PLANT-PARASITIC NEMATODES IN FIELD CROPS

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Nematodes are tiny but complex animals that inhabit soil in great numbers. These unsegmented roundworms occur worldwide in all environments. Most species are saprophytes that live in compatible association with plants and other organisms. They are important members of the food chain and many are important contributors to decomposition of organic matter. Some, however, are parasitic on plants or animals. About 10 percent of the 20,000 nematode species currently identified are plant parasites. Plant-parasitic species cause an estimated annual crop loss valued at $8 billion in the U.S. and $78 billion worldwide.

Plant-parasitic nematodes in soil are generally 0.02 to 0.08 inch (0.5 to 2 mm) long and are visible under low magnification. They typically are transparent and eel-shaped (vermiform) (Fig. 1). Exceptions are the females of several genera, which become swollen and saclike. Nematodes have bodies that are anatomically differentiated for feeding, digestion, locomotion, and reproduction. High magnification is required to identify individual genera and species. All nematodes develop from eggs and pass through a succession of juvenile (larval) stages before adulthood. Reproduction may be sexual or parthenogenic, with generation times as short as 2 to 4 weeks or as long as 9 months.

Figure 1. Microscopic photographs of (left side) a cereal cyst nematode adult (1.3 mm long), juvenile (0.5 mm) and cyst (0.4 x 0.6 mm), and (right side) two root-lesion nematodes (0.5 mm).

Most nematodes are mobile within thin water films, with motility being greatest in soils near field capacity. Spread over distances greater than 3 feet usually occurs passively in running water and in soil dispersed by wind, plant products, higher animals, and machinery. Some species are more abundant in sandy soils and others in silt or clay soils. Some are well adapted to survive during time intervals between hosts by becoming dormant (anhydrobiotic) in very dry, cold, or hot soils, or by migrating deeply into the soil profile where moisture and temperature extremes are moderated.

Plant-parasitic nematodes puncture cells and feed by injection and extraction mechanisms. They damage plants mechanically and chemically (by introducing toxins or enzymes) and predispose plants to other pathogens by providing points of entry. Ectoparasitic nematodes feed from the plant surface. Endoparasitic nematodes feed within and between cells. Some species have both ecto- and endoparasitic feeding habits. Most nematodes penetrate root cells by means of a sharp, hollow stylet. A few genera, which are not discussed in this paper, penetrate cells using a grooved "tooth". Species that are not parasitic on plants do not have a stylet or tooth.

Nematode feeding reduces plant vigor and induces lesions, rots, deformations, galls, and root knots. The stress of nematode infections lowers the general disease resistance of host plants. Root disorders caused by parasitic nematodes are difficult to diagnose and often are unnoticed or are attributed to other causes such as drought, nutrient deficiency, or root rots caused by fungal pathogens such as *Pythium* or *Rhizoctonia*. Affected crops appear uneven, usually with patches of stunted, yellow plants. Symptoms are likely to be most evident during or following periods of hot weather, drought, low fertility, and other stresses. The only way to determine if plant-parasitic nematodes are involved is to have soil and root samples assayed for nematodes.

Collections of nematodes from plant roots and soil normally contain mixtures of plant-parasitic and non-plant-parasitic species which must be counted separately. Inferences about the importance of genera and species of plant-parasitic nematodes are drawn from their feeding habits, relationship of plant symptoms to species frequency, and experiments that have demonstrated the virulence of each species.

Plant-parasitic nematode species known to occur in fields where small grain crops are produced in the Pacific Northwest are shown in Table 1. Root-lesion nematodes and cereal cyst nematode appear to cause the most important damage to wheat in this region.

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

Cereal cyst	*Heterodera avenae*
Dagger	*Xiphinema* species
Pin	*Paratylenchus* species
Root-gall	*Subanguina radicicola*
Root-knot	*Meloidogyne chitwoodi*, *M. naasi*, and others
Root-lesion	*Pratylenchus neglectus*, *P. thornei*, *P. penetrans*, and others
Stunt	*Geocenamus brevidens*, *Tylenchorhynchus clarus*, and others

CEREAL CYST NEMATODE (*Heterodera avenae*)

The cereal cyst nematode was first reported in the USA during 1974. It was found on oats in western Oregon. This nematode has now been identified on wheat and barley in many counties of northeast, north central and southern Oregon, southern Idaho, southeast and south central Washington, northern California, central Montana, central Utah, and south central Colorado. Other regions are also presumed to be infested but have not yet been detected or reported.

