A Pacific Northwest Extension Publication
Oregon State University • University of Idaho • Washington State University

PNW 620 • October 2010

Cereal Cyst Nematodes

Biology and management in Pacific Northwest wheat, barley, and oat crops

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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 the food chain. Some species, however, are parasitic to plants or animals. One type of plant-parasitic nematode forms egg-bearing cysts on roots, damaging and reducing yields of many agriculturally important crops.

The cyst nematode genus *Heterodera* contains as many as 70 species, including a complex of 12 species known as the *Heterodera avenae* group. Species in this group invade and reproduce only in living roots of cereals and grasses. They do not reproduce on any broadleaf plant. Three species in the *H. avenae* group cause important economic losses in small grain crops and are known as the cereal cyst nematodes. *Heterodera avenae* and *H. filipjevi* are the two economically important species that occur in the Pacific Northwest (PNW). *Heterodera avenae* is by far the most widespread species (Figure 1) and generally occurs alone, but mixtures with *H. filipjevi* have been found in some eastern Oregon fields.

The infective stage of these cereal cyst nematodes can be seen only by using specialized methods to remove them from soil and view them through a microscope. The infective stage is transparent, eel-shaped, and about 0.5 mm (1⁄64 inch) long. These nematodes puncture root cells, which reduces root depth, plant vigor, and uptake of water and nutrients.

Plant-parasitic nematodes are difficult to identify and to demonstrate as the cause of important crop damage. Symptoms expressed in the foliage are generally assumed to be associated with

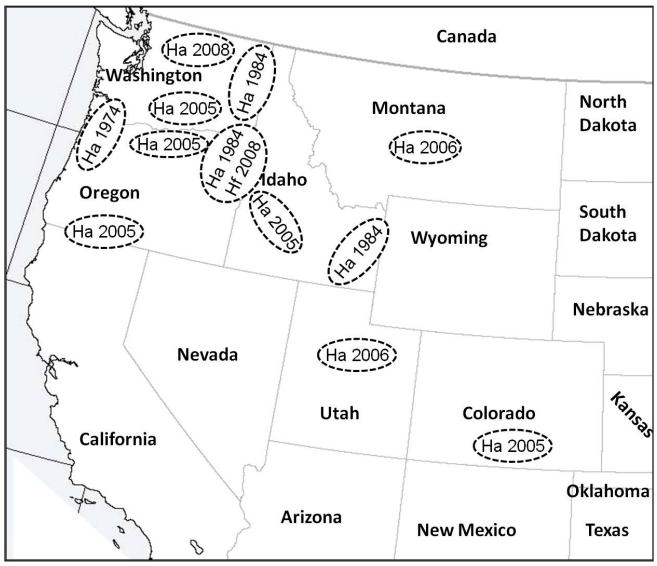

Figure 1. Year in which *Heterodera avenae* (Ha) and *H. filipjevi* (Hf) were first reported in regions of the western United States.
Image by Richard W. Smiley, © Oregon State University.

irregularities in soil depth, soil texture, soil pH, mineral nutrition, water availability, or diseases such as barley yellow dwarf. The foliar symptoms of cereal cyst nematode infestation also have many of the same characteristics as symptoms of root diseases such as Rhizoctonia root rot or take-all. Farmers, pest management advisors, and scientists routinely underestimate or fail to recognize the impact of cereal cyst nematodes on wheat. It is now estimated that this generally unrecognized pest reduces wheat profitability by at least $3.4 million annually in the PNW states of Idaho, Oregon, and Washington.

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Biology

The biology of *H. avenae* and *H. filipjevi* is complex because different pathotypes (i.e., strains or races) of these species occur in different regions of the world and even within regions and individual fields. Pathotypes vary in their ability to reproduce on individual varieties and species of cereal crops. The reproductive capacity of the *Heterodera* pathotype(s) in each geographic region must be understood before successful sources of plant resistance can be introduced into those regions.

Heterodera species complete only one generation of their life cycle during each crop season. The infective juvenile stage (Figure 2a) has a vermiform (eel- or pencil-shaped) body that is 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 (0.1 mm) is about five times greater than the diameter of the infective juvenile stage of this nematode.

