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Plant-parasitic nematodes affecting small grain cereals in the Pacific Northwest

Richard W. Smiley

Nematodes are roundworms with complex organ systems. They are not segmented and are therefore very different than the larger worms called earthworms.

Nematodes occur worldwide in all environments. Most species are beneficial to agriculture by contributing to decomposition of organic matter and nutrient cycling, and they are important in the soil food web.

Some nematode species are parasitic to plants or animals. More than 2,000 of the 20,000 identified nematode species are plant parasites. The plant-parasitic species cause estimated annual crop losses of $8 billion in the United States and $78 billion worldwide. Most plant-parasitic species live in the soil and are so tiny they can be seen only with the aid of a microscope.

Table 1 (page 2) lists plant-parasitic nematode species that may occur in Pacific Northwest (PNW) fields where small grain crops are produced. Cereal cyst and root-lesion nematodes cause most of the economic damage in the region. These species are estimated to reduce profits from wheat production by at least $54 million annually in the PNW.

Nematode biology

Feeding

Nematodes that parasitize plants have a specialized feeding tube called a stylet (Figure 1). The stylet is thrust rapidly in and out of the nematode body to penetrate the cell wall. The stylet then transfers the contents of plant cells to the nematode digestive system. Nematode species that are not parasitic to plants do not have a stylet.

Plant-parasitic species differ in the types of plant they must feed on in order to thrive. The plant-parasitic nematode is able to acquire energy for sustenance and reproduction only when a compatible crop (a “host crop”) is actively growing.

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

Figure 1. Protrusible feeding stylet of a root-lesion nematode. Stylets are thrust in and out of the body very rapidly in order to penetrate plant cells. Stylets are used to withdraw fluids from plant cells and, for some species, to inject toxic substances into cells. Beneficial nematodes (e.g., those that are not parasitic to plants) do not have a stylet.

Most species of economic importance to small grains in the PNW feed on roots rather than on foliar tissues. Stunt and pin nematodes can feed along the surface of any root tissue, from root tips to older segments of roots. Root-lesion nematodes can also feed upon and enter root segments of any stage of maturity and can remain active in soil whenever the soil is moist but not frozen. Cereal cyst nematodes can only enter the meristematic tissue near a root tip. This occurs mostly during the spring because most juveniles emerge from overwintering cysts during the spring.

Richard W. Smiley, Professor emeritus of plant pathology, Columbia Basin Agricultural Research Center, Oregon State University

Table 1. Plant-parasitic nematodes in Pacific Northwest small grain crops.

Most likely and able to cause economic damage	
Cereal cyst	*Heterodera avenae* and *H. filipjevi*
Root-knot	*Meloidogyne naasi*
Root-lesion	*Pratylenchus neglectus* and *P. thornei*
Stunt	*Merlinius brevidens*
Present but unlikely to be of widespread economic importance	
Foliar	*Aphelenchoides* species and *Megadorus megadorus*
Dagger	*Xiphinema* species
Lance	*Hoplolaimus* species
Pin	*Paratylenchus* species
Ring	*Criconemoides*, *Criconema*, and *Criconemella* species
Root-gall	*Subanguina radicicola*
Root-knot	*Meloidogyne chitwoodi*
Root-lesion	*Pratylenchus penetrans* and other species not shown above
Spiral	*Helicotylenchus* species
Stem	*Ditylenchus* species
Stunt	*Tylenchorhynchus* species
Stubby root	*Trichodorus* and *Paratrichodorus* species

Life cycle

Plant-parasitic nematodes differ greatly in the complexity of their life cycle. The type of reproduction differs among and within nematode groups. Most parasitic species reproduce sexually: copulation between a male and a female is required to fertilize eggs produced by the female. Fertilized eggs hatch to release a vermiform (worm-shaped) juvenile stage. Juveniles molt several times before a final molt results in an adult male or female. However, in some species, males are rare or unknown, and the females reproduce through a process called parthenogenesis (Greek for "virgin birth"), in which eggs are produced and become viable without being fertilized.

The time period required to complete a full life cycle varies greatly among species. The life cycle for a pin nematode can be as short as 3 weeks; the life cycle of a root-lesion nematode ranges from 6 to 9 weeks depending on environmental conditions. In contrast, a cereal cyst nematode completes only one life cycle each year.

Nematodes can be spread from infested to non-infested fields in soil carried on equipment, animals, shoes, or plants such as root and tuber crops and ornamentals. These nematodes are also dispersed in blowing dust and in surface water.