Cereal cyst nematodes are a group of closely-related species and are recognized as one of the most important groups of plant-parasitic nematodes on cereals. *Heterodera avenae* is the most commonly recorded species of economic importance on cereals worldwide, and is the only species of this group that is currently known to occur in the western USA. *H. avenae* parasitizes only members of the Poaceae ('grass family') with oats being most susceptible, wheat and barley less susceptible, and rye, triticale, corn and many grass species also serving as hosts. In the Pacific Northwest, host crops of *H. avenae* are produced on 70 million acres and are valued at $1.2 billion annually.

Above-ground symptoms are more visible on seedling than on older wheat plants. Symptoms consist of uneven patches of poor-growing plants that are randomly distributed across a field or may be concentrated in the lowest-lying areas. Damage to plants and the size and number of patches are directly related to nematode population levels as well as nematode distribution in the field. Under monoculture, such as annual wheat or annual barley, the patches coalesce and damage can uniformly cover the entire field. Severely-infected plants remain stunted. Leaves become pale, yellowish-green in color, with thin and narrow leaf blades and generally fewer tillers. Symptoms produced on roots differ for different hosts. A much-branched root system is characteristic of *H. avenae*-infested wheat. Root division takes place at the points of juvenile invasion, giving an appearance of a "bushy knotted" root system (Fig. 2). Several white females, called cysts, are usually visible at each knot. The cysts are glistening white-gray initially and dark-brown when mature. Cysts are about 0.5 mm in diameter.

Figure 2. Damage to wheat roots caused by the cereal cyst nematode, *Heterodera avenae*. 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.

Only one reproductive generation occurs during a cropping season. Males remain worm-like and females become lemon-shaped and spend their life inside or attached to a root. Eggs are retained within the white swollen female body. After the female has died, the body wall hardens to a resistant brown cyst, which protects several hundred eggs and juveniles. The moment such cysts turn brown, juvenile emergence stops. Eggs within a cyst remain viable for several years.

Juvenile emergence from eggs in brown cysts requires a period of dormancy of two or more months and is strongly regulated by an increase in temperature. Often the periods of mass emergence from cysts coincides with a cropping season. Temperature, availability of moisture, and root diffusate are important determinants of juvenile emergence. Emergence of *H. avenae* can take place at soil temperatures between 50 and 75 F.

Cereal cyst nematodes are spread when contaminated soil moves on or in vehicles, equipment, plants, shoes, animals, dust, water, or other means. For instance, potatoes are an example of a crop to which soil adheres following harvest. *H. avenae* cysts were collected from tare soil remaining in a seed-potato storage building after the potatoes had been removed and transported. Cysts were also collected from soil and dust that dropped off a truck's unloading draper when the seed potatoes were being transferred to planting equipment in a production field 100 miles away from the infested storage building. Likewise, turfgrass sod was at one time produced on fields now known to be infested with *H. avenae*, and was transported to markets in at least four states. Dust was found to be contaminated with cysts when it was swept off the floor of a pickup at a location 150 miles from the site where the driver's boots became soiled with a light layer of mud. A dryland wheat field was found to be infested by *H. avenae* after contaminated soil dislodged from a seed drill used previously in an infested field 100 miles away. Cereal cyst nematode will continue to be disseminated long distances in soil adhering to agricultural equipment, automobiles, plant materials, and animals. It also is dispersed by wind (in dust) and water.

Heterodera avenae is managed most efficiently with resistant varieties and grass-free rotations using non-host crops or clean fallow. These practices can cause populations of *H. avenae* to decline by 70 to 80% annually, keeping populations below damaging thresholds. There are no chemicals or biological agents available for controlling the cereal cyst nematode.