Juveniles penetrate epidermal and cortical cells only at the tips of new roots. They feed on the root's water- and nutrient-conductive tissues, into which they inject compounds that induce the formation of enlarged feeding cells called syncytia. Males remain mobile, but females become embedded in the root tissue and continue to feed from the syncytium. The males fertilize the sedentary females, and the female bodies become swollen as they each fill with 100 to 600 eggs.

The presence of a white, swollen female body embedded in a root is diagnostic (Figure 2b). A swollen female body is about the size of a pinhead: 0.5 to 2 mm (1/64 to 1/16 inch) in diameter. It protrudes from the root surface, glistens when wet, is white to light gray, and can be seen most easily when the invaded plant is flowering. This structure is best viewed by gently washing the roots and observing the root mass under low magnification (×20). Adhering soil often obscures white females among knotted roots, but one or more females are generally visible at points where there is an abnormal proliferation of branch roots (see the "Symptoms" section). Females are attached loosely and dislodge easily when soil is washed vigorously from roots.

When invaded roots mature and die, the female dies, and the outer membrane hardens into a resistant brown cyst (Figure 2c) that protects the eggs (Figure 2d) and is the same size and color as many soil particles. Most dry cysts dislodge into the soil (Figure 2e) as the wheat roots decompose and as soil is tilled. The cysts protect eggs and juveniles (Figure 2f) from desiccation, cold, and heat between crop cycles. Eggs inside a cyst can remain viable for several years.

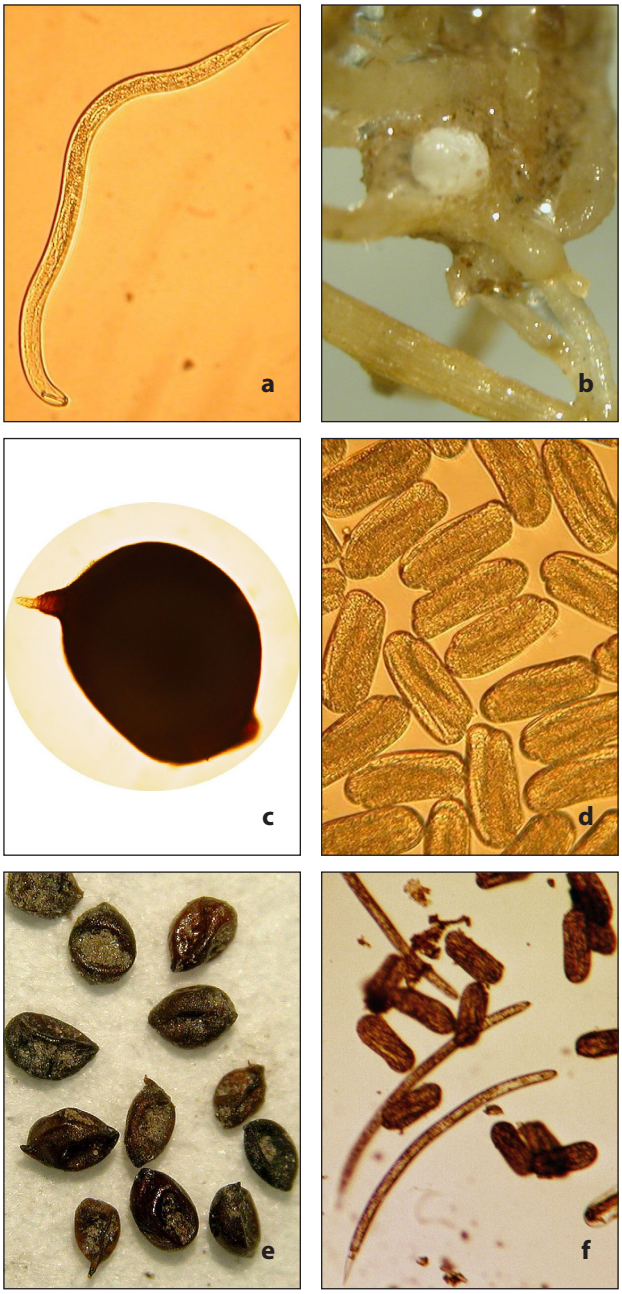

Figure 2. Life stages of *Heterodera avenae*: (a) vermiform shape of the infective juvenile stage that emerges from a cyst (0.5 mm long); (b) enlarged white female embedded in a root; (c) lemon-shaped brown cyst (0.5 × 0.7 mm) containing hundreds of eggs; (d) eggs (50 × 130 µm) containing faint outlines of the developing infective juvenile stage; (e) egg-bearing cysts extracted from dry soil; (f) eggs and infective juveniles released when a dry cyst was crushed.
Photos by Guiping Yan and Richard W. Smiley, © Oregon State University.