Stunt and pin nematodes

Stunt and pin nematodes exemplify a group called migratory ectoparasites, meaning that they feed only from outside the root tissue. Populations of migratory ectoparasites can be detected only by extracting nematodes from the soil.

Root-lesion nematodes

Root-lesion nematodes are an example of a group called migratory endoparasites and ectoparasites, meaning that they may feed on root hairs and epidermal root tissue (Figure 2) and may also enter the root cortex. These nematodes never lose their

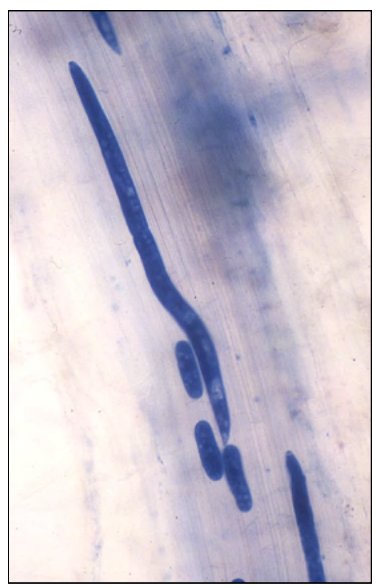

Image courtesy of Dr. Vivien Vanstone, Western Australia Department of Agriculture, South Perth, Western Australia.

Figure 2. Microphotograph of a wheat root that contains juveniles and eggs of a root-lesion nematode. Juveniles are 0.5 mm (1/64 inch) long, have a diameter of 0.02 mm (1/1000 inch), and are translucent. For comparison, a human hair has a diameter (0.1 mm) five times greater than these nematodes. The nematodes in this photo were stained blue to reveal their presence in the root tissue. Juveniles can feed on root hairs and invade older as well as younger root segments.

ability to move from cell to cell within the root or to migrate back outside the root and through the soil. While these nematodes acquire sustenance only from living root cells, the adults may reproduce inside root tissue or in soil.

When a field does not contain an actively growing crop or susceptible weed species, the root-lesion nematodes extracted from soil samples adequately represent the total number of nematodes present. When crops or weeds are growing, the root-lesion nematodes inside the roots and those in the soil must each be extracted by separate procedures to estimate the total number of migratory endoparasites present.

Many *Pratylenchus* species, such as *P. penetrans*, reproduce sexually and have populations with nearly equal numbers of males and females. However, *P. neglectus* and *P. thornei* (the two species of greatest economic importance in non-irrigated, small-grain fields) reproduce by parthenogenesis, and there are few if any males in the populations of these species. See OSU Extension publication number PNW 617 for more detail (https://catalog.extension.oregonstate.edu/pnw617).

Root-knot nematodes

Root-knot nematodes are an example of a group called sedentary endoparasites. The adult females become nonmotile (incapable of motion), feed exclusively from specialized cells inside the root, and remain attached to the root until after the root and the female have died. Root-knot nematodes lay the majority of their eggs outside the body and the females stay embedded in the root even after death. Barley root-knot nematode is the only root-knot nematode that damages cereals in the PNW, but it is not widely distributed.

Cereal cyst nematodes

Cereal cyst nematodes are another example of sedentary endoparasites. The dead female body (the cyst) is dislodged from the dead root and serves to protect up to several hundred eggs and juveniles. The juvenile cereal cyst nematode may emerge from the cyst (Figure 3) as soil temperatures warm up during the following spring. However, many juveniles may remain within the cyst for several years, assuring that not all juveniles will emerge at a time when a host crop may not be planted in the infested field.

Photo by Dr. Guiping Yan; courtesy of Dr. Richard Smiley, Oregon State University.

Figure 3. Microphotograph of a juvenile cereal cyst nematode emerging from an over-wintering cyst. During the spring, each tiny dark-brown cyst (0.5 mm diameter × 0.7 mm long) can release hundreds of translucent juveniles, each of which is 0.5 mm (1/64 inch) long and has a diameter that is 80% smaller than a human hair. Juveniles invade young root tissue just behind the root cap.

Once a juvenile emerges from the cyst, it moves through the soil and invades the root of a susceptible host (small grains or certain grasses) that may be present. Once inside the root of a susceptible host, successive molts of juvenile stages lead to development of a mature male or female. The females become immobile as the head becomes lodged deeply inside the root tissue and the tail remains exposed outside the root. Mature males remain mobile and exit the root to migrate along the root surface or through nearby soil. The male copulates with the female to fertilize the eggs. The female body becomes greatly enlarged as it becomes filled with eggs.