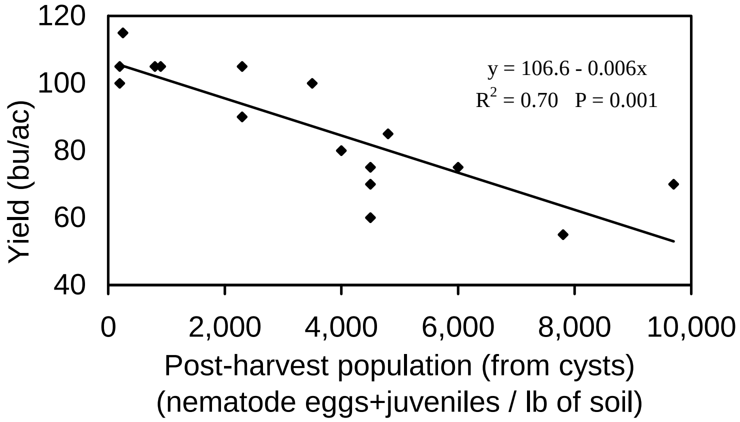

Figure 3. Association of yield and density of *Heterodera avenae* in soil following a uniform planting of 'Stephens' winter wheat in a crop rotation and tillage management experiment near La Grande, Oregon.

Cereal cyst nematodes cause more severe damage to spring wheat than to winter wheat. On all wheat, damage becomes greatest when the population of *H. avenae* increases as the frequency of host crops increases (Fig. 3). Economic damage can be greatly reduced by any rotation that includes at least one growing season without cereals or grass weeds. The sanitizing effect of the rotation can be lost if grass weeds are allowed to grow during the spring in any phase of the rotation. For instance, in our long-term crop management and crop rotation experiments, yields of annual wheat and wheat following rotations in which grass weeds were allowed to grow during spring, were half the yields for wheat rotated with "volunteer-free and grass-free" summer fallow, with Kentucky bluegrass, or with "grass-free" alfalfa, pea, or Brassica species. Crop rotation and field sanitation were more critical than the specific rotation.

Current research is focused upon developing resistant wheat varieties that will allow producers to maintain yield potential whenever they find it necessary to plant host crops frequently into fields infested with *H. avenae*. Recent research indicates that the *H. avenae* pathotype (e.g., "race") in eastern Oregon is Ha12, a pathotype that also is common in northern Europe. A wheat line possessing the appropriate gene for resistance (Cre3) to that pathotype is being tested to assure that the gene is effective against local strains of this nematode. If so, crosses between the gene-donor parent and locally adapted high-yielding wheat varieties will be made to provide a resource for growers whose fields are infested with *H. avenae*. Research is also underway to determine if the same pathotype occurs in eastern Washington and southern Idaho. If not, wheat lines with genes for resistance to other pathotypes of this pest are also maintained at Pendleton.

ROOT-LESION NEMATODES (*Pratylenchus* species)

Root-lesion nematodes are among the most commonly encountered nematode pests in agronomic settings and are responsible for significant yield losses worldwide. These species have only recently been studied in broad-acre field crops in the Pacific Northwest but for many decades they have been known to develop high and sometimes damaging populations in irrigated crops such as potato, mint, and alfalfa.

This nematode penetrates epidermal cells of roots and then as it feeds it migrates between and through cells of the root cortex. The nematode may migrate back into the soil and then either reenter the root at another location or remain living (but not feeding) in soil. Adult females lay eggs in roots and in soil. Root-lesion nematodes multiply quickly in roots of wheat and may reach population densities as high as many thousands per gram of dry root tissue.

Damage from the invasion of roots and subsequent migration within the roots causes extensive damage to the root cortex. Root branching is reduced (Fig. 4) and plants may become chlorotic and stunted, and have reduced tillering. Roots damaged by root-lesion nematodes are unable to extract all of the available soil water and nutrients, leading to premature onset of water and/or nutrient stress at times when non-parasitized plants would continue to grow and mature normally. Roots damaged by this nematode are often prone to secondary invasion by fungi and bacteria. Lesion nematodes have been widely implicated in disease interactions with root-rot fungal pathogens. At least some of the root damage commonly attributed to *Pythium* and *Rhizoctonia* is now known to be confused with damage caused by root-lesion nematodes.

Damage caused by root-lesion nematodes is very difficult or impossible to detect by looking only at the plant canopy or the rate of plant growth. Soil testing and examination at a nematode diagnostic laboratory are required to pinpoint the cause of yield reductions by these root parasites.

Figure 4. 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.