Infective *H. avenae* juveniles emerge from the brown cysts after a required period (2 months or more) of cold temperature. In the Willamette Valley of western Oregon, infective juveniles are found in soil from late January to late April, with peak numbers during late February (Figure 3). In colder regions of eastern Oregon, infective juveniles move into soil from late February to late May, with peak numbers during mid-April (Figure 3).

Emergence of *H. filipjevi* juveniles has not been fully investigated in the PNW. In a preliminary study conducted during spring in eastern Oregon, peak numbers of *H. filipjevi* juveniles in soil occurred at least 2 weeks earlier than peak numbers of *H. avenae* juveniles. However, recent reports from Asia, Europe, and the Middle East indicated that in those regions, *H. filipjevi* did not require a period of cold temperature before infective juveniles emerged from cysts. The juveniles began to emerge during the fall from cysts developed on recently harvested crops of wheat or barley. The emergence rate of juveniles decreased over the winter and then resumed in early spring.

It is important to identify the species of cereal cyst nematode that occurs in each field or region because wheat, barley, and oat varieties may differ in their response to attack by *H. avenae* and *H. filipjevi*. Methods to detect and distinguish these species are complex and traditionally have been based on careful measurements of many body features viewed under high magnification. Molecular (DNA-based) procedures are now available (Figure 4) to identify these nematodes more accurately and rapidly.

Symptoms

Specific symptoms occur only on roots, and the type of symptom varies by host species. To detect root symptoms, gently wash the soil from the roots, and then closely observe the root branching pattern. Abnormal rooting patterns are generally not recognizable until a month or more after infective juveniles have invaded the root. Wheat and barley roots branch excessively at locations where *H. avenae* females have established a feeding syncytium. The result is a bushy or knotted appearance on the root (Figure 5a). Invaded roots often fail to continue growing deeply into soil at sites where nematodes have caused abnormal branching (Figure 5b). The roots of invaded plants are

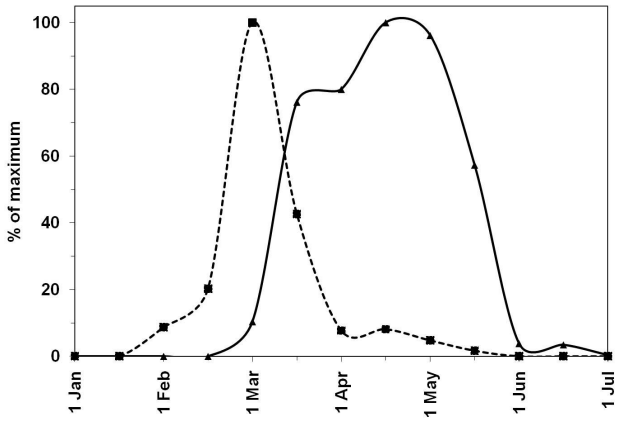

Figure 3. Density of infective *Heterodera avenae* juveniles present in soil during the spring on farms in western Oregon (dotted line) and eastern Oregon (solid line).
Graph by Richard W. Smiley, © Oregon State University.

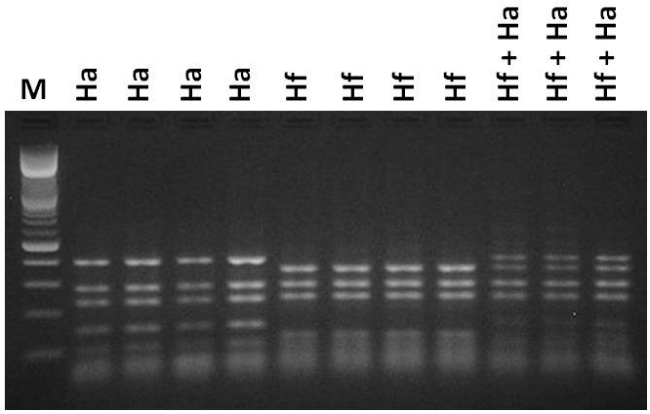

Figure 4. Molecular identification of *Heterodera avenae* (Ha), *H. filipjevi* (Hf), and mixtures of these species from wheat fields in Oregon.
Image by Guiping Yan, © Oregon State University.