At the end of the plant-growing season, when the roots die, the female body also dies and forms a leathery sheath (the cyst) that protects the eggs over the winter and through adverse (dry, hot, or freezing) conditions between growing seasons of susceptible crops. See OSU Extension publication number PNW 620 for more detail (https://catalog.extension.oregonstate.edu/pnw620).

Symptoms of injury by cereal cyst and root-lesion nematodes

Plant-parasitic nematodes that feed on roots reduce the ability of roots to absorb water and nutrients by reducing rooting depth and numbers of branch roots and root hairs. They typically do not kill plants. They may cause crops such as wheat, barley, or oats to lack vigor, to become stunted, and to produce fewer tillers and less grain. In all cases, root symptoms are unlikely to be detected until plants are more than 6 to 8 weeks old.

Symptom development in the foliar canopy may be lacking or of poor diagnostic value. If symptoms are visible in the foliage, they are often similar to nutrient deficiency or drought because the plant-parasitic nematodes restrict the uptake of nutrients and water from the soil. Also, visible symptoms in the plant canopy, if any occur, are not likely to be uniform across the crop because the nematode density in soil generally varies greatly over very short horizontal distances.

Nematode feeding often results in injured root cells that leak nutrients, which may favor colonization by root-rotting fungal pathogens and saprophytic bacteria, fungi, and nematodes that are not plant parasites. These secondary organisms cause more intense rotting and discoloration than that caused by the plant-parasitic nematode itself.

Cereal cyst nematodes

Cereal cyst nematodes cause different symptoms on different cereal crops. Wheat roots become bushy, knotted, and shallow (Figure 4); oat roots become thickened and shortened; and barley roots exhibit no readily discernible symptoms. Leaf tips often become discolored: reddish-yellow on wheat, red on oats, and yellow on barley. Plants of each cereal crop may become stunted in distinctly defined patches or in irregular patterns across the field, causing an undulating appearance in the height of the plant canopy that does not correspond to natural variations of soil features such as terrain, depth, or old streambeds.

Image courtesy of Dr. Richard Smiley, Oregon State University.

Figure 4. Damage to wheat roots caused by the cereal cyst nematode. Note the "witches broom," where clusters of branch roots emerge from a single point on the main roots. This symptom occurs on wheat but not on oats or barley.

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

Figure 5. Damage to wheat roots caused by root-lesion nematodes. Note the general absence of branch roots along the main root axes, and the "thin" appearance of most roots.

Root-lesion nematodes

Root-lesion nematodes reduce numbers and the integrity of root hairs and branch roots (Figure 5). Outer layers of root tissue (the cortex) disintegrate and cause washed roots to appear thin and poorly branched. Dark lesions may form on the root surface, but this symptom is often not readily apparent on roots of small-grain cereals.

Root symptoms are difficult to detect in the field and are easily confused with symptoms caused by Pythium root rot or Rhizoctonia root rot. Affected areas of fields appear generally unthrifty, yellow (especially lower leaves), or droughty. Symptoms of nematode damage can easily be confused with those of nutrient deficiency, drought, root disease, or barley yellow dwarf.

Yield constraints

Yield reductions cannot be proven without specialized studies. Figures 6 through 8 (page 5) show results of representative nematode–yield studies in northeastern Oregon fields infested with cereal cyst nematode or root-lesion nematode. These data were obtained by developing detailed associations between the variation in nematode density and the crop yield at multiple sampling sites within small experimental areas. While crop damage is expected to become greater with increasing density of nematodes in soil, a precise relationship between plant-parasitic nematode density and wheat yield is difficult or impossible to generalize over large regions because yield responses are influenced strongly by a multitude of interacting features of climate, plant, and soil. For instance, there are no specific "threshold values" above which economic damage can be accurately predicted.