In the Pacific Northwest the predominant species of *Pratylenchus* in many irrigated crops is *Pratylenchus penetrans*. In contrast, the only species detected in most dryland fields and some irrigated fields are *P. neglectus* and *P. thornei*. Populations of *P. penetrans* consist of near-equal numbers of males and females, and copulation is required for reproduction of this species. Males are rare or absent in populations of *P. neglectus* and *P. thornei*, and reproduction of these species is almost entirely parthenogenic, meaning that females lay viable eggs without the need for fertilization. Parthenogenic reproduction appears to convey an adaptive advantage where nematode movement is more often constrained by dry soil environments.

Root-lesion nematodes develop damaging populations particularly in annual cropping systems and in winter wheat-summer fallow systems in which volunteer cereals and/or winter-annual weed grasses are allowed to grow for up to five months during the “fallow” winter. From a nematode’s perspective, wheat-fallow rotations that have a lengthy over-wintering green bridge are functionally equivalent to annual cropping.

At least half the dryland fields in northeast and north-central Oregon and in east-central and south-central Washington are infested by high populations of *P. neglectus* or *P. thornei*. Mixtures of these species are common. Populations as high as 16,000/lb of soil have been detected and there does not appear to be a pattern with respect to rainfall, temperature, or tillage. Cultivated fields are as infested as direct-drill fields. Populations greater than the economic threshold level of 900/lb of soil can reduce intolerant wheat yields as much as 50%. Measurable yield reductions also are caused by lower population densities. Peak populations have been found to occur as deep as two or three feet.

The relationship between yield and population density in Oregon has been studied in dryland winter and spring wheat. During 1999, for instance, winter wheat (cv ‘Madsen’) was planted over an entire experimental area during the final year of a long-term replicated crop rotation and tillage management experiment near Pendleton. Yield was negatively correlated with the population of *P. neglectus* (Fig. 5). Numbers of nematodes in the various treatments were highest in a 3-year rotation that included winter wheat, canola and summer fallow, and were lowest in a 3-year rotation that included winter wheat, spring barley and summer fallow. Intermediate numbers occurred in annual no-till spring wheat and in rotations where winter wheat was alternated with cultivated or chemical fallow.

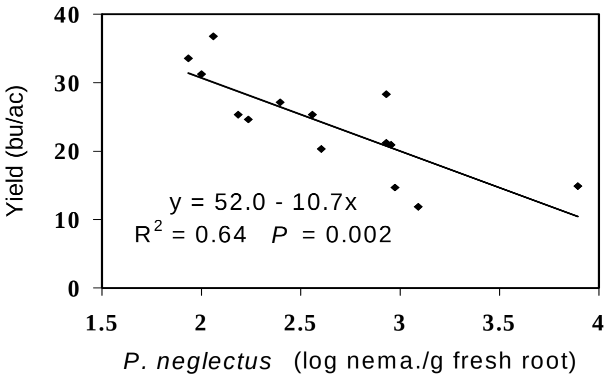

Figure 5. Association of yield and density of *Pratylenchus neglectus* in roots for a uniform planting of 'Madsen' winter wheat following five years of seven crop rotation and tillage management treatments near Pendleton, Oregon.

Crop management options other than genetic tolerance and resistance are unlikely to be economically feasible for dryland wheat producers in low-rainfall regions. Chemicals are neither registered nor economically feasible in dryland agriculture. Reducing the frequency of host crops is constrained by the broad host range of these nematodes. Populations of root-lesion nematodes are not greatly affected by the intensity of tillage.

The host ranges of *P. neglectus* and *P. thornei* includes most cereals and potential rotation crops such as grain legumes, pasture legumes, and oilseeds. Minimal reproduction of *P. neglectus* and *P. thornei* occurs on pea and safflower, reducing the level of risk for subsequent crops. Reproductive rates are high on many chickpea varieties, amplifying the risk to subsequent crops. *P. neglectus* reproduces very well on most varieties of canola, mustard and lentil. *P. thornei* reproduces at significantly lower rates on those crops. Reproduction of both species is generally greater on wheat than barley but large differences occur among varieties of both crops.