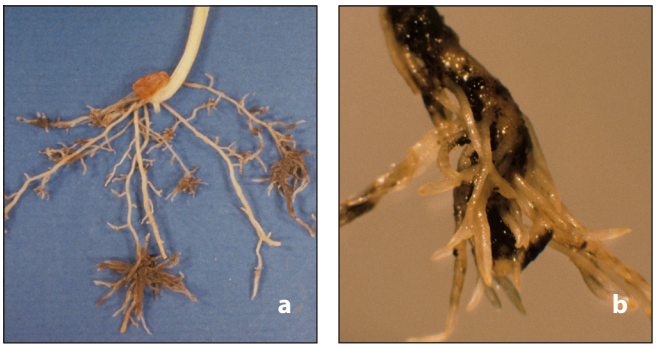

Figure 5. Abnormal branching (a) and shallow rooting (b) at sites where *Heterodera avenae* juveniles invaded roots. Images a and b are from plants collected in fields shown in Figures 8 and 9, respectively.
Photos by Richard W. Smiley, © Oregon State University.

shallower (Figure 6) and less capable of extracting soil water and nutrients than roots of healthy plants. When *H. avenae* invades oats, the roots become shortened and larger in diameter but do not develop the knotted symptom.

Plants with heavily damaged roots often appear initially as unthrifty pale green seedlings that occur in patches (Figure 7). Damage may become widespread and uniform over entire fields when susceptible cereals are planted frequently in the crop rotation (Figure 8). Symptoms become more pronounced when affected plants are also exposed to a stress such as inadequate nutrition, shallow soil, or a shortage of available water. However, affected plants generally do not respond well to additional applications of fertilizer or water. Plants with heavily damaged roots may be severely stunted and may mature early (Figure 9), similar to plants affected by root and crown diseases such as take-all.

Root tissues invaded by cereal cyst nematodes provide greater opportunities for additional damage by root-rotting fungi and saprophytic bacteria, fungi, and other nematodes. The rotting and discoloration caused by these secondary organisms are not direct symptoms of root invasion by cereal cyst nematodes.

Yield Reduction

Grain yields are often negatively correlated with the number of cereal cyst nematodes in soil at the time of planting (Figure 10). However, a definite relationship between the number of nematodes and the magnitude of yield suppression is difficult to generalize because yield responses are strongly influenced by interactions between climate, crop variety, management practice, and nematode distribution and density within the field as well as chemical, biological, and physical properties of soil. For instance, the importance of a given

Figure 6. Spring wheat roots lightly (left) and heavily (right) invaded by *Heterodera avenae*.
Photo by Richard W. Smiley, © Oregon State University.

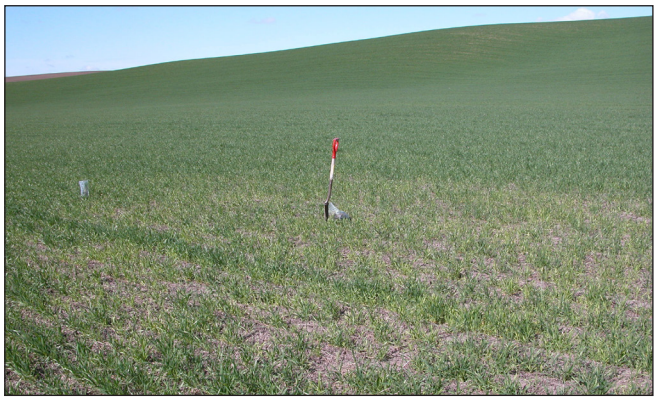

Figure 7. Patchy growth of dryland winter wheat caused by *Heterodera avenae*.
Photo by Richard W. Smiley, © Oregon State University.

Figure 8. Damage caused by *Heterodera avenae* plus inadequate plant nutrition on a third consecutive crop of irrigated annual spring wheat. Symptoms in the foreground were masked by a doubled rate of fertilizer applied along the field border.
Photo by Richard W. Smiley, © Oregon State University.

