65	P	P
Hairy vetch	Purple Bounty	G	M
Hairy vetch	Purple Prosperity	G	M

* Hosting ability ratings are as shown on Table 1.

Resistance of range grasses

Most range grasses are also good hosts for the reproduction of root-lesion nematodes. However, the level of susceptibility differs for each combination of grass variety and nematode species (Table 6, page 11). It is common to detect high populations of root-lesion nematodes when land is transitioned into the production of field crops after a long history of native sod or of grasses grown under contract for the USDA Conservation Reserve Program (CRP). Some first crops of wheat do not perform as well as expected following the transition from CRP. When attempting to determine the cause of poor performance in such crops, consider the possibility that root-lesion nematodes are present. If root-lesion nematode populations are high, a more tolerant and resistant crop, such as barley or one of the crops shown in Table 5, may be a better option to reduce the economic loss during the transition. This may also reduce the population density of the nematode and lower the risk of damage to a sensitive crop, such as wheat, that follows.

Resistance of weeds

Some weed species allow higher rates for reproduction of *P. neglectus* than of *P. thornei* (Table 6). In general, the weeds tested in the PNW are more favorable for reproduction of *P. neglectus*. However, the opposite is true for downy brome and rattail fescue, which favor the reproduction of *P. thornei*. Most notable is that jointed goatgrass is a very good host of both nematode species.

Control of weeds and volunteer cereals during the fallow phase of wheat-fallow rotations is as important as it is during the in-crop phase. Root-lesion nematode population densities may increase when volunteer wheat or susceptible weeds or both 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 nematode, the presence of living plants during the fallow phase of a rotation converts a two-year, wheat-fallow system into an annual cropping system, and an annual spring cropping system into a double cropping system. These possibilities occur because the nematodes may increase in population density during the 4 to 5 months (during the late fall or early winter) when volunteer cereals and weeds grow until they are killed in the spring for planting a spring crop or making land fallow. It is therefore important to prevent the occurrence of "greenery" in nonplanted fields during the winter to reduce the numbers of nematodes and to reduce the density of pathogenic fungi that cause diseases such as take-all, Pythium root rot, Rhizoctonia root rot, and Fusarium crown rot.

Susceptibility of downy brome to *P. thornei* and of jointed goatgrass to both *P. neglectus* and *P. thornei* pose the potential for additional concern when a field infested by either of these weeds is planted with a wheat variety that carries resistance to an imazamox herbicide. The reason for planting imazamox-resistant wheat varieties is to facilitate the application of that herbicide over the entire plant canopy to kill the weeds but not the wheat. If root-lesion nematodes have colonized the roots of both the weed grass and the wheat, the nematodes will not be killed by the herbicide but will migrate out of the dying roots of the weeds to look for a new source of sustenance provided by a nearby wheat root. Killing the infested weed may therefore encourage the transfer and concentration of even

Table 6. Hosting ability ratings[*] of cropland weeds and of selected range and USDA-Conservation Reserve Program grasses

Cropland weeds	*P. neglectus*	*P. thornei*	Range & CRP grasses	Variety	*P. neglectus*	*P. thornei*
Broadleaf			**Bluegrass**			
Common lambsquarters	M	P	Big	Sherman	VG	M
Dandelion	P	P	Thickspike	Critana	VG	VG
Horseweed	P	P	**Bromegrass**			
Kochia	VG	P	Smooth	Manchar	G	G
Palmer amaranth	G	P	**Fescue**			
Prostrate spurge	P	P	Hard	Durar	M	G
Redroot pigweed	G	P	Sheep	Blacksheep	M	G
Russian thistle	M	P	**Wheatgrass**			
Tumble mustard	G	P	Beardless	Whitmar	G	G
Grass			Crested	Fairway	VG	G
Downy brome	M	G	Crested	Hycrest	VG	VG
Green foxtail	VG	M	Intermediate	Greenar	G	G
Jointed goatgrass	VG	VG	Siberian	Vavilov	G	VG
Large Crabgrass	G	M	Snake River	Secar	VG	VG
Rattail Fescue	M	VG	Standard Crested	Nordan	G	VG
Wild oat	G	M	Tall	Alkar	G	M
			Western	Rosana	VG	M

[*] Hosting ability ratings are as shown on Table 1.

higher numbers of nematodes in the wheat roots. This should be considered among the possible explanations for low yield, if an imazamox-resistant variety fails to produce as much grain as had been anticipated.