The frequency of favorable host plants can be minimized by not allowing volunteer cereals and winter-annual weeds to grow during winters between planted crops. For example, the summer of 2000 was very dry but autumn rains began on September 3 and were frequent into the winter. Seeds of volunteer wheat and downy brome germinated in September and seedlings became well established by mid-October. Numbers of root-lesion nematodes in roots of volunteer wheat and downy brome during October were comparable to numbers of these nematodes in planted spring and winter wheat crops during May. Many growers allow volunteer to survive through the winter. If a spring crop is to be planted the volunteer and weeds are killed several weeks before the new crop is planted. If a winter wheat crop is to be planted, the field is usually cultivated, fertilized, and maintained weed-free by multiple rod weedings during the summer. In each case, the presence of volunteers surviving through the winter greatly reduces the effective interval of the sanitizing break from one harvest to the next planting. The phenomenon named the "green bridge" has received emphasis for reducing damage by fungal pathogens and is equally applicable to nematodes, insects and virus diseases.

Genetic tolerance and resistance are two different principals, are under different sources of genetic control, and may differ independently. When roots are invaded, yields of intolerant varieties are reduced and yields of tolerant varieties remain near normal. A variety may be tolerant to *P. neglectus* and intolerant to *P. thornei*, or visa versa, or tolerant or intolerant to both species. Tolerance is therefore a measure of yield stability and is studied in highly infested fields. Also, when roots are invaded, nematodes do not multiply in highly resistant varieties but multiply rapidly in susceptible varieties. Plant resistance therefore affects nematode populations capable of posing risk to subsequent plantings of intolerant crops or varieties, with little regard to the potential response of the current host. Resistance must be studied by quantifying nematode reproductive rates in greenhouse-grown plants. In fields infested with *P. neglectus* or *P. thornei*, producers without knowledge of tolerance and resistance levels are at risk that their current and/or subsequent crops will not yield as well as expected, depending simply on their choice of variety. Levels of tolerance and resistance for wheat and barley varieties and advanced breeding lines in the Pacific Northwest are now being quantified.

Australian spring wheat varieties with known levels of tolerance to root-lesion nematodes were studied in annual direct-drill systems in Oregon from 2001 to 2005. Increasing densities of root-lesion nematodes often were strongly associated with reduced growth and yield of intolerant varieties (Fig. 6). When nematode populations were high, plant biomass and grain yield for moderately tolerant varieties were often double those for intolerant varieties (Fig. 7). The relationship between nematode population and wheat yield was also evaluated by comparing yields in adjacent plots treated or not treated with the nematicide Temik, which is not and will not be registered for this use. Banding of Temik below the seed at planting often led to a doubling of yield for intolerant varieties of spring wheat.

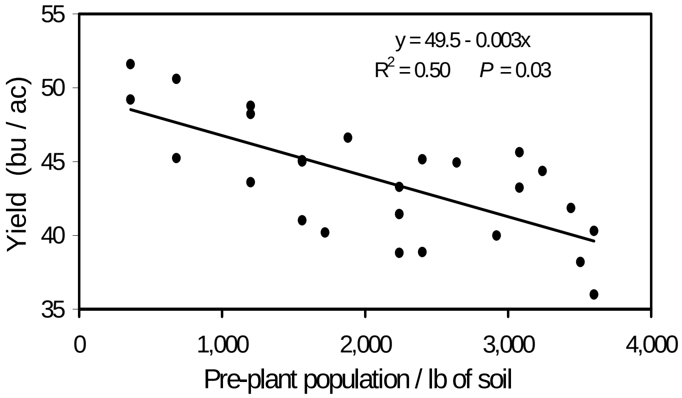

Figure 6. Influence of *Pratylenchus neglectus* density on yield of 'Zak' spring wheat at Moro, Oregon.

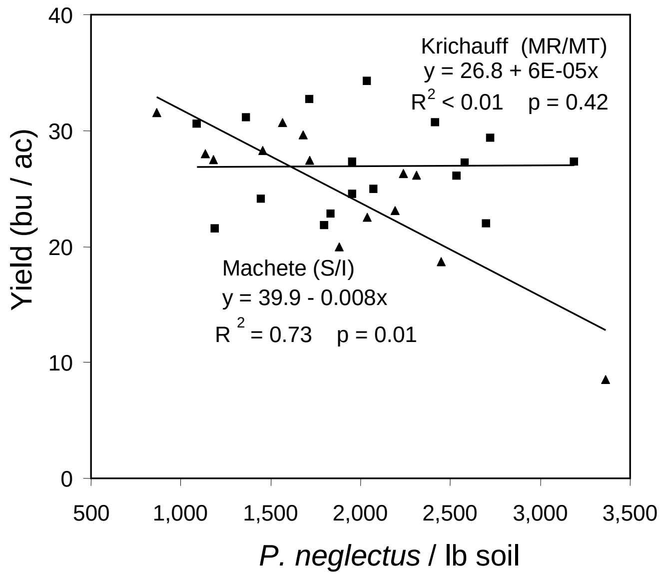

Figure 7. Yield stability for two spring wheat varieties grown in soils with increasing populations of *Pratylenchus neglectus* in a field near La Grande, Oregon; Machete is intolerant and Krichauff is moderately tolerant to invasions by this nematode species.