Figure 9. Patchy growth of winter wheat caused by *Heterodera avenae*. The field was not irrigated, and the surface was uniformly level.
Photo by Richard W. Smiley, © Oregon State University.

density of nematodes at the time of planting will become greater if affected plants are later subjected to drought, inadequate nutrition, an impediment to deep penetration of roots into soil, or adverse temperature. The potential for damage may also differ among varieties if, for example, those varieties have different abilities to replace damaged roots.

In general, however, research has demonstrated that reduced wheat yields may occur when the number of *H. avenae* eggs plus juveniles from cysts plus juveniles already present within the soil matrix exceeds five nematodes per gram of soil, which is approximately 2,000 nematodes per pound (or pint) of soil. This density is often exceeded in at least some portion of infested fields in Idaho, Oregon, and Washington.

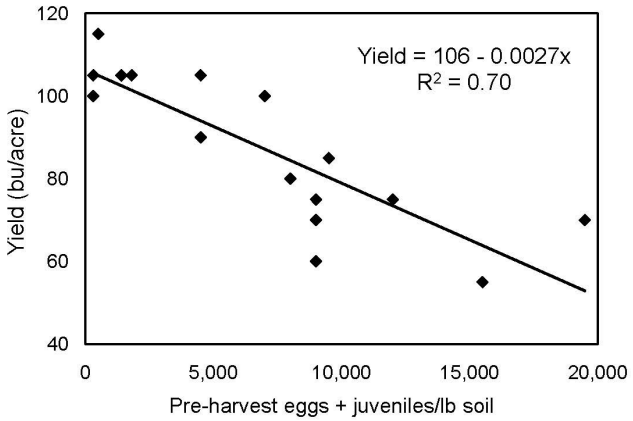

Figure 10. Relationship between number of *Heterodera avenae* before planting and yield of irrigated winter wheat.
Graph by Richard W. Smiley, © Oregon State University.

Crop Management

Management of cereal cyst nematodes involves an integrated approach that includes field sanitation, crop rotation, genetic resistance, crop nutrition, and water supply.

Field sanitation. Once cereal cyst nematodes have been introduced into a field, eradication is nearly impossible. Therefore, efforts to minimize the transmission of soil from infested to noninfested fields or regions are of critical importance. These nematodes are transmitted in all manners in which soil is moved from location to location. A common means of transport is soil that adheres to equipment, vehicles, animals, humans (boots), and plant products such as root and tuber crops, turfgrass sod, and some horticultural nursery crops. Cysts with viable eggs are also carried in dust blowing from infested fields and in soil carried by water moving from infested fields either by erosion or in return ditches at the discharge end of flood-irrigated fields.

After cereal cyst nematodes have been detected in a field, damage can be minimized by reducing the density to fewer than 2,000 nematodes per pound of soil. Commercial labs report nematode densities on the basis of the amount of soil used for the test. Approximate conversions are as follows:

- Reports based on "500 cc of soil" represent approximately one pound or one pint of soil.
- Reports based on "100 g of soil corrected for moisture" represent approximately one-quarter of a pound.

Crop rotation. Damage from cereal cyst nematodes is greatest when susceptible crops are produced annually. Yield losses can also become very high in 2-year rotations of cereals with summer fallow and in 3-year rotations such as winter wheat, spring cereal, and a nonhost broadleaf crop or fallow. Crop rotations that include broadleaf crops, corn, fallow, and resistant wheat, barley, or oat varieties can greatly reduce the nematode density. In addition, growing susceptible hosts less than 50% of the time in heavy-textured soils and less than 25% of the time in light-textured soils can dramatically reduce numbers of *H. avenae*.

Genetic resistance. The use of host resistance is an effective method of controlling these nematodes. Resistance is defined as the ability of the host to inhibit nematode multiplication. The benefit of resistance is that it reduces the intensity of risk to the next crop of barley, oats, or wheat. However, even when reproduction is prevented or suppressed, infective juveniles usually invade and injure roots of resistant plants, which can reduce yield. Ideally, resistance should be combined with tolerance, which is the ability of the host plant to maintain its yield potential in the presence of nematodes. Varieties that are resistant and tolerant offer the best control option. No wheat, barley, or oat varieties currently available in the PNW are resistant to *H. avenae*, and degrees of tolerance have not been evaluated. However, genes that greatly suppress reproduction of *H. avenae* were recently identified for each of these

crops (Tables 1 and 2, Figure 11). The most effective wheat resistance gene for controlling *H. avenae* pathotypes in the PNW (*Cre1*) has been crossed into local varieties. The *Cre1* gene appears to suppress but not eliminate production of *H. filipjevi*. Sources of resistance for barley and oats have not yet been crossed into PNW varieties.