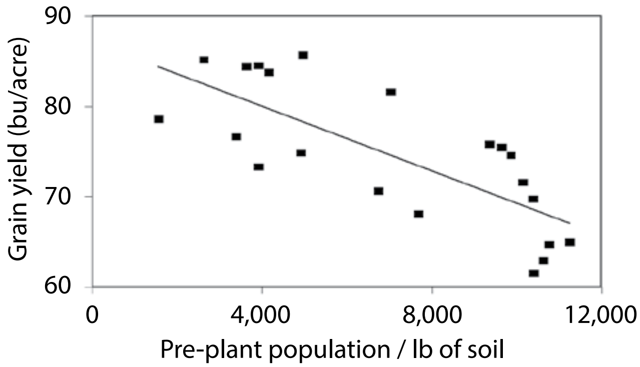

Figure 6. Influence of root-lesion nematode (*Pratylenchus thornei*) on yield of Zak spring wheat (Pendleton, OR).
Chart data: Richard Smiley, © Oregon State University

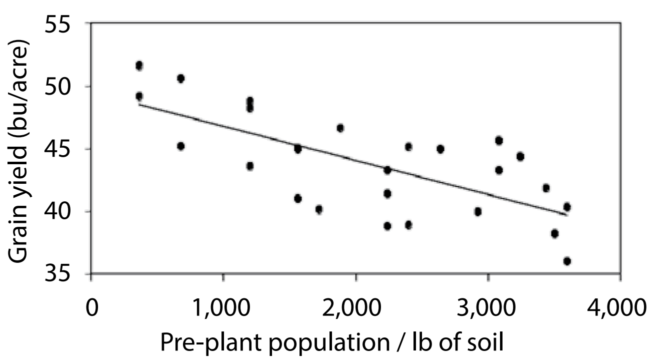

Figure 7. Influence of root-lesion nematode (*Pratylenchus neglectus*) on yield of Zak spring wheat (Moro, OR).
Chart data: Richard Smiley, © Oregon State University

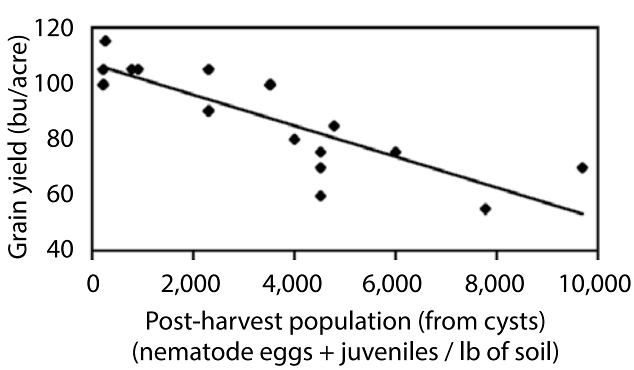

Figure 8. Influence of cereal cyst nematode (*Heterodera avenae*) on yield of Stephens winter wheat (Union County, OR).
Chart data: Richard Smiley, © Oregon State University

Management

There are no chemicals or biological agents available for controlling cereal cyst or root-lesion nematodes in **non-irrigated** crops. Resistant wheat varieties are being developed for use in high-risk farming systems in highly infested fields.

Cereal cyst nematodes

Cereal cyst nematodes attack only members of the grass family (Poaceae). Therefore, broadleaf crop species are an important component of farming practices that seek to reduce the economic risk associated with high numbers of cereal cyst nematodes in a field that will be planted to wheat, barley, or oats. Economic damage can be greatly reduced or eliminated by any rotation that includes at least one growing season without cereals, grasses, or grass weeds. A 2-year rotation away from a cereal or grass crop is more effective than a single year without a cereal. The sanitizing effect of the rotation can be lost if grass weeds are allowed to grow in the fallow or in a broadleaf crop in any phase of the rotation. See OSU Extension publication number PNW 620 for more detail (https://catalog.extension.oregonstate.edu/pnw620).

Spring cereals and late-planted winter cereals are often damaged more severely than early-planted winter cereals because new root tips of the spring cereals and late-planted winter cereals are more vulnerable when the invasive juvenile stage emerges from cysts during the spring.

Root-lesion nematodes

Root-lesion nematodes have a very broad host range, including many crops and weeds likely to be produced in eastern Oregon and Washington. However, the susceptibilities of different crops and weeds may differ greatly for the two primary species of root-lesion nematode. Crops that are susceptible to at least one of these nematode species include wheat, canola, mustard, chickpea, field pea, lentil, and alfalfa. Management by crop rotation is possible only if more resistant alternate crops such as barley, flax, safflower, or triticale are profitable for growers. Damage is likely to be highest where susceptible crops are produced annually. See OSU Extension publication number PNW 617 for more detail (https://catalog.extension.oregonstate.edu/pnw617).