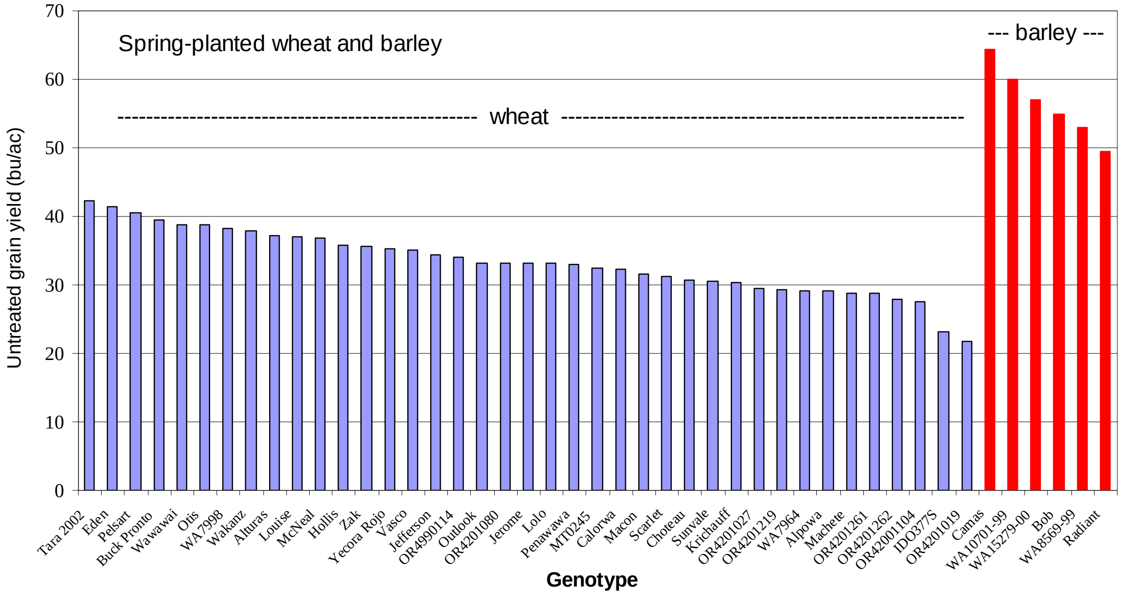

Figure 8. Influence of *Pratylenchus neglectus* on yield of spring-planted wheat and barley varieties and lines near Heppner, Oregon.

Selecting and breeding wheat and barley for tolerance and resistance to root-lesion nematodes is very likely to improve productivity and economic efficiency of the entire cropping system where susceptible and intolerant host plants are currently grown.

The first evaluations of Pacific Northwest wheat and barley varieties and advanced breeding lines were performed during 2006. These experiments were conducted at sites where either *P. neglectus* or *P. thornei* was the dominant species present. We examined the influence of each species on yields for 79 wheat and 11 barley entries; 45 of which were planted during spring and 45 were planted during the fall. Entries included 24 advanced breeding lines and 57 commercial varieties representing production on about 95% of winter wheat acreage and 85% of spring wheat and barley acreage in Oregon and Washington. Australian susceptible and tolerant "standards" were included for comparison. Yields of intolerant entries on *P. neglectus*-infested soil were half those for tolerant entries, for both spring- and fall-planted cereals (Fig. 8). The same yield differential occurred at another site infested by *P. thornei*, however, each wheat entry did not always respond in the same way to attack by the two nematode species, indicating a need to screen wheat varieties separately against each *Pratylenchus* species.