Other management strategies

Management practices, other than crop rotation and use of resistant and/or tolerant varieties, are less effective in managing *Pratylenchus* populations.

Field sanitation will provide some level of protection to fields that are not already infested by root-lesion nematodes, but the value of field and equipment sanitation is limited. Root-lesion nematodes are transmitted when soil is moved from location to location, even by common means such as with soil adhering to equipment, vehicles, animals, humans (boots), and plant products.

Tillage has not had a significant effect on densities of root-lesion nematodes in PNW soils. It appears that the greatest impact of conservation cropping systems on root-lesion nematode density is not associated with the presence, absence, or intensity of tillage but instead with the time of year crops are planted, and the frequency and duration of growth of host crops, weeds, or volunteer cereals.

There are no chemicals or biological agents currently available to control damage in wheat caused by root-lesion nematodes. 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 economical and practical control of root-lesion nematode damage to wheat.

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. However, several *Pratylenchus* species can multiply in roots of potential bio-fumigant crops such as sudangrass and mustard (Table 5). 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 on the collection of living nematodes that migrate from moist soil or moist roots into a container. These nematodes can be killed by improper handling, such as overheating 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 the soil. The density of root-lesion nematodes is often greater in roots that appear healthy compared to those that are significantly deteriorated. This occurs because the nematodes move out of root cells that have become dysfunctional and migrate into cells or root segments that are still functional.

Samples of root-lesion nematodes can be taken at a depth of 12 inches in deep silt loams. However, nematodes may be found as deep as 6 feet, and the maximum population density may vary from the first to the third foot of depth (Figure 3), depending upon variables such as intensity of surface cultivation, type of crop, and seasonal rainfall. Therefore, sampling at a depth of 18 inches provides a more precise evaluation. If unfamiliar with nematode sampling procedures, contact a 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 listed at the end of this publication. Both commercial labs provide a courier service to transport samples.

Nematode Identification

Identification of the *Pratylenchus* species is essential for choosing a control tactic based on the tolerance of the cereal grain being planted. However, identification is difficult because there are few morphological characteristics to rapidly and accurately differentiate the *Pratylenchus* species present in most PNW soils. Therefore, diagnostic labs usually identify *Pratylenchus* nematodes only to the genus level and do not differentiate species as a regular component of their testing services. Molecular procedures using a single DNA extract from soil have been developed and are now available to differentiate and quantify individual species of root-lesion nematodes in a soil sample. One of the listed commercial nematology labs now provides a service that includes DNA-based diagnostic procedures to differentiate *P. neglectus* and *P. thornei*, as well as the species of cereal cyst nematodes and fungal pathogens.

Nematode testing labs

1. Kuo Testing Labs (two locations): 1300 6th Street, Umatilla, OR 97882 and 337 South 1st Avenue, Othello, WA 99344. 800-328-0112. http://kuotesting.com
2. Oregon State University Nematode Testing Service, 1089 Cordley Hall, Corvallis, OR 97331. 541-737-5255. http://plant-clinic.bpp.oregonstate.edu/nematodes
3. University of Idaho Parma Research and Extension Center, Parma, ID 83660. 208-722-6701. http://extension.uidaho.edu/parma/tag/nematology/
4. Western Laboratories, 211 Highway 95, Parma, ID 83660. 208-649-4360. http://www.western-laboratories.com (Services include DNA-based species identification.)

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For more information

OSU Extension Service

Plant-parasitic nematodes affecting small grain cereals in the Pacific Northwest (PNW 674). https://catalog.extension.oregonstate.edu/pnw674

Cereal cyst nematodes: Biology and management in Pacific Northwest wheat, barley, and oat crops (PNW 620). https://catalog.extension.oregonstate.edu/pnw620

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Use pesticides safely!

- Wear protective clothing and safety devices as recommended on the label. Bathe or shower after each use.
- Read the pesticide label—even if you've used the pesticide before. Follow closely the instructions on the label (and any other directions you have).
- Be cautious when you apply pesticides. Know your legal responsibility as a pesticide applicator. You may be liable for injury or damage resulting from pesticide use.

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