Crop management. Other aspects of integrated pest management are important but less efficient than crop rotation and planting resistant cultivars. One cultural method of cereal cyst nematode control is manipulating sowing time to minimize the impact of the major hatching period. For example, planting winter wheat rather than spring wheat favors strong root development before the majority of infective *H. avenae* juveniles hatch during the spring. Where sufficient water is available, planting a susceptible

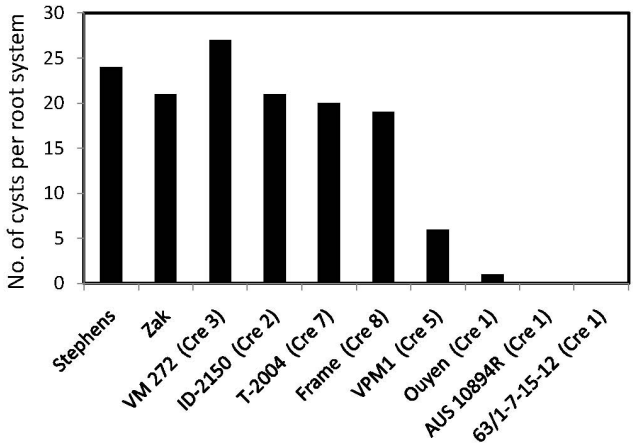

Figure 11. Reproduction of *Heterodera avenae* on wheat roots in naturally infested soil. Identities of resistance genes are shown in parentheses.
Graph by Richard W. Smiley, © Oregon State University.

Table 1. Reproduction of *Heterodera avenae* pathotypes from Hillsboro and Union, Oregon, on barley, oat, and wheat varieties evaluated in greenhouse tests.

	Number of egg-bearing cysts produced on each root system		
Test entry and [resistance gene, if any]	Hillsboro	Union	Resistance rating[1]
Barley			
Ortolan *[Rha1]*	10	14	S
Martin 403-2 *[Rha2]*	0	0	R
Morocco *[Rha3]*	0	1	R
Emir *[RhaE]*	11	27	S
Varde	22	45	S
Oat			
I376 [multiple genes]	0	1	R
IGV.H.72-646	0	1	R
Sun II [multiple genes]	20	43	S
Nidar II	58	73	S
Wheat			
AUS10894 *[Cre1]*	0	1	R
Loros *[Cre1]*	0	1	R
Ouyen *[Cre1]*		4	R
ID-2150 *[Cre2]*		48	S
VL125 *[Cre3]*		65	S
VPM1 *[Cre5]*		12	S
T-2003 *[Cre7]*		17	S
Frame *[Cre8]*		31	S
Arminda		45	S
Capa	8	50	S
Stephens		29	S
Zak		39	S

[1] R = resistant, S = susceptible.

Table 2. Reproduction of *Heterodera avenae* pathotypes from St. Anthony, Idaho; La Grande, Oregon; and Colfax, Washington, on barley, oat, and wheat varieties evaluated in greenhouse tests.

	Number of egg-bearing cysts produced on each root system			
Test entry and [resistance gene, if any]	Idaho	Oregon	Washington	Resistance rating[1]
Barley				
Ortolan *[Rha1]*	5	3	22	S
Bajo Aragón 1-1 *[Rha2]*	0	0	1	R
Oat				
Sun II [multiple genes]	11	8	46	S
Nidar II	18	29	65	S
Wheat				
AUS 10894 *[Cre1]*	0	0	0	R
Capa	7	6	48	S

[1] R = resistant, S = susceptible.

host as a trap crop during the fall or early spring can reduce *H. avenae* densities in soil. The trap crop encourages nematodes to invade roots in a plant stand that will be killed during mid-spring before new egg-bearing cysts are developed. This strategy is particularly useful where growers plan to produce a nonhost warm-season crop, such as peas or beans, in a 2-year rotation following a crop of susceptible wheat or barley. Also, because the greatest crop loss occurs when nutrients or water become limiting for maximum plant growth, supplying optimal plant nutrition and, where possible, supplemental water during intervals of drought can minimize (mask) crop damage.