STUNT NEMATODES

Stunt nematodes include species in the genera *Geocenamus*, *Tylenchorhynchus*, and others. Most species do not cause stunting or other detectable damage to wheat. However, *Geocenamus brevidens* has been associated with reduced growth and yield of wheat in the Pacific Northwest (Fig. 9). This nematode has a broad host range that includes many grass, cereal, vegetable, legume, Brassica, fruit, and fiber crops. Combinations of stunt nematodes with other plant-parasitic species, or with plant-pathogenic root-infecting fungi, have been shown to be more damaging than a single species acting alone.

High densities of *G. brevidens* may cause wheat roots to become restricted in length and in number of branches, without discoloration, enlargement, or premature senescence of root tissue. Foliar symptoms are not diagnostic but may include chlorosis of lower leaves and reduction in plant height, tillering, head size, and kernel size. Damage occurs on both winter and spring wheat. The damage threshold and particularly the threshold variance under different environmental conditions have not been reported.

Stunt nematodes are migratory ectoparasites that feed on epidermal cells and root hairs mostly in the cell elongation region. Adults have slender bodies up to 1.0 mm long. Peak nematode densities in soil may occur at varying depths (0 to 48 inches) depending on tillage systems and crop rotations. Eggs are released into soil as females feed on roots. A juvenile stage is released as each egg hatches. Collections of *G. brevidens* from soils nearly always yield only females that reproduce by parthenogenesis; males are very rare.

Crop rotations and summer fallow cause populations to decline and direct-drill conservation systems may allow populations to become large. No chemical or biological agents are registered for controlling damage by stunt nematodes on wheat, and sources of genetic resistance have not been identified.

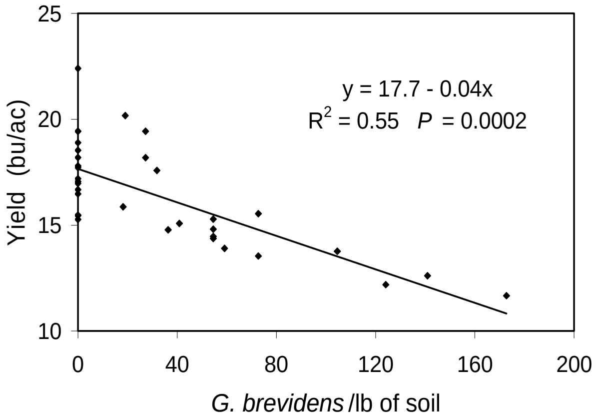

Figure 9. Influence of pre-plant populations of *Geocenamus brevidens* on grain yield for 'Zak' spring wheat in a field near La Grande, Oregon.

ROOT-KNOT NEMATODES

Root-knot nematodes cause large galls or knots in roots of broadleaf plants and small, club-like thickenings on wheat roots. Galls on wheat are most visible in spring and summer, are often inconspicuous to the naked eye, and are typically curved, horseshoe, or spiral shaped. Infection by root-knot nematodes may result in stunted, chlorotic wheat plants. Several species of *Meloidogyne* parasitize wheat but *M. chitwoodi* and *M. naasi* are by far the most damaging species. These nematodes are also involved in disease complexes with fungal pathogens.

The Columbia root-knot nematode, *M. chitwoodi*, causes especially severe damage to potato. Both races of this nematode are virulent on wheat, barley and oats. Because the larvae hatch during early spring, yield losses caused by *M. chitwoodi* are typically greater on spring wheat than on winter wheat. Wheat planted in the fall is usually well developed and escape severe damage when larvae invade roots in the spring. Fortunately, winter wheat is the most common cereal planted on irrigated fields where this nematode occurs.

More than 100 plant species are hosts to *M. naasi*, including wheat, barley, rye, onion, and sugar beet. Wheat yield losses up to 20% can be induced by this species. *M. naasi* is controlled by rotating wheat with non-host plants such as oats and certain root crops.

Larvae of *Meloidogyne* hatch and invade wheat roots mostly during early spring. Juveniles become sedentary after they enter the root. They establish a permanent feeding site and become more swollen with each of three successive molts. At the last molt, adult males re-attain the vermiform shape and migrate to fertilize the adult females. The adult female stage remains swollen, saclike, and sedentary, with the posterior end exposed to the outside of the root surface. By midsummer, females (0.2 to 0.7 mm in diameter) extrude their egg masses (400-1,000 eggs per female) on the root surface, but otherwise remain embedded in root tissues. Egg masses are normally transparent but darken when exposed to air, resembling cysts of *Heterodera* species. Damage to wheat is directly related to the population density of eggs and juveniles in soil at the time of planting.