Damage is generally less in winter wheat/summer fallow rotations than in fields planted to susceptible crops annually or during 2 of every 3 years. However, even in wheat/fallow rotations, the numbers of root-lesion nematodes can become very high if volunteer cereals and/or weeds are allowed to grow through the winter and into early spring. Damage to winter wheat has been less in 3-year rotations that include winter wheat, spring barley, and summer fallow. Tillage has not had a strong influence on root-lesion nematodes; nematode numbers have been nearly equal following cultivated fallow and chemical fallow.

Wheat varieties vary greatly in sensitivity to invasion by root-lesion nematodes. Yields of some varieties are affected very little and others can sustain yield reductions as great as 50 percent. Selection of an insensitive (tolerant) variety is recommended for fields that are heavily infested by root-lesion nematodes. See OSU Extension publication number PNW 617 for tolerance ratings of spring wheat varieties (https://catalog.extension.oregonstate.edu/pnw617).

Root-knot nematodes

Root-knot nematodes that attack potato in irrigated cropping systems also can cause severe damage to spring cereals. However, rotations in irrigated fields often emphasize production of winter cereals rather than spring cereals, thereby minimizing potential damage to the cereal crop. Also, nematode control measures generally are applied to the highest-value portion of the rotation; for example, a biofumigant crop such as brown mustard or Sudan grass, or a preplant application of a nematicide before planting potato. Application of a nematicide at any time in the crop rotation is likely to reduce the potential for nematodes to damage small grain cereals planted into the treated fields.

Sampling

Nematode detection and identification require the services of a professional nematologist. The diagnostic procedure in some labs is based upon the collection of living nematodes that migrate from moist soil or roots into a container, from which they are identified and quantified. Samples must be collected and handled carefully because 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.

Between crops, it is often sufficient to extract nematodes only from soil samples to determine whether they may cause damage to the following crop. Population densities of root-lesion nematodes in actively growing crops are determined by extracting the nematodes from root segments as well as from soil. Labs charge a higher diagnostic fee to extract nematodes from both soil and roots because the procedures required are very different. If you are unfamiliar with nematode sampling procedures, contact the nematode testing lab for instructions on how to collect and handle samples.

Sampling for root-lesion nematodes

Samples for root-lesion nematodes must be taken to a depth of at least 12 inches in deep silt loams. These 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, 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 a 12-inch depth.

Sampling for cereal cyst nematodes

Samples for cereal cyst nematodes must also be taken to a depth of 12 inches. Most cysts are located within the upper 4 to 8 inches of soil.

Cysts of the cereal cyst nematode are not motile, and their extraction requires a special procedure based on buoyancy and sieving. This requires an additional diagnostic service to that which extracts the vermiform (worm-shaped) stages needed for most nematodes (including root-lesion nematodes). Services for determining numbers of eggs and juveniles from extracted cysts are charged separately from extractions of migratory (motile) plant-parasitic nematode species. You must request both types of extractions if you wish to fully evaluate nematodes that may affect cereal crops.

Rather than collecting samples randomly or in a predetermined whole-field sampling pattern, detection of cereal cyst nematodes is often more successful when

- soil samples are collected after cereal crops mature or after harvest, and
- sampling is focused within areas where patches of stunted plants occurred during the seedling growth stage.

Identification

Basic diagnostic services generally include counting all plant-parasitic nematodes detected in each sample and identifying most of the plant-parasitic nematodes to the genus level. However, identifying nematodes to the species level is essential for a control tactic based on selection of a tolerant or resistant variety. For cereal cyst and root-lesion nematodes present in most PNW soils, identification at the species level is technically difficult and labor-intensive because there are few easily visualized body characteristics to aid in rapidly and accurately differentiating them. For this reason, labs charge additional fees to identify most plant-parasitic nematodes to the species level.

One commercial lab in the PNW now provides species identification services based on modern DNA-based molecular diagnostic methods. These procedures extract DNA directly from soil or nematodes and precisely and simultaneously identify and quantify individual nematode species.

There are two commercial and two university labs in the PNW that provide nematode testing services (see list below). Both commercial labs provide a courier service to transport samples from many PNW locations.

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://www.science.oregonstate.edu/bpp/Nematodes/contact.htm
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

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

Root-lesion nematodes: Biology and management in Pacific Northwest wheat cropping systems (PNW 617). https://catalog.extension.oregonstate.edu/pnw617

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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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