Biofumigation. Some green manure crops are used as biofumigants to reduce numbers of soilborne plant-pathogenic fungi, plant-parasitic nematodes, root-feeding insects, and weed seeds. These crops are used mostly where water is not a limiting factor for wheat growth. When green tissue from a biofumigation crop of mustard, rapeseed, or sudangrass is thoroughly macerated and incorporated into soil, the toxic products generated during degradation of that tissue are sometimes capable of reducing the nematode density in soil. The time interval between incorporating the green manure crop and planting a crop of wheat, barley, or oats must be adequate to avoid phytotoxicity to seeds and seedlings of the newly planted cereal crop.

Chemical nematicides are effective and widely used in research but are generally not considered economically feasible or environmentally appropriate for managing cereal cyst nematodes on small grains, particularly in nonirrigated fields. Applying fumigant-type nematicides prior to planting high-value rotation crops such as potato can reduce the density of cereal cyst nematodes and thereby provide effective and economical control of these parasites in a subsequent wheat crop.

Tillage does not have an appreciable effect on the density of *Heterodera* species, and biological control products are not commercially available. In some locations, however, the action of fungal or bacterial parasites that degrade *H. avenae* eggs and juveniles appears to maintain *H. avenae* densities at moderate levels. There are no known reliable means for managing these biological agents in commercial agriculture.

Sampling and Identification

Nematode detection and identification requires the services of a professional nematologist. Population densities of cereal cyst nematodes are determined by extracting the nematodes from cysts and extracting the motile stages that may occur in soil. Two commercial and two university labs that provide nematode testing services in the PNW are listed below. Both commercial labs provide a courier service to transport samples from many locations throughout the region.

Take soil samples for cereal cyst nematodes to a depth of at least 12 inches. Detection of these parasites is often more successful when samples are collected after plant maturation or harvest and from areas where patches of stunted plants occurred during the seedling growth stage (rather than collecting samples randomly or in a predetermined whole-field sampling pattern). Collect and handle samples carefully because nematodes can be killed by improper handling, such as leaving samples in direct sunlight or in a car trunk on a hot day. The testing lab can provide specific instructions.

Identification of *H. avenae and H. filipjevi* to the species level is an essential prerequisite for using a control tactic that is based on selection of a resistant variety. Because identification with a microscope is difficult and time consuming, diagnostic labs typically identify cereal cyst nematodes only to the genus level. Molecular procedures using nematode DNA are now available to precisely differentiate individual species. Molecular procedures using DNA extracted from soil are being developed to simultaneously identify and quantify individual species.

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, 1090 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.
4. Western Laboratories, 211 Highway 95, Parma, ID 83660. 208-722-6564. *http://www.westernlaboratories.com*

For More Information

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Acknowledgements

Research cited in this bulletin was supported by grants from the Idaho Wheat Commission, Oregon Wheat Commission, Washington Wheat Commission, USDA-CSREES-Solutions to Economic and Ecological Problems (STEEP) program, Oregon Agricultural Research Foundation, and USDA-Agricultural Research Service Special Cooperative Agreement "*Control of Root Diseases of Wheat and Barley.*" The authors appreciate assistance by Sandra Easley, Shannon Goff, Jennifer Gourlie, Jason Sheedy, Alison Thompson, Paul Thorgersen, and Hui Yan (OSU-Pendleton); collaborations by Dr. Russell Ingham (OSU-Corvallis) and Dr. Jack Pinkerton (USDA-Agricultural Research Service, Corvallis); land donations by wheat producers in Idaho, Oregon, and Washington; nematology services by Dr. Harry Kreeft (Western Laboratories, Parma, ID) and Kathy Merrifield (OSU, Corvallis); and seed supplied by the Australian Winter Cereals Collection (Tamworth, New South Wales), CIMMYT International Wheat Improvement Program (Ankara, Turkey), Nordic Gene Bank (Alnarp, Sweden), and USDA-ARS National Small Grains Collection (Aberdeen, ID).

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Published and distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914, by the Oregon State University Extension Service, Washington State University Extension, University of Idaho Extension, and the U.S. Department of Agriculture cooperating.

Published October 2010