Wheat varieties differ in susceptibility to root-knot nematode species but management of these nematodes is almost always focused on the phase of the rotation leading to the planting of the highest-value crops. Potato and sugar beet are commonly rotated with wheat in infested irrigated fields and the value of these host crops is very sensitive to damage caused by root-knot nematode. These crops also generally increase the population of *Meloidogyne* species. Pre-plant or in-season chemical nematicides are commonly applied to reduce root-knot nematode populations to levels below the economic threshold for damage to these high-value crops. Rotations of high-value crops with summer fallow or non-host crops can also be effective. Of particular value and interest is the use of fall or winter cover crops such as rapeseed and sudan grass. When young plants of these crops are fragmented and incorporated into soil they release toxic compounds (isothiocyanate) that reduce nematode populations before high-value crops are planted. Management practices for high-value crops generally preclude the need to control root-knot nematode populations before planting wheat.

ROOT-GALL NEMATODE

Subanguina radicicola has not been proven to cause economic damage to wheat but affected seedlings sometimes show leaf chlorosis and stunting, and galls can be easily confused with those caused by root-knot nematodes. Roots frequently are bent at gall sites and therefore resemble root knots caused by species of *Meloidogyne*. Nematodes extracted from galls must be examined to differentiate these genera and species.

S. radicicola is an endoparasite. Adults are vermiform in shape and up to 3 mm long. Juveniles leave the egg and penetrate the root tip, where they cause hypertrophy of cortical and epidermal root cells without affecting the conducting tissues within the stele. The volume of infected cells is increased by a factor of five to ten times. Galls on wheat roots may be inconspicuous or up to 8 mm in diameter, with large galls containing as many as 1,000 juveniles, eggs, and adult males and females. Each of these stages may persist in galls over the winter. Second-stage juveniles leave the gall as the soil warms during spring and invade new wheat or other grass roots. A second generation leaves the galls during mid- to late summer. In a 10-inch rainfall region of eastern Oregon, *S. radicicola* has been found to cause one or more galls to develop on every winter wheat plant when seed was sown after a 14-month summer fallow period. Survival of the nematode was surely enhanced by the presence of volunteer wheat and downy brome for up to four months during the winter of the fallow season.

Control measures are not currently justified. However, *S. radicicola* populations are diminished by rotating wheat, cereal or grass crops with legumes, root crops, or with summer fallow in which volunteer cereals and grass weeds are not allowed to persist. There are no chemical, biological, or genetic resistance practices available to reduce populations of *S. radicicola*.

DIAGNOSTIC SYSTEMS FOR THE FUTURE

Nematode extraction, quantification and identification procedures are labor intensive and technically difficult. Modern molecular diagnostic systems reduce the sample processing time and skill required, while also increasing the diagnostic precision. Molecular diagnostic systems are currently being refined to strengthen our ability to detect and quantify plant-parasitic nematodes as well as plant-pathogenic fungi. Nematode and fungal DNA are extracted from soil or plants, measured, and then transformed into units describing the population density for each nematode or fungus species. Tests are currently available for detecting cereal cyst and root-lesion nematodes, and the fungal pathogens that cause Fusarium crown rot, take-all, Pythium root rot, and Rhizoctonia root rot. As demand expands, it is anticipated that commercial soil and plant testing laboratories will incorporate these tests into the services they offer.

ACKNOWLEDGEMENTS

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NEMATODE ANALYTICAL LABS IN THE PNW

Kuo Testing Labs***** (2 locations), 1300 6th Street, Umatilla, OR 97882 (541-922-6435); or 337 South 1st Avenue, Othello, WA 99344 (800-328-0112); http://kuotesting.com

Western Laboratories*****, 211 Highway 95, Parma, ID 83660 (800-658-3858); http://www.westernlaboratories.com

OSU Nematode Testing Service, 1089 Cordley Hall, Corvallis, OR 97331-2903 (541-737-5540)

University of Idaho, Parma Research and Extension Center, Parma, ID 83660 (208-722-6701)

***** Kuo Testing Labs and Western Laboratories may be contacted regarding their courier services for transporting samples to their labs from many locations in Idaho, Oregon, and Washington